Advances in Computational Social Science and Social Simulation

Francisco J. Miguel, Frédéric Amblard, Joan A. Barceló & Marco Madella (eds.)

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Volume Editors

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SOCIAL SIMULATION CONFERENCE 2014

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10th Conference of the European Social Simulation Association ESSA

1st Simulating the Past to Understand Human History SPUHH

Organized by

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Milà i Fontanals Institute (IMF-CSIC),

Computer Applications & Quantitative Methods in Archaeology (CAA).

This book is the conference proceedings of SSC 2014, a scientific meeting that held together both the “10th AE Series Conference”, the “10th European Social Simulation Association Annual Meeting”, and the “SPUHH Conference”. Readers will find results of recent research on computational social science and social simulation -economics, management, sociology, history- written by leading experts in the field. SOCIAL SIMULATION (former ESSA) conferences constitute annual events which serve as an international platform for the exchange of ideas and discussion of cutting-edge research in the field of social simulations, both from the theoretical as well as applied perspective, and the 2014 edition benefits from the cross-fertilization of three different research communities into one single event. The volume consists of **121** papers, corresponding to most of the contributions to the joint conferences, in three different formats: short abstracts (presentation of work-in-progress research), posters (presentation of models and results), and full papers (presentation of social simulation research including results and discussion). This compilation is completed with indexing lists to help finding articles by title, author and thematic content. We are convinced that this book will serve interested readers as a useful compendium which presents in a nutshell the most recent advances at the frontiers of computational social sciences and social simulation research.

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Welcome

On behalf of the 2014 Social Simulation Conference organizing committee, we would like to extend you a very warm welcome to the SSC 2014 meeting at the Autònoma University of Barcelona (UAB). The Bellaterra Campus has a long history of involvement with social simulation, organizing previous meetings and pioneering teaching and research of computer simulation for the study of social, economic and historical phenomena, and so it is a privilege to welcome researchers from such a variety of fields.

This year we host three different, but closely related, communities and this week promise to be a stimulating combination of symposia, discussion sessions and plenary talks from speakers across the wide spectrum of Artificial Economics, Artificial Intelligence, Computational Sociology, Historical Simulation and other Computational Modelling approaches to social phenomena. In addition to the plenary talks of our guests keynote speakers, the conference are intended to foster dialogue and debate – we hope you'll find old and new topics thought provoking.

We look forward to meeting you at the daily coffee breaks and luncheons, at the Catalonian Wine Tasting reception on Monday afternoon, and at the Conference Dinner in Barcelona's Old Harbour on Wednesday evening. We would like to thank both the ESSA management committee, the AE series meetings committee, and the organizers of SPUHH for selecting our Campus to host SSC'14. And we like to thank all the Tutors for their commitment in the "Tools Tutorial Day" on Monday, the organizers of the modelling workshop ESSA@work, all the reviewers of the submitted contributions, the staff of the Laboratory for Socio-Historical Dynamics Simulation (LSDS-UAB) and the rest of the the local organizing committee, including the student helpers for all their hard work in making the event a success.

Francesc J. Miguel, Conference Chair

Frederic Amblard, AE Chair

Joan A. Barceló and Marco Madella, SPUHH Co-Chairs

The AE 10th contributions will be published in a special Springer volume:

Amblard, F., Miguel, F.J., Blanchet, A., Gaudou, B. (Eds.) *Advances in Artificial Economics*,
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Modelling Routeways in a Landscape of Esker and Bog

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***Abstract*—With the models used in this research, we can identify routeways which can be used to understand landscape and contextualise archaeological remains, while also learning about the decision-making process of people in the past and how they negotiated the landscape. ArcGIS and NetLogo are used to demonstrate the cumulative process which leads to the creation and evolution of routeways over time in a series of actions that approaches efficiency. The environment of North Offaly in the Irish Midlands is used as an example, as it is a landscape of natural routeways and obstacles for which we have rich archaeological and documentary evidence supporting interpretation of movement.**

I. Introduction

THE aim of this research is to understand how people exploited natural routeways and manoeuvred around obstacles in the landscape in the past, using the archaeological evidence from North Offaly in the Irish midlands to explore this question. This research uses modelling and computer applications, augmented by fieldwork and documentary sources, to identify likely routeways.

Two digital approaches are used, namely Least Cost Paths to *calculate* a routeway, and Agent-Based Modelling to *grow* [1] one. ArcGIS 9.3 is used, in what is considered a routine method to identify potential routes through the application of Least Cost Paths. NetLogo 5.0.3 [2] has been used to emulate individual actions which lead to the evolution of routeways. While Least Cost Path procedures are ideal for identifying the optimal path through a landscape, the process has access to global information, which is not what agents on the ground experience when attempting to negotiate the landscape. Modelling allows us to investigate the overall evolution of a routeway as individual agents have access only to local information, allowing them to approach the optimal path over time through a process of iterative attempts to traverse a landscape.

The outputs may be used to point to parts of the landscape that merit further research in the field, and comparison of both results to the archaeological and documentary record can improve the parameters in both simulations and help to develop a method which can be used in other study areas for which we do not have such rich records.

This research is funded by the Galway Doctoral Research ScholarshipScheme of the College of Arts, Social Sciences and Celtic Studies, National University of Ireland, Galway

II. The Study Area

A. The Landscape of North Offaly

The landscape of North Offaly (Fig. 1) is dominated with esker, bog and, in the past, extensive natural woodland. An esker is a long, sinuous ridge of sand and gravel, which are the remains of deposits left by rivers of melt-water beneath the surface of glaciers 15,000 years ago. In Ireland, a series of these ridges stretches from the East Coast to the West Coast and are known by the collective name of the *Eiscir Riada.* Some of the finest examples of high-sided and single-crested eskers are found in the study area (see [3]). The bogs, which are slightly younger, began to form about 10,000 years ago as glacial retreat filled dips and valleys with nutrient-rich meltwater. Poor drainage caused these shallow lakes to build up with partially decomposed plant material and eventually they grew into the typical dome shape of raised peat bogs. The Irish midlands are renowned for their raised bogs, or the Bog of Allen as they are generally known, and a number of archaeological surveys and excavations have demonstrated their importance since early prehistoric times [4], [5], [6]. A stretch of dry land, known as the Midland Corridor [7], bisects this landscape in a northeast by southwest orientation, acting as a major interregional routeway and valuable agricultural land. When Ireland was first populated around 7800BC, the eskers were in already in place and the bogs were in their infancy, so these features would have influenced human activities since the arrival of the first settlers in Ireland.

B. Eskers

The eskers, being well-drained, elevated, relatively straight and flanked by wetlands, are quite suitable for routeways, as is clear from the large number of trails and roads currently located on these ridges (see Rahugh Ridge, Fig. 8). The early medieval routeway known as the *Slighe Mór*, which is associated with the birth of King Conn Céadcathach and therefore usually dated to the early 2nd century AD, is defined for much of its course by the *Eiscir Riada*. From the

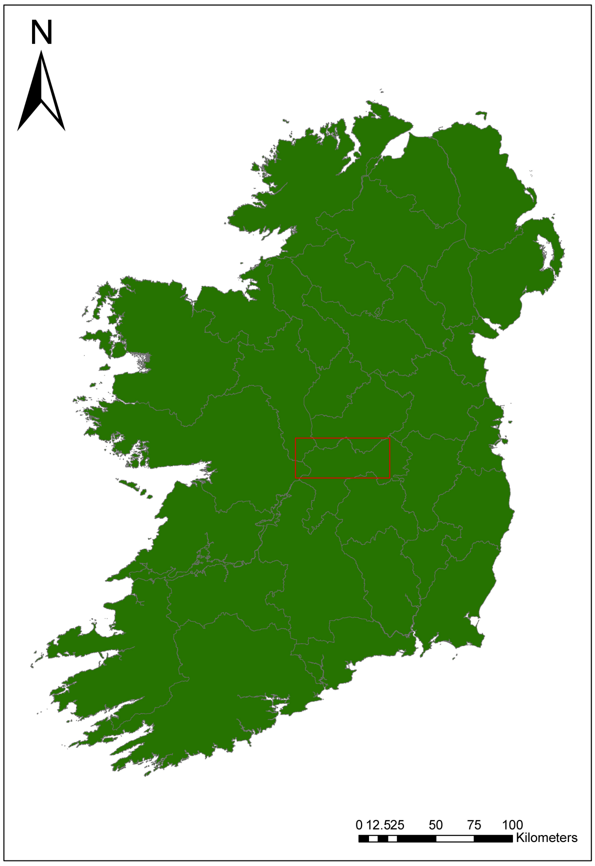

Fig 1: Location of study area

early medieval period on there is a considerable increase in the amount of settlement, particularly ecclesiastical settlement, along the course of the eskers. The presence of a small number of standing stones and burials in proximity to eskers suggest a significance to this feature in prehistory also, but at this time the Midland Corridor with its north-east-southwest axis would have been the more important route. The esker must nevertheless, have been an important local routeway at this time, for negotiating the bogs which would have been even wetter early in their developments.

C. Bogs

While bogs are obstacles, they are not necessarily impenetrable if one is prepared to invest energy in the construction of a trackway. Archaeological evidence [4], [5], [6] has revealed a series of timber trackway constructions in these wetland locations, suggesting that there were incentives to traversing the bog, rather than diverting around it using dry land. The principle incentive would have been the saving of time and energy by significantly shortening a journey. Typically, trackways traverse the bog at narrow points, although exceptions exist which are speculated to be for ritual purposes or to access resources within the bog. This means the trackways can be divided into two categories, those crossing the bog which treat it as an obstacle, and those accessing the bog which treat it as an objective.

D. Hills and Rises

The terrain throughout the study area is relatively flat, ranging from 40m OD around the River Shannon basin in the West, to 90m in the East. Apart from the extinct volcano at Croghan Hill, with a height of 220m, most rises are quite low, but nevertheless highly visible. These rises often mark the narrowest crossing point across bogs, and they offer a visual cue to anyone traversing the landscape, as well as an ideal vantage point to gauge the terrain ahead.

E. The Slighe Mór

Documentary itineraries survive which tell us the names of settlements where the *Slighe Mór* passed [9]. Within the study area, it is known to have passed through Rhode, Croghan, Kiltober, Durrow, Ballycumber, Togher, Ballaghurt and Clonmacnoise. For most of these locations, early ecclesiastical sites have been chosen as nodes between which the models are run.

III. Methodology

A. Data

The map for the study area was produced using Copernicus data and information funded by the European Union – EU-DEM layers, with soil information from the Soils and Subsoils Database from the Environmental Protection Agency. Road data is © OpenStreetMap and Contributers, CC-BY-SA and the Record of Monumements and Places is © Department of Arts, Heritage and the Gaeltacht. I am grateful to Conor McDermott, University College Dublin, for providing survey data from the Irish Archaeological Wetland Unit.

B. Least Cost Paths

The natural features which create potential routeways or obstacles in this landscape are characterised by soil type more so than slope. The Weighted Overlay tool was used to give soil type a weighting of 75% and slope a weighting of 25% to produce a Cost Surface. A scale value of 1 to 10 was applied to each soil type with the following hypothetical values;

Cutover peat – 10
Limestone till – 2
Limestone sands and gravels – 2
Basic esker – 1
Alluvium – 8
Rock – 6
Fen peat – 10
Water – 10
Lake sediment – 10
Made ground – 4
Sandstone till – 2
Marl – 6
Karstified limestone – 6

ArcGIS Least Cost Paths are anisotropic, meaning they are direction dependent. As such, each segment was run in both directions in order to gauge the effect of direction on movement. A realistic path ought to be a hybrid of both of

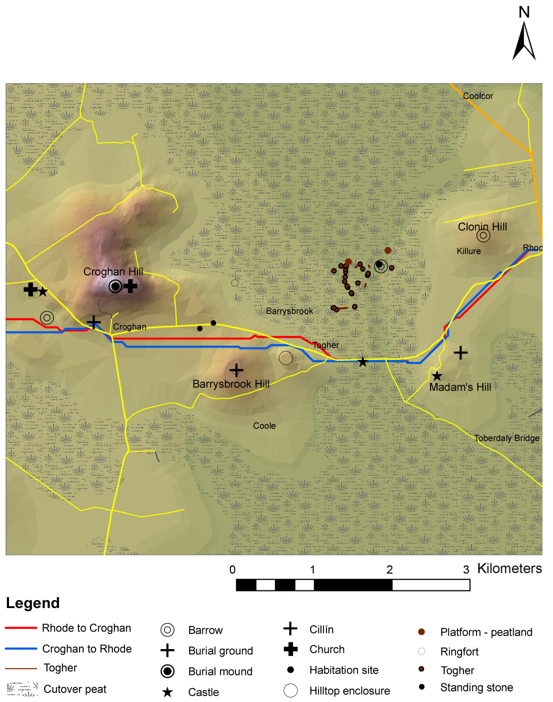

Fig 2: Rhode to Croghan

these paths, but it is not unusual to take a different route depending on direction of travel. Even in the case of established roads, pedestrians often take a different route to and from a location to avoid particular slopes or to maintain a straight course for as long as possible before changing course. It was thus decided to record both results.

C. *Agent-Based Modelling*

The NetLogo GIS extension was used to import the relevant shapefiles to the model, including soil types and elevation data. This model was similarly run in both directions to gain a fuller understanding of the effect of direction on movement. A set number of agents, or turtles in NetLogo terminology, are created at one settlement which is known to have been on the *Slighe Mór* and told their target is the next settlement.

The leading turtle, or `leader` breed, turns its heading to its target. Since these settlements are next to significant landscape features such as hills, it was deemed realistic to set a heading in this way from the beginning of the journey, as a traveller in reality would use the hills as visual cues. After setting its heading, the turtle must then negotiate the landscape using a series of simple instructions.

Booleans were used to differentiate between `obstacle` and `not obstacle`, with bogs acting as obstacles. When a bog is encountered, the turtle is obliged to find a suitable crossing point by using the in-cone reporter which emulates visual perception in reality to find dry land within a set distance and radius. With this code, the leading turtle can find the most efficient crossing point within a reasonable distance without having to circle the entire bog.

Slope was also considered, with instructions to turn the heading towards the patch with least slope within 2 patches. In this way, steep climbs are avoided and minor corrections are made as the more problematic obstacles are negotiated.

All subsequent turtles, known by the `follower` breed, are released at regular intervals and they have the same capabilities as the `leader` to solve any obstacles encountered. They have the advantage, however, of having already had the problem solved by the `leader`, albeit in an inefficient way. Using the same method as the Ant Lines model [8], each follower turns its heading to its immediate predecessor, while still running its own code to negotiate obstacles and manage slope. This has the effect of smoothing the path over time. Rather than maintaining a heading from the beginning to the opposite settlement, turtles later in the sequence aim straight towards the first solution to an obstacle. This cumulative process approaches an efficient path, as evident from the final turtle matching quite closely the path created through Least Cost Paths.

IV. Rhode to Croghan

A. *Landscape*

The settlements of Rhode and Croghan in northeast Co. Offaly occupy slight elevations which are surrounded by a series of hills of volcanic origin and are separated by Ballybeg Bog (Fig. 2). O' Lochlainn [9] tells us that the *Slighe Mór* linked these two settlements in the Early Medieval period, so a routeway must have existed between them despite the obstacle of the bog. Clonin Hill, which overlooks Rhode, is topped with a substantial Bronze Age ring barrow, while Croghan Hill is the location of an extremely prominent burial mound. The dating of this monument is uncertain, but the lack of an external ditch would suggest that it is a Neolithic cairn, rather than a Bronze Age barrow. Within the bog itself, the remains of Bronze age settlement and minor trackways which are not designed to cross the bog have been recovered in wetland survey of the area [10], [11]. The presence of prehistoric archaeology at these locations suggests prolonged use of this landscape, which would have required a routeway connecting these sites at an even earlier date than the *Slighe Mór* is usually dated to.

B. *Least Cost Path Results*

The Least Cost Paths predictably traverse the bog at the narrowest point (Fig. 3). This point is flanked by Madam's Hill in Toberdaly, east of the bog, and Barrysbrook Hill to the west. The paths skirt around the lowest slopes of each of these hills avoiding as much as possible the patches of ground with bedrock at the surface, which have a relatively

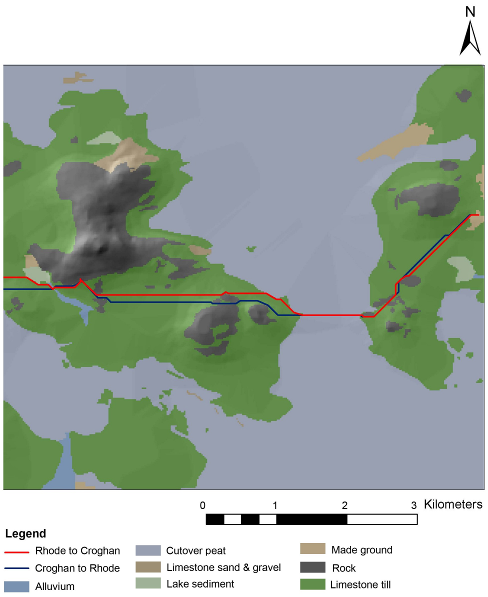

Fig 3: Rhode to Croghan Least Cost Path

high value on the weighted overlay, and which tend also to have increased slope values.

C. Agent-Based Modelling Results

A direct path from Rhode to Croghan and vice versa would traverse Ballybeg Bog at an unsuitable crossing point, so the leading turtle is obliged to search for a narrower point, which it finds between Toberdaly and Barrysbrook, just as Least Cost Paths found (Fig. 4). Each follower is able to shorten the path to the crossing point, leading to an eventual path which makes straight for the crossing, with minor corrections made for slope. With the bog crossing complete, the remainder of the trip is unimpeded and a relatively straight route can be taken to the objective.

D. Archaeological Evidence

This path taken by both programs through Ballybeg Bog coincides with the existing roadway which crosses this obstacle. A map dating to c. 1563 (Fig. 5) illustrates this crossing point, a causeway between Cnocarderin and a series of hills East of Croghan. The feature is labelled as a togher and defended by a castle, demonstrating the strategic importance of this crossing. The Togher of Croghan, or *Tóchar Cruachain Brí Éile*, is mentioned in the Annals at least as early as 1385, so the current roadway, and the path suggested by the modelling, mark a crossing of some antiquity. Given the prehistoric archaeology in the area, it would be likely that this crossing would have been exploited at an earlier date also.

The section of road linking the togher with Croghan is 19th century in date but it matches the path predicted by both modelling procedures and happens to have been flanked by two standing stones. An older road circles south of Barrysbrook Hill, before meeting a crossroads which can be taken back towards Croghan. When walking this routeway, it is clear that the series of hills which make up this landscape (Clonin Hill, Madams Hill, Barrysbrook Hill and Croghan Hill) create visual cues which one aims towards when navigating the terrain. In particular, the target generally seems to be towards a low point on the slope, offering a suitably dry area for comfortable walking without an unnecessarily high climb, and providing an ideal vantage point to view the ground ahead. With this in mind, it would make no sense to move south of Barrysbrook Hill to reach Croghan. This path would only make sense if one was bypassing Croghan in favour of Kilclonfert, another ecclesiastical settlement which was reputedly on the *Slighe Mór* [12].

This author would suggest that the standing stones, the models and the trajectory which the landscape impresses on a traveller through visual cues is sufficient to seriously consider the presence of an older routeway between Barrysbrook Hill and Croghan Hill. Perhaps any earlier routes through Croghan Demesne would have been discouraged – it is clear that older road south of Barrysbrook Hill skirts around the grounds of the townland of Croghan Demesne.

Fig 4: NetLogo model - Rhode to Croghan

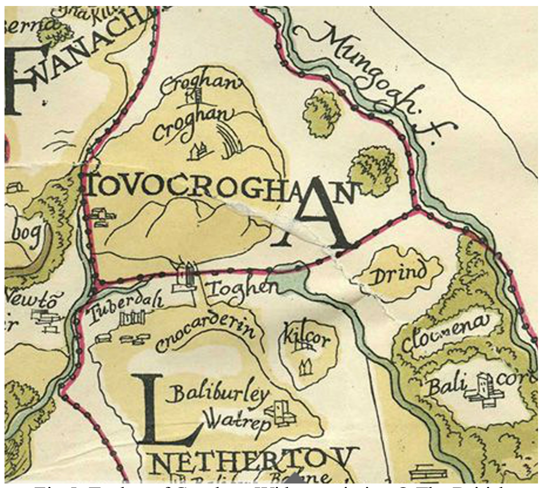

Fig 5: Togher of Croghan. With permission © The British Library Board. Cotton Augustus MS I ii 40. North to right of image.

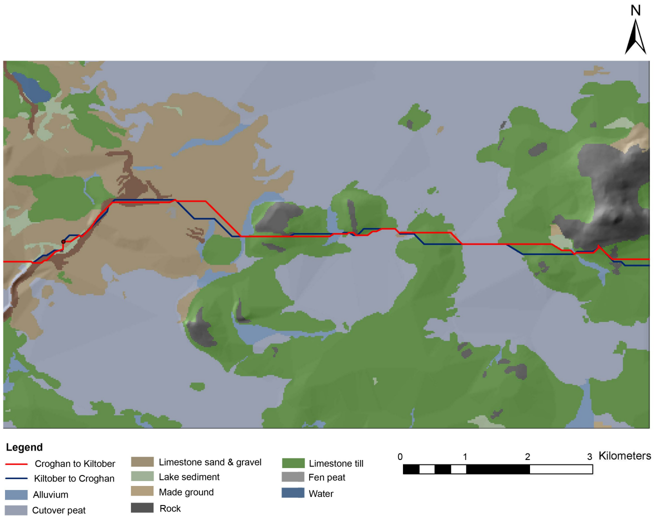

Fig 6: Croghan to Kiltober Least Cost Path

V. Croghan to Kiltober

A. Landscape

Kiltober townland is largely composed of limestone sands and gravels with the very substantial Rahugh esker creating the southeastern border (Fig. 6). This is a particularly significant part of the *Slighe Mór* as it marks an intersection with the Midland Corridor. The importance of this intersection is demonstrated by the distribution of barrows in prehistory and ringforts in the medieval period, with particular emphasis on areas with limestone sand and gravel subsoil.

Clonearl Bog and Raheenmore Bog are located between Croghan and Kiltober, and these must be negotiated to move between the settlements. Just as in the previous segment, a series of low hills are present at Oldcroghan, Kilduff, Clonagh and Mullagharush Hill and they mostly flank the narrowest points of the bogs.

B. Least Cost Path Results

The Least Cost Paths for this segment similarly traverse the bogs at the narrowest points available without deviating course more than a few degrees (Fig. 6). Clonearl Bog is crossed at a narrow point on its northern extent, between rises at Oldcroghan and Kilduff. Raheenmore Bog narrows to only 10m East of Clonagh Hill, and the paths skirt the southern base of that rise and Mullaghrush Hill. The hills mark the most convenient crossing points, but they are only climbed as much as is necessary to gain dry land. The esker is climbed at a suitably gentle point on its northeastern extent, after which this level, single-crested esker leads directly to the Kiltober.

C. Agent-Based Modelling Results

The journey from Croghan to Kiltober requires the crossing of Clonearl Bog and Raheenmore bog (Fig. 7). The `leader` finds the narrowest points in these bogs, which is

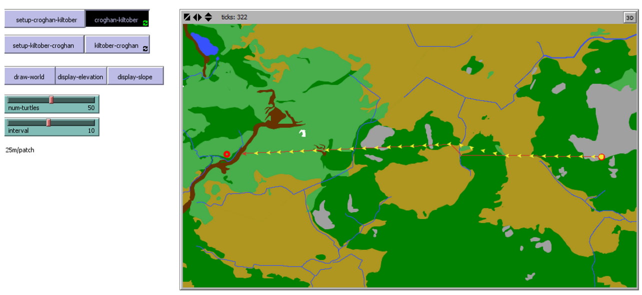

Fig 7: NetLogo model - Croghan to Kiltober

exactly the same point which Least Cost Paths identified as the most efficient route. The model differs significantly from the ArcGIS version on the Western extent where the esker is accessed. The model does not give preference to the esker and climbs it c. 1km South of the Least Cost Path. This esker has been used as a road, with two castles situated along its course, one being a motte and bailey castle which dates to the late 12th or early 13th century, suggesting lengthy use of this esker as a road. It is clear then that eskers are more important in the placement of roads than slope alone would suggest. This is down to their elevation and the composition of the subsoils, which are well-drained and ideal for use as a pathway. This supports the preferential weighting given to eskers in the Weighted Overlay in ArcGIS.

D. Archaeological Evidence

Clonearl Bog is most recognised for the Iron Age bog body found there in 2003. Oldcroghan Man, as he is known, was found 1.3km Southeast of the proposed crossing, where the bog is at its widest. As discussed above (II D), activities in the bog can be separated between those which treat the bog as an obstacle and those which treat it as an objective. The deposition of Oldcroghan Man was a ritual activity and it is no surprise that it should take place in a different location to simple negotiation of an obstacle, but it is a good indication for activity in the environment, from which we can assume movement was taking place.

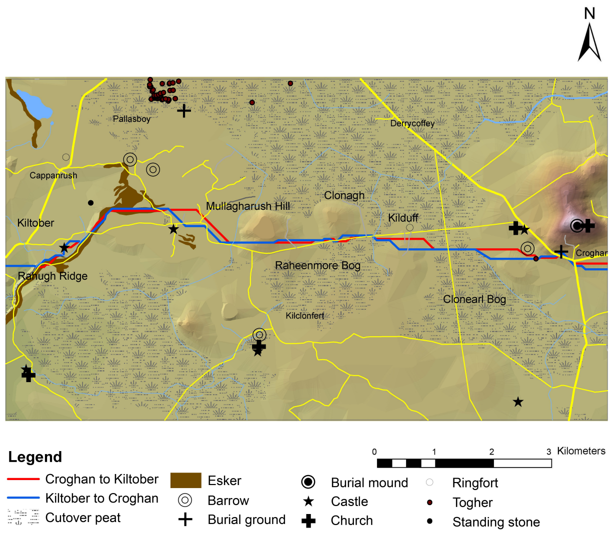

Fig 8: Croghan to Kiltober

The predicted paths closely correlate with existing roads at the Raheenmore Bog crossing and along the southern slopes of Clonagh and Mullagharush Hill (Fig. 8). While the existing road climbs the esker 0.5km South of the Least Cost Path prediction, they maintain a very similar course to the target.

A standing stone and several barrows are in close proximity to the esker on its west side. These are part of the cluster of barrows which mark where the Midland Corridor enters into the ancient kingdom of Leinster and are more closely associated with that route rather than the esker. With only a few exceptions however, this esker delimits the extent of this distribution. The orientation of this esker is unusual as most examples in Offaly are of an east-west orientation. This unusual esker is therefore acting as a wrapping mechanism, delimiting the Midland Corridor and the barrow distribution, as well as representing the crossing point of two important routeways.

VI. Discussion

Those natural features which are conducive to movement must be exploited and established in the mental map of individuals before they can truly be called routeways. While ArcGIS can effectively show us the end product and a potential routeway, NetLogo shows how routeways are established through a series of discrete actions around those natural features, acted out by individual agents over time. The ability of agents to effectively learn from their predecessors through the use of the Ant Lines model, allows for quicker problem-solving on the part of the individual and more efficient paths than initial attempts would produce.

In real world problem-solving, this would appear as a series of trails which impress upon any subsequent traveller. If an opportunity arises to smooth the trail through cutting corners it is usually done, as is evident in the elaborate network of *desire lines* which can be seen in managed parklands or city green areas. The most efficient path becomes the most established one both mentally, through repeated experiences, and physically, through repeated use and perhaps even enhancement through construction. In this way, a stable macrostructure emerges from the interaction of local agents and feedback from microstructures [1].

Both Agent-Based Modelling and Least Cost Paths reflect different facets of the theoretical approach of this research. Complex systems can be derived from a variety of factors involving simple rules and no centralised control. Energy and physical factors which GIS handle so well are crucial in this, but experiential concerns and other qualitative factors ought also to be considered in the emergence and development of routeways and subsequent networks.

VII. Conclusion

The use of these methodologies allows us to not only hypothesise the position of paths in the landscape, but to understand the processes which lead to their creation. Having done so, we can compare predicted paths with existing roads to identify the locations which merit further research archaeologically. Archaeological monuments in proximity to these paths can be better understood as part of their overall landscape by understanding how they fit into the existing system of routeways. The segments discussed have included portions which were important enough to have warranted castles to protect them, such as the Togher of Croghan, while the presence of prehistoric archaeology throughout each example demonstrates the necessity of routeways from the earliest settlement in this area. Viewing these monuments in a movement-centric framework has helped to place them into the context they would have been experienced in the past.

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Roman Bazaar or Market Economy? An Agent-based Network Model of Tableware Trade and Distribution in the Roman East

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Abstract—**This paper aims to evaluate notions of two crucial studies on the Roman economy by Bang and Temin based on the study of distribution patterns of ceramic tablewares in the Roman East in the period 150BCE-200CE. It presents an agent-based network model simulating the social networks which represent the flow of information and goods between traders. Results of the simulation are subsequently compared to the tableware data collected in the ICRATES database. Preliminary results suggest, contrary to Bang's hypothesis, that limited availability of reliable commercial information from different markets is unlikely to give rise to the large differences in the wideness of product's distributions observed in the archaeological record.**

I. Introduction

Ceramic tableware is one of the most common find categories on Roman sites in the Eastern Mediterranean and therefore lends itself particularly well to quantification. It offers archaeologists a key tool for approaching aspects of the ancient economy. One of the most robust patterns observed in the collected tableware data is the variability of distribution patterns of different tablewares at consumption sites (products characterised by a distinct clay fabric and produced in different centres). Some wares such as Eastern Sigillata A (ESA) were distributed on a supra-regional scale for centuries, others were more of regional importance (Eastern Sigillatas B, C, and D), whilst yet other wares were produced for local consumption. What were the mechanisms that led to differences in the wideness of products' distribution patterns? A number of hypotheses have been published identifying, coupling and balancing particular combinations of possible contributing factors, such as state involvement, redistributive centres, consumption "pulling forces", commercial "piggy-back" trade, closeness to large-scale agricultural production, connectivity, etc. [1]-[4]. Most scholars seem to agree that a complex mix of mechanisms working on multiple levels was responsible for the considerable differences in tableware distribution patterns. Since there is evidently no lack of hypotheses, the main challenge becomes to recognise the mix of contributing factors that is best supported by the available evidence, and finding a more quantitative approach that allows one to distinguish between the archaeological "signatures" of different hypothetical scenarios. The development of such approaches has so far been limited in Roman studies [5]-[6].

This paper aims to contribute to this on-going discussion by evaluating two hypotheses of the role of social networks in tableware trade and distribution. It uses a combination of an exploratory analysis of the collected tableware data from the Roman East between 150BCE and 200CE (using the ICRATES database of tablewares) with computational modelling of hypothetical trade mechanisms.

In this paper we will focus our efforts on exploring the potential role of social networks as a driving force of the Roman trade system. The concept of social networks is here used as an abstraction of the commercial opportunities of traders, acting as a medium for the flow of information and products. We aim to formalise and evaluate aspects of two models of the Roman trade system in which such social networks play a key role: Peter Bang's *The Roman Bazaar* [7] and Peter Temin's *The Roman Market Economy* [8]. Bang considers three factors as crucial to understanding trade and markets in Roman Imperial times: bazaar-style markets, the tributary nature of the Roman Empire, and the agrarianate nature of ancient societies. The engine of the model, however, is clearly the concept of the bazaar: the existence of local markets characterised by a high uncertainty of information, and relative unpredictability of supply and demand. This limited availability of commercial information led to poorly integrated markets throughout the empire. Bang argues that different trajectories for the flow of goods could emerge as the result of different trajectories for the flow of information. In other words, the observed distribution patterns of tablewares and different workshops' products (when these can be identified) were at least in part a reflection of the structure and functioning of past social networks as defined above.

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Temin agrees with Bang that the information available to individuals was limited and that local markets were structuring factors. However, contrary to Bang he believes that the Roman economy was a well-functioning integrated market where prices were determined by supply and demand. In Temin's model the structure of social networks allows for commercial information to be more reliably and widely available between markets than in Bang's model, resulting in more integrated markets across the Roman Empire.

II. The Model

An agent-based network model was designed to test the above two hypotheses. In the model 2000 traders are located at 100 sites and are connected in a social network. Four products are produced at four different 'production sites', and are subsequently distributed through commercial transactions between pairs of traders that are connected in the social network.

Setup procedures: the model is initialised by arranging the sites along a circular layout and distributing the traders among the sites following an exponential frequency distribution, which represents observed differences in settlement sizes and the consumption demands of their populations, i.e. the existence of large urban centres with high demand. Four sites which are equally spaced along the circular layout are then selected as production sites of four different products (i.e. four different tablewares).

Traders are subsequently connected to each other to form a social network in three steps which results under different variable settings in the networks shown in Fig. 1:

1. Traders on the same site are connected following a *small-world* structure, with a high clustering coefficient and a low average shortest-path-length [9]. This is a suitable representation of the communities of traders in Bang's model who are more likely to only share commercial information to community members, since a feature of 'small-world' networks is the efficient spread of information within clusters whilst few intermediary traders will allow information to flow between clusters. The procedure to create a network with a *small-world* structure is inspired by the model for the growth of social networks by [10], previously applied in an archaeological model of exchange by [11].
2. We ensure that at least one pair of traders is connected between every pair of adjacent sites, and that the network consists of one connected component (the latter is done at the very end of the setup procedures), which guarantees that each trader can, in theory, obtain an item of each product. This step results in a high average shortest-path-length between traders at different sites.
3. A variable proportion (0% - 0.1%) of all pairs of traders are connected if they are located at different sites. The proportion is determined by the variable *proportion-inter-site-links*.

Distribution procedures: in every time step traders perform the following tasks in sequence:

- traders determine their demand;
- traders discard a small proportion of their stock (due to items going out of fashion or breaking). This proportion is

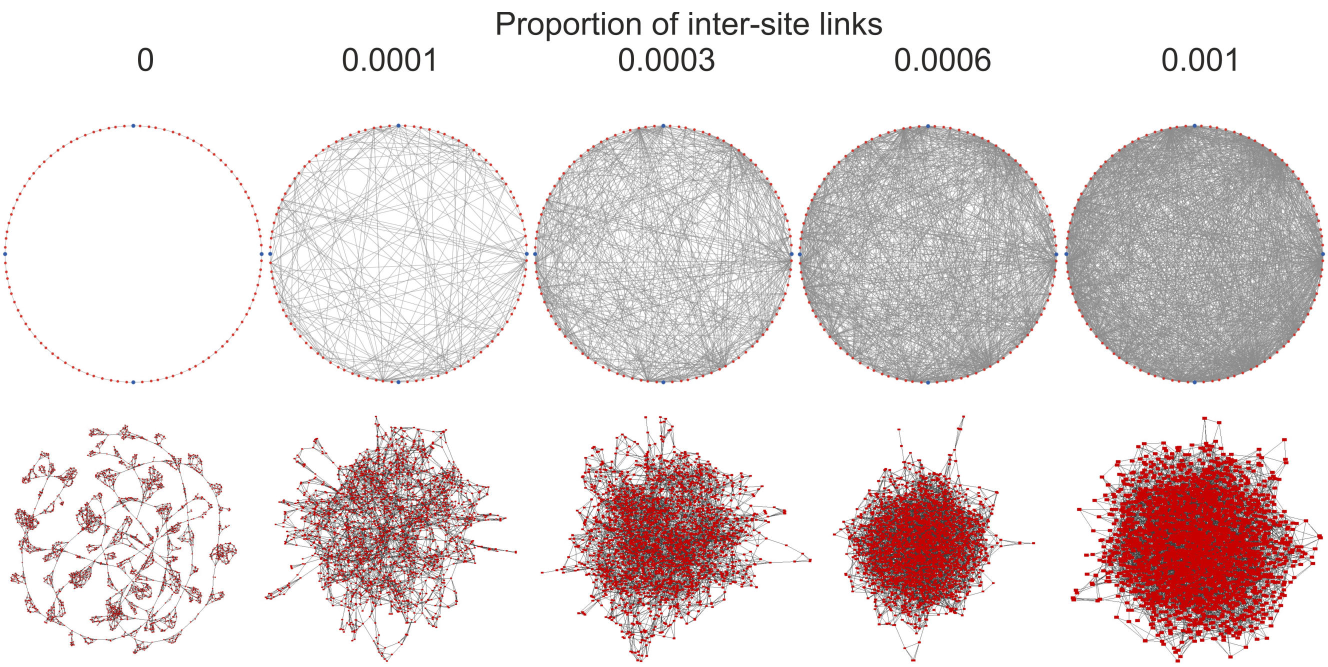

Fig 1: Example of the network structure generated in the setup procedure of the ABM for different values of the proportion-inter-site-links variable. At the top sites are layed out along a circle and traders are positioned at sites. At the botton sites are no longer included and the traders' social network is layed out using a force-directed layout algorithm (yFiles Organic layout in Cytoscape) to display its structure. Note the existence of clusters of traders on sites connected to few other clusters, a pattern which gradually disappears as traders receive more inter-site links and the sites become more integrated.

set to 14% following the model of the use-life of tableware by [12];

- traders on tableware production sites obtain new items if their current possession is below their demand;
- traders obtain commercial information from their neighbours in the network;
- traders determine what they believe to be the current price of an item using this commercial information;
- finally, all items owned by all traders in that turn are considered for trade.

Every time step each trader will only have commercial information available from a proportion (10% - 100%) of its link neighbours. This proportion is determined by the variable *local-knowledge*. The trader then calculates the average demand and average supply of this proportion of neighbours, including his own supply and demand. Using this information he calculates the price of a product as the average demand divided by the average supply (normalised so that the values fall between 0-1). When each product is considered in a transaction a seller will only agree to sell an item if the buyer's price is equal to or higher than this price.

Each item is considered for trade once per time step. An item is put in a trader's stock if he cannot make a profit or if none of his neighbours in the network requires an item (i.e. their demand equals 0). Items in stock can be redistributed in the next time step. An item is sold to a buyer if the buyer's price promises a profit or break-even for the seller. The buyer either places the obtained item in stock for redistribution if the average-demand is higher than his demand (i.e. redistribution holds the promise of a higher profit), or he sells it to a consumer. In the latter scenario the buyer's demand is decreased by 1, the item is taken out of the trade system, and it is deposited on the buyer's site.

III. Preliminary Results

A number of experiments were run to test Bang's and Temin's models by varying two variables: *proportion-inter-site-links* and *local-knowledge*. The experiments presented here were run 10 times each, with 10.000 time steps per experiment, and with parameter settings of the social network adopted from the model by [10]. When *proportion-inter-site-links* is increased traders will have a more diverse availability of information. Moreover, the average shortest-path-length will become shorter, which enables products to spread throughout the network in a lower number of steps, but the clustering coefficient will also decrease, reducing the community structure that is so prominent in Bang's model. When *local-knowledge* is increased traders will have more commercial information. High settings of either of these two variables therefore reflect Temin's hypothesis of a higher availability, diversity and reliability of information that allows for integrated markets across the Roman Empire.

The proportion-inter-site-links variable: setting this variable to 0 results in different products being deposited on a small but more or less equal number of sites, whilst high values result in strong differences between the number of sites different products are deposited on. A few examples are given: a proportion of 0% (0 random inter-site links) results in products being only deposited to the two neighbouring sites of the production centre, products have an equally wide distribution, and volumes of products deposited on sites decrease with distance away from the production centre. However, increasing this to a proportion of only 0.01% of all trader pairs (200 random inter-site links) will give rise to strong differences in the number of sites a given product is deposited on (the largest number of sites a given product is deposited on = 22 out of 100 sites; the maximum difference between product's distributions = 16 out of 100). Further increasing the proportion to 0.1% of all trader pairs (1999 random inter-site links) makes these differences even stronger (a single product is invariably distributed to up to 90 out of 100 sites; the maximum difference between products' distributions = 84 sites).

The local-knowledge variable: increasing this variable did not lead to differences in the wideness of products' distributions, but did have a strong impact on the proportion of failed and successful transactions. This is not surprising since in this model sellers aim to optimise their profits, and will not agree to lower a price which they know to be the correct price in their part of the network.

IV. Conclusion

Preliminary results suggest that the *local-knowledge* variable has a limited effect on the wideness of tableware distribution, whilst the *proportion-inter-site-links* variable has a strong effect. Limited commercial knowledge can still give rise to wide differences in distributions, but only in systems with highly integrated markets. This means that the *local-knowledge* variable is not instrumental in giving rise to the pattern of interest, whilst the *proportion-inter-site-links* variable is. Limited availability and high uncertainty of information, and a weak integration of different markets in an economy governed by supply and demand, is unlikely to give rise to large differences in the distribution patterns of tableware. Preliminary results of this model therefore reject Bang's claim that limited market integration, availability and reliability of commercial information can give rise to differences in the wideness of products' distributions. However, more experiments and a detailed comparison with the archaeological record are required to support these results and to evaluate other aspects of Bang's and Temin's interesting models. Indeed, the main contribution of this preliminary model is to illustrate how aspects of the many hypotheses surrounding the study of the Roman economy can be formalised and tested, an approach which we believe to be all too rare but valuable and necessary for Roman studies as a whole.

In future work a number of other experiments will be performed, including: a higher number of iterations per experiment proportional to the stochasticity in the model; experiments that add a transport cost for transactions between sites; experiments in which the traders are distributed uniformly and normally; and a comparison with random network structures rather than the *small-world*. Furthermore, a more detailed goodness of fit between experiments' results and the actual tableware record of the ICRATES database will be evaluated.

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Calm Before the Storm? Modelling Military Supply and Movement

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***Abstract*—Food production and transport infrastructure play a large role in the outcome of a military campaign and the results of failure can have a profound effect on the whole state. Yet these are areas often poorly covered by contemporary sources. The Medieval Warfare on the Grid project is using agent-based modelling to produce quantitative data to examine the mechanisms required to move armies across a pre-industrial landscape. Though focused on the march of the Byzantine army to the Battle of Manzikert in AD1071, the results can improve our understanding of the logistical challenges faced by armies in other periods and places. The use of quantitative data from later sources provides valuable assistance to both design and validation of the models.**

I. Introduction

Although simulation studies have been applied within historical studies for some considerable time there has been a noted increased level of interest in agent-based modelling in recent years [1], In part this may be a simple reaction to the availability of appropriate technology for such work although these developments have taken place in the context of an increasing awareness of the potential of simulations to answer novel questions that traditional studies are not well placed to resolve and, perhaps, within areas of study where there is an absence of traditional data for concrete analysis and where the presumption of the action of unseen agents may make such studies essential if we are to make sense of past behavioural data.

The choice to undertake such studies should, therefore, be based upon a number of questions including whether such techniques are appropriate for simulation and also whether data (direct or proxy) is available to support simulations of events which are poorly recorded or where there is is no direct parallel or proxy data to provide basic behavioural rules for simulation. This lack of data is particularly noticeable during the validation of models. For that reason it is essential that simulation studies are explicit about why studies are undertaken and what their significance is to the chosen subjects but also how behavioural rules are developed for modelling purposes.

This paper provides an account of the Medieval Warfare on the Grid project (MWGrid) project and outlines how some of the data used by the project were developed during the period of research. Although the full project will be published during 2015 the need to promote debate on the nature of such projects is of value to identify areas of best practice and also to avoid those situations in which modelling appears to be an aim in itself and, consequently, where disciplinary goals are not well developed and the content of the simulations is not well suited to providing substantive historical research outputs.

Contemporary accounts of historical military campaigns traditionally focus on battles and personalities. If we are to believe the accounts of the participants, it is on the battlefield that heroic deeds are performed, commanders show their genius and questions of power are decided. It is this bias within the historical record that gives the impression that the operations which precede the battle are simple, mundane and unimportant. Yet it is the raising, moving and feeding of armies that occupies the resources of a state and provides a large drain on incoming taxes. Food production and transport infrastructure play a large role in the outcome of a military campaign and the results of failure can have a profound effect on the whole state. Gaps in the historical record regarding these systems are therefore both important and noticeable. The lack of historical detail regarding military support infrastructure means that other sources of data must be used in order to examine the ways in which premodern states moved and fed their armies. Quantitative data, so often ignored in favour of qualitative details, is required in order to establish the limits of what is possible under certain circumstances.

The MWGrid project [2], [3] has been simulating the march of the Byzantine army across Anatolia to the Battle of Manzikert in AD1071. It uses agent-based modelling (ABM) to simulate the movement and supply of an army with varying sizes, compositions, types of organisation and distances covered. This paper describes the organisation and aims of one set of these models, those simulating a single day's march of an army. The initial project design called for a single model to simulate the whole march across Anatolia in one single run. This was to explore the interrelation between settlement, transport infrastructure, army size and composition and the provision and transport of equipment and food. A single day's march became the main focus of the MWGrid modelling effort when it was realised that the number of variables needed to be drastically reduced in order to properly explore the parameter space. The models detailed here focus on the way that small details in organisation affect the army's overall speed, noting how this would affect the supply situation. Further models will build on this work to expand the scope of the project.

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The results of these models show a more complex situation regarding the organisation of the army's march than that depicted in contemporary accounts. Using the details of eyewitnesses combined with other Byzantine military writing and more modern data, the MWGrid models seek to create quantitative data that can be combined with the qualitative data in the written sources in order to provide parameters in which the campaign can be framed.

Not only do the historical sources not tell us how the army moved or was fed, they give no indication of what was possible within the medieval period. However there are fixed points from which we may anchor any model that seeks to investigate these problems. Terrain, human and animal movements speed, calorie consumption and the physical size of the army's participants and equipment can be plausibly modelled based on modern or historical data. Simulation can then test unknowns such as organisation and army size and composition in order to provide minimum and maximum values to some of the many variables associated with an army on the march. This gives us a range of possibility within which to reframe the historical debate regarding how the Byzantine army moved and fed itself. This also allows us to attempt to assess the effects of the army on the communities through which it travelled.

II. Problems

In AD1071, the Byzantine Emperor, Romanos IV Diogenes, led an army from Constantinople towards the south-eastern corner of what is now the modern state of Turkey. It formed an attempt to engage and decisively beat the Seljuk Turk nomads who had been raiding Byzantine Anatolia since the middle of the 11th century. Romanos was confronted by the Seljuk Sultan Alp Arslan at the fortress of Manzikert, just north of Lake Van. The defeat of the Byzantine army at the Battle of Manzikert and the subsequent period of civil war that followed has been described as "the most decisive disaster in Byzantine history"[4]. From this point on the Byzantines never exerted control over the whole of Anatolia and the Turkic people were never driven out.

Considering the importance of the event and the number of historians, both contemporary and subsequent, who have described and commented on the events of the battle, the lack of reliable quantitative data is profound. Byzantine sources give no numbers for the size of the army at all. Arabic and Armenian sources give figures which are considered by modern historians to be exaggerated to emphasise the scale of the Seljuk victory. More broadly, the logistical mechanisms by which the Byzantine Empire could move an army "more numerous than the sands of the sea"[5] across a landscape with limited transport infrastructure and occasionally scarce food resources are barely described at all. This lack of supporting data poses problems not just for the design of an ABM but also for the validation of any ABM produced. There are, however, some starting points that can be plausibly assumed. The terrain of Anatolia is largely the same now as in the 11th century, in elevation although possibly not in the type of transport infrastructure and vegetative cover. Humans and horses take up roughly the same amount of space and move at roughly the same speed now as they did then so there is a solid base on which to build a crowding model. It can be assumed that the human body burns calories as a result of work done in much the same way.

III. The Day's March Models

There are many factors involved with moving an army, including availability of resources, number of participants, proportion of cavalry and infantry, number of baggage animals etc. Some of these factors are interdependent, for instance the number of baggage animals required depends on the size and composition of the army and the distance between resupply locations[6]. Computer simulation can be used to model some of these factors and provide parameters within which the historical debate can be framed. ABM's architecture of autonomous agents moving and interacting within an environment of resources seems an appropriate method of simulating the actions taken by an army on the march.

A series of scenarios have been run, each set focussing on a single aspect of the march. This is an attempt to explore the parameter space as fully as possible. The problems of using models to extract the maximum useful data while being able to perform the modelling in a useful time are well known. As a point of comparison, a day's march for 100 agents takes around 90 seconds to run. The same scenario for 10,000 agents takes around 90 minutes and for 40,000 agents it takes around 90 hours.

A. *Size and distance*

An army consisting of homogeneous agents is marched from one day's camp to the next. These camps are at a variety of distances between 10km – 30km. Three sizes of army are used: 101 agents, 10,001 agents and 40,001 agents. The extra agent represents the structure in the model in which 1 main route planning agent heads the column and squads featuring regular numbers of soldiers follow in order of march.

B. *Composition*

Cavalry are added to the army in varying percentages in order to assess the effect this has on overall army speed and arrival time. Cavalry agents differ from infantry agents in that they move faster (4mph as opposed to the 3mph of infantry agents) and occupy more space in an environment cell.

C. *Variable cavalry speed*

Furse [7] suggests that cavalry spend part of the march on the trot, part walking and part being led by their riders. This ensures the horses are well exercised but don't become fatigued. This is implemented in the model in order to assess its effect on arrival time.

D. *Resting*

Periodic resting on the march is recommended in the 19th century literature. This not only gives soldiers the opportunity to drink or release water but also operates as a mechanism to close up an army column that has a tendency to elongate over time. A certain part of the rest period can be used to close up the gap on the unit in front if it has moved too far ahead. The effect this has on arrival time and column length is assessed.

E. Day length

Night marching is to be avoided where possible. For this reason the models are set up to only simulate the length of time corresponding to the amount of daylight. The Manzikert campaign ran from early March to August and so would have seen a variety of lengths of daylight in each day. The effects of this are modelled.

F. Splitting into columns

One method of increasing the 'bandwidth' of the army is to split the force into separate columns who travel to the same destination via different routes. This is especially prevalent with the increased army sizes of the Napoleonic era but can provide benefits for armies of the proposed size of the Byzantine army at Manzikert. The benefits include having more soldiers on the march at the same time. However, there can only be one optimal route, soldiers sent via alternative routes will either have a longer or harder march. Splitting the army into 2 or 3 columns is compared to single column marching.

G. Baggage

It is clear from both Byzantine and more modern sources that the organisation of baggage was rarely simple. A tripartite division of the baggage animals is often suggested where each squad has its own baggage animal for frequently used items with a unit baggage train for less frequently used items and an army baggage train for reserves of supplies and siege equipment. The MWGrid ABM has the ability to add baggage animals in a variety of organisational schemes and compare the effects on both equipment carrying ability and overall army speed.

H. Terrain

Terrain affects route planning, resulting in longer travelling time and more calories burned. The movement of the army would have depended on existing routes which themselves would have depended on a variety of factors. Unfortunately there is not enough reliable data on Byzantine road systems to produce a plausible transport infrastructure. We also lack data such as land use and the location of water courses in order to factor in the effects that these undoubtedly had on route planning. The best we can do is take into account the factors we can simulate plausibly, namely terrain and its effects on calorie consumption. For this reason, the route planner tries to take the shortest route while avoiding steep inclines. The degree to which it tries to avoid steep climbs varies based on the ABMs parameters and the effects of these parameters is explored in these scenarios.

I. Cumulative effects

Although it is not yet practical to model every days march of the Manzikert campaign consecutively as the campaign took around 6 months and some models take longer to simulate than the corresponding march took to complete. Nevertheless, by

J.

K. The Manzikert campaign

The only real method of validating the model via direct comparison to contemporary accounts is to see if the army as modelled would be able to travel over 700 miles across Anatolia from Constantinople to Manzikert within the time provided. Representative samples of days marches using plausible historical army sizes at various points along a hypothetical route are used to determine whether the 6 months of the actual campaign are possible for the army as modelled. The army itself would have been subject to various delays for a variety of reasons, unmodelled within the ABM and so we would expect the model to outperform reality. If that is not the case, if the modelled army would have been unlikely to be able to reach Manzikert within the time recorded by historical accounts then it is a sign that the model may be wrong enough to not be useful. If the model does outperform the actual army that does not of course prove that the army moved itself as modelled.

The scenarios described above represent over 100 different runs of the simulation requiring a processing time of over 1,000 hours. Even so there are combinations of ABM parameters that have not been modelled. The parameter space is just too large to sensibly explore all of it. This presents a problem within historical ABMs in general where there are few known points with which to anchor a model and too many variables with too great a range to completely explore the possible combinations.

IV. Validation

Validation can be problematic when dealing with historical ABMs. This is certainly the case with the MWGrid models, where comparative data is scarce. The length of the campaign as a whole is known but the behaviour of the army on a day's march and the way in which the various factors interrelate are almost complete unknowns. Historical records can produce bits of information that can be used to calibrate the models, however contemporary accounts of the Manzikert campaign are unhelpful. Byzantine military treatises exist from the 10th century but these are often light on the actual quantitative data required to compare to the output of an ABM. Quantitative data from similar situations can be found from other sources. However, the 19th century saw the publication of a number of military manuals and memoirs, some of which contain detailed descriptions of military manoeuvres under similar circumstances and of the same scale as the Manzikert campaign.

The late 18th century and early 19th century was a period in which military writing flourished along with the accessibility of written publications. The early 18th century saw the hugely influential writings of Clausewitz [8] and Jomini [9] but higher standards of literacy and lower publishing costs subsequently ensured an audience for the writings of veterans of the wars of the mid to late 18th century. There were not only personal memoirs written of wars in Europe and the Americas e.g. [10], [11] but also military manuals, produced for the consumption of both the military themselves and an interested public. Virtually unknown today, some of these military manuals were written by highly decorated and experienced officers. George Armand Furse was a Colonel in the Black Watch and wrote a series of books on such subjects as 'The Art of Marching' [7] and 'Provisioning Armies in the Field' [12]. He had served in the Boer War and had also been Quartermaster General of the Nile Expedition to relieve Khartoum in 1884-1885. Colmar Freiherr von der Goltz was a Prussian Field Marshal who served in the Franco-Prussian War and later spent twelve years helping to reorganise the Ottoman army after the Russo-Turkish War of 1877-1878. He also wrote a series of books based on his experiences e.g. [13], [14].

These books often contain a wealth of information regarding 18th century military organisation, much of it applicable to pre-modern examples. Although the invention of the railroad and canned food had altered military logistics, there were still plenty of campaigns away from a railway network and plenty of food consumed that did not come in a tin. The mechanisms were still there to promote war in the same way that it had been done since the time of Alexander the Great. People, animals and goods still needed to be transported across unpaved roads, mules were still much in demand, wagons still carried heavier weights but were less tolerant of poor road conditions than pack animals. The basic elements were all there in the British campaigns in 18th century India that had been used by Alexander a little further West, some 2,200 years before.

The extent to which army movement can be compared between the two periods is of course debatable. Nevertheless, where similar circumstances are mentioned in both Byzantine and 19th century military writing, the advice given is usually strikingly similar. Examples of advice common to both Byzantine and 19th century military manuals include:

- Baggage trains should be kept as small as possible.
- Civilian populations should be respected.
- A combination of supply and foraging is required.
- Soldiers should be well-fed.
- March order should be rotated.
- The route needs marking with signs or people.
- Leaders who share in the soldiers' lives are more respected.
- There is a tripartite division of baggage: Army, unit and personal level.
- Parties should be sent ahead to clear the road.
- Some space should be left on one side of column for local traffic or army cavalry/messengers.
- Wagons are standard but pack animals are quicker and should be used if speed is a factor.
- Care should be taken over camp locations, the criteria for which stays the same over time.
- In case of the column lengthening, the front should slow rather than the rear speed up.
- Local knowledge is very important.

This overlap between the advice of experienced military officers of the 19th century and that of the Medieval period allows large amounts of new data to be included in the design phase of any models. This increases the number of behaviours within the model that can be supported by historical data. This then reduces the parameter space that needs to be explored during the simulation process. In addition, the presence of quantitative data within the 19th century manuals allows them to be used to validate the results of the models. Within the 19th century manuals can be found speeds of units and columns, weights of equipment, capacity of baggage animals and the degree to which an army column lengthens on the march, all data absent from Medieval sources. The substantial overlap between the areas that are covered by sources from both periods gives confidence that the 19th century sources may be used as plausible supporting data in areas which are ignored by Medieval accounts.

V. Results

The MWGrid ABM outputs 2 text files, a dayfile and a tickfile. The dayfile contains one line for each agent which provides aggregated data for the day's march. These include:

- Distance travelled
- Calories expended
- Amount of time on the march spent resting
- Arrival time at camp

The tickfile records the location of each agent for each tick of the simulation and can be very large, over 11Gb for 40,000 agents over 12,000 ticks. This tickfile can be processed by a Python script to create 2D and 3D images and animations via Blender, the open-source 3D modelling package [15]. The data contained in both dayfile and tickfile can also be visualised via graphs and tables.

In addition, data can be derived from the dayfile and tickfile in order to produce data such as maximum and minimum length of an army column and the actual travel time of each individual agent. This data should not be taken as a direct statement of historical fact but is often more useful as a comparison between other runs of the simulation. For instance, calories expended on the march can give an indication of any extra food that would be needed based on different types of march but it should be remembered that this does not include activity before and after the march and so can only be used for comparative purposes.

VI. Broader applicability

The similarity between Byzantine and 19th century military writing supports the hypothesis that while battlefield tactics can change quickly over time as commanders respond to changing opponents, weapons and battlefields, the twin enemies of the logistician are distance and hunger and these have more stable characteristics over time. This results in a greater commonality in problems occurring over a larger range of time and space and consequently more stability in the systems used to overcome those problems. therefore the results of the MWGrid project should not only interest Byzantine military historians but those interested in the logistics of all pre-industrial eras and even some more recent campaigns in circumstances that mirror those of the Medieval period.

The Manzikert campaign was conducted as though the enemy were too far away to be a threat to the marching army and this, as mentioned in Byzantine military treatises, results in a different order of march. It presumably also alters the attitudes of the campaign's participants. A rethink of the agent behaviours will be necessary if the march of an army near an enemy is to be modelled.

VII. Conclusions

This paper began with a statement that appealed for explicit and critical assessments of simulation models and their capacity to answer the questions posed by historical researchers. It should be clear from the body of the paper that the MWGrid project required significant input from sources that had not been identified at the onset of the research. Whilst there is no doubt that the project was able to incorporate these new data it is apparent that the final output was not a holistic solution. For instance, the focus of these models on distance moved and calories consumed may lead to a deterministic view of an army on the march. Significant elements are unmodelled however and any conclusions drawn from the project must take this into account. Although the number of calories consumed during marching can be plausibly calculated, the number consumed before setting off on the march and upon arrival at camp are unknown and likely to vary greatly depending on circumstances. This will in turn affect the supply situation of the army which will in turn affect movement. However the results of this project are not our conclusions but a baseline against which we can measure our conclusions and the conclusions of others. They can be an arbiter of how practical the previously untestable hypotheses regarding the march of the Byzantine army to Manzikert are. The infrastructure created in the MWGrid project deals with problems fundamental to army movement and supply in many pre-industrial and some post-industrial settings and can therefore be used to model military logistics in other times and places.

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Personal Protective Behaviour During an Epidemic

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***Abstract*—The TELL ME simulation model is being developed to assist health authorities to understand the effects of their choices about how to communicate with citizens about protecting themselves from influenza epidemics. It will include an agent based model to simulate personal decisions to seek vaccination or adopt behaviour such as improved hand hygiene. This paper focusses on the design of the agents' decisions, using a combination of personal attitude, average local attitude, the local number of influenza cases and the case fatality rate. It also describes how personal decision making is connected to other parts of the model.**

I. Model Structure

The European funded TELL ME project includes a planning model about communication to encourage protective behaviour in response to influenza pandemics. The model has three model entity types for which interaction and behaviour rules are required:

- *Messages*, packaged as communication plans;
- *Regions*, which hold information about the local progression of the epidemic; and
- *Individuals*, who adopt protective behaviour, influenced by the messages they receive and their circumstances.

A communications plan provided as input to the model will involve multiple messages. Each message will have several properties based on the transmission oriented communication framework [1], [2]: Sender, Message, Channel, Receiver, and Effect. The Sender is always the health authority and is not explicitly provided to the model. The Effect is included in the model rules rather than the language describing the communication. The remaining three properties together define which individuals receive the message, either because they have targeted characteristics (such as high risk) or are exposed to the appropriate channel (such as social media), and the content of the message (such as a recommendation to vaccinate). The message language also provides timing and triggering mechanisms to coordinate the communication plan.

Modern understandings of communication are much more sophisticated, for example recognising that there are many contextual factors that influence how a message is encoded by the sender and decoded by the receiver [3]. Such nuanced interpretation of message content is beyond the scope of the model, but is considered in other parts of the TELL ME project.

The progress of the epidemic is managed by the region entities. Their properties include population density and the proportion of the population in specific epidemic states such as 'infected'. The most appropriate simple model for influenza transmission is the SEIR model, This process of transitions is simulated by stepping through discrete time, based on a set of differential equations [4]. : People start in the susceptible (S) state, become exposed (E) but not yet infectious, then become infectious (I) and are eventually removed from calculations (R) because they either recover and become immune or they die.

A key parameter in the transition from S to E is the force of infection, which incorporates probability of transmission given contact and contact rate. The individuals in the model do not transmit the epidemic. However, the protective behaviour of individuals, combined with the efficacy of the behaviour, is used to modify the force of infection. This is equivalent to the approach taken in many mathematical models that have feedback between personal behaviour and epidemic progress [5]. Each region is updated separately, with migration between regions to allow the epidemic to spread.

The model includes several thousand agents representing individuals, with demographic and psychological characteristics that are important for protective behaviour, such as gender and 'high risk' health status perception [6]. Individuals perceive the epidemic state of regions for risk assessment, the content of messages directed to them, and the attitude of other individuals so as to monitor norms. They adopt or abandon protective behaviour according to their policies. The theoretical basis for this behaviour and how it is operationalised in the TELL ME model is the subject of the remainder of this paper.

II. Psychology of Health Behaviour

There are several well established models from psychology that predict (or explain) behaviour and change in behaviour on the basis of other variables such as attitude or perceived risk. Three of these are particularly important. The Theory of Planned Behaviour is the dominant general purpose behaviour model in psychology. The Health Belief Model and Protection Motivation Theory are also popular in the health behaviour literature.

There is no agreement on which of these psychological models is most suitable for any specific type of behaviour, and there is insufficient detail about parameters that may be appropriate for epidemic influenza. Thus, they cannot be directly applied to determine protective behaviour for simulated individuals in the TELL ME model. Nevertheless, they provide guidance on the factors that should be included in the simulation model. Some of the explanatory factors are shared, and there have been attempts to develop a theory that combines the strengths of each.

A. *Theory of Planned Behaviour*

The Theory of Planned Behaviour is an extension of the earlier Theory of Reasoned Action, which asserts that intention is the best predictor of behaviour, and that intention is predicted by three factors [7]. According to the earlier theory, intention is increased in the presence of:

- attitude: favourable evaluation about the specific behaviour;
- subjective norms: perceived social pressure to perform the behaviour, or approval from other people; and
- behavioural control: perceived ease of undertaking the behaviour.

The Theory of Planned Behaviour extends this understanding by adding perceived behavioural control as a predictor of behaviour, in addition to its role in predicting intention [8]. This extension was introduced to recognise that many factors can interfere with intended behaviour, and that perceived control is one way to estimate the likely impact of these factors.

The model does not simply identify the important contributing factors but also proscribes the way they are combined. In particular, intention is a linear combination (weighted sum) of attitude, norms and control. However, the parameters associated with each explanatory variable depend on both the behaviour to be predicted and the situation [8]. Predictive power varies considerably, with a major review of 185 empirical studies finding that, on average, 27% of the variation in behaviour is explained by the proposed explanatory variables [9]. Thus, although the structure can be adapted for the TELL ME model, there is limited guidance on the parameter values to use in rules to control behaviour.

B. *Health Belief Model*

For preventative health behaviour, an important alternative is the Health Belief Model [10]. This asserts that behaviour arises from two dimensions that motivate action—susceptibility and severity—and two that determine the action to be taken—benefits and barriers. There is also some underlying ‘cue to action’ or trigger (such as symptoms or exposure to media) to stimulate the need for a decision.

There is some evidence that the model has only limited predictive power [11]. This is at least partly because the model is primarily descriptive; there are no standards about how to measure each of the four input factors or how to combine them into a prediction of behaviour, and only limited research about the triggers. Two specific reviews [12], [13] found that published studies do not support the use of the Health Belief Model as a predictive model.

C. *Protection Motivation Theory*

Protection Motivation Theory [14] and related theories such as the Extended Parallel Process Model [15] focus on the role of threat in explaining preventative health behaviour. They argue that fear motivates intent, but behaviour only occurs if there is an effective remedy available. If threat is high but capacity to cope low, Protection Motivation Theory suggests that denial or other maladaptive behaviour will occur instead.

There are six explanatory variables, divided into two groups of three, appraising threat and coping strategy respectively. Threat combines vulnerability (perceived likelihood that the threat personally applies), severity (perceived seriousness of consequences of the threat) and fear arousal (level of worry about the threat). Capacity to cope comprises response efficacy, self-efficacy (perceived ease of undertaking the behaviour) and the absence of costs or barriers that interfere with undertaking the behaviour.

There is empirical support that the framework is useful in explaining existing ongoing behaviour, but less support for its use in predicting future behaviour [16]. In particular, the threat appraisal elements are only weakly predictive, but this could be due to difficulties in varying perceived severity in an experimental setting.

D. *Combining psychological theories*

In a 1992 workshop sponsored by the (US) National Institute of Mental Health, leading supporters of different theories discussed the overlap and reached consensus on eight important factors that explain variations in behaviour [7]. For the purpose of operationalising behaviour in a simulation model, the consensus recognition that some of the explanatory factors included in separate models are essentially the same is particularly relevant. For example, the attitude measure from the Theory of Planned Behaviour is very similar to the combination of benefits and barriers from the Health Belief Model. While Protection Motivation Theory was not included in this reconciliation, it overlaps substantially with the Health Belief Model with, for example, threat appraisal adding only the emotional aspect of worry to the motivation factors of severity and susceptibility.

At least three studies [17], [18], [19] have tested influences from both the Theory of Planned Behaviour and the Health Belief Model for predicting vaccination against an influenza epidemic. All found that attitude and subjective norms from Theory of Planned Behaviour are important predictors and that predictive power increased with the addition of variables from the Health Belief Model. Systematic reviews of psychological factors associated with vaccination against epidemic influenza using the framework of Protection Motivation Theory [20], [6] found similar results, with evidence supporting that the threat appraisal variables of susceptibility and severity are associated with vaccination.

III. Operationalising Individual Behaviour

The TELL ME model focusses on attitude, subjective norms and threat as the key inputs to protective behaviour decisions.

Threat is modelled as a combination of disease severity and local prevalence.

The broad model logic is at Figure 1. The major flow of influence is the effect that communication has on attitude and hence behaviour, which affects epidemic transmission and hence prevalence. Prevalence contributes to perceived risk, which also influences behaviour, establishing a feedback relationship.

An individual's initial attitude is affected by many factors, including health status and culture. Social Judgement/Involvement Theory [21] asserts that the change in attitude induced by communication depends on two key factors, the position of the communication and the latitude of acceptance for the receiver. Conceptually, attitudinal positions have a value over some range. Both the person receiving the message and the message itself have positions. The attitude of the person receiving the message changes toward the position of the message, but only if the message has a sufficiently similar position so as not to be simply rejected (in the agent-based modelling literature, this concept is referred to as bounded confidence, as in [22]). The latitude of acceptance refers to the range of positions that are considered and integrated into the receiver's updated attitude.

For messages within the latitude of acceptance, the amount of change is proportional to the discrepancy between the individual's existing attitude position and the position of the message. Thus, a greater difference in position will result in more change. In addition to the evidence directly supporting Social Judgement / Involvement Theory, there is empirical support for change in attitude proportional to discrepancy [23], [24].

Simulated individuals within the model will be assigned two initial attitudes as values between 0 and 1, representing attitude toward vaccination and toward all non-vaccination protective measures (such as hand hygiene, face masks and social distancing). The initial attitudes will be based on survey information about willingness to adopt protective behaviour, including subpopulation specific attitudes.

Attitude scores will change in response to the messages (created as part of the input communications plan) that are received by the individual. The model will also include some attitude change arising from informal communication, such as discussion with friends or exposure to media.

Subjective norms describe how a person believes family, friends and other personally important people expect them to behave and the extent to which they feel compelled to conform. The norm will be operationalised as the average attitude of individuals in the same or nearby regions, together with some contribution from average attitude in other regions. If there is a message in the communication plan that emphasises norms, then perceived norms will be higher than the weighted average of actual attitudes.

Perceived threat will reflect both susceptibility and severity, with an adjustment intended to capture relative anxiety (that is, some people naturally worry more than others). Severity will be modelled from the case fatality rate and will therefore change as the epidemic progresses. However, early deaths and deaths that are geographically close will be given additional weight.

Following the method of [25], susceptibility will be modelled with a discounted cumulative incidence time series. That is, perceived susceptibility will increase as the epidemic spreads but recent new cases will impact more strongly than older cases. This approach also allows perceived susceptibility to increase but then gradually fade away after the peak has passed. Explicit modelling of the epidemic in the TELL ME model will allow geographical information to modify perceived susceptibility rather than rely entirely on national cumulative incidence. That is, perceived susceptibility will be higher for the simulated individuals that are close to the new cases than for those further away.

The choice of how to combine the explanatory variables and make the behaviour decisions (for example, weighted sum or logistic) will be made during calibration based on the available data. Regardless of this choice, three additional parameters will be required for behaviour policies: the thresholds at which a simulated person seeks vaccination, and adopts or ceases non-vaccination protective behaviour.

IV. Conclusion

This paper describes the planned implementation of cognition in the TELL ME model, which is currently being developed. Simulated individuals are to respond to communication with attitude change and to perceive threat based on local epidemic progress and its severity. Their attitude, perceived subjective norms (based on average attitudes) and perceived threat are used to determine their protective behaviour: seeking vaccination, adopting other protective measures or ceasing protective measures.

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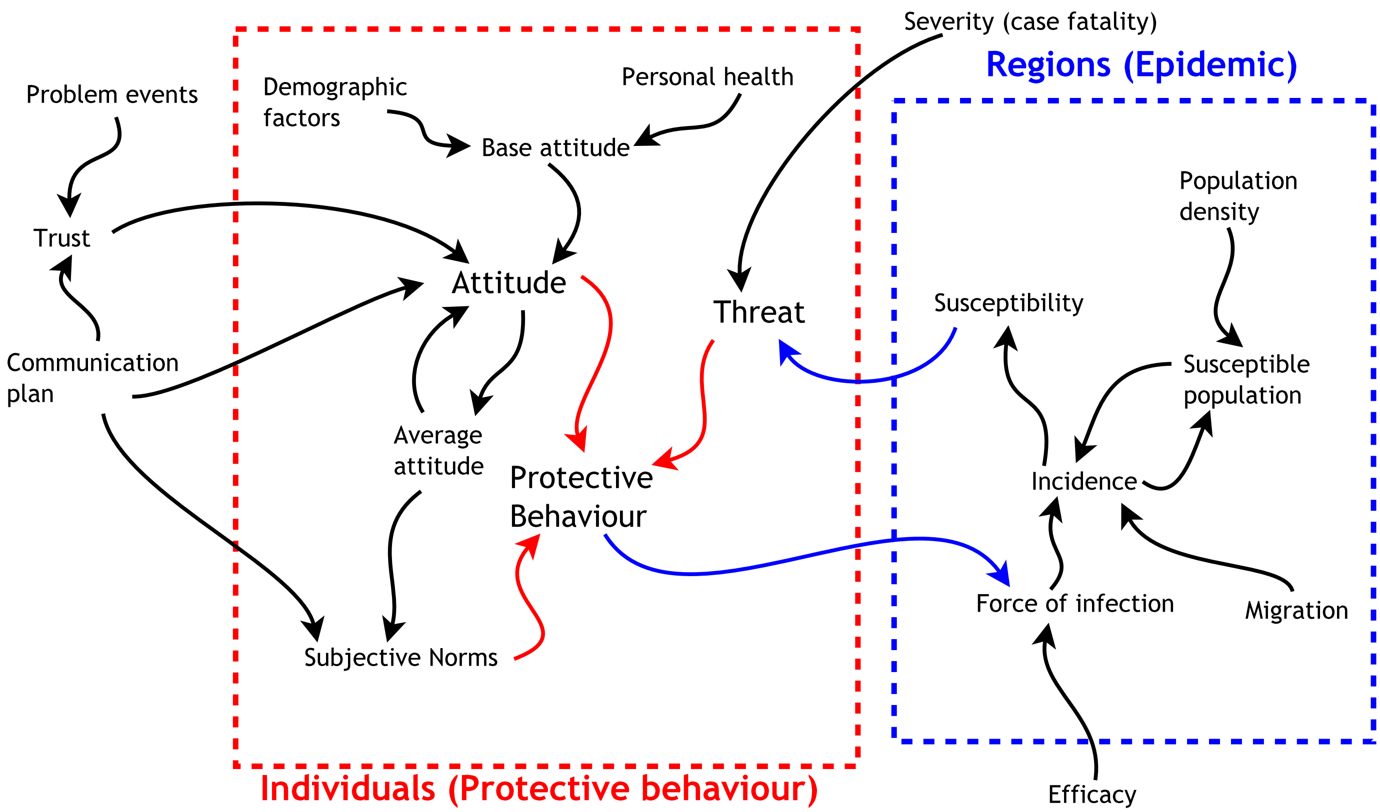

Fig. 1. TELL ME model logic, identifying the influences between variables and organised by model entity. The arrows identify the pattern of influences between properties of entities. At each timestep, attitudes of individuals are updated in response to received messages, then individuals decide their protective behaviour. Adopted behaviour and its efficacy reduces the force of infection of the epidemic and hence its spread.

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Strategic Interactions and Information Exchange on Networks: An Agent Based Simulation Model of Landowner Behaviour in Conservation Incentive Schemes (Extended Abstract)

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Abstract— Starting with data obtained from human-subject experiments to investigate farmers' responses to a conservation incentive scheme, we derive a cognitive model of the farmers' decision-making behaviour, and implement this model within an agent-based simulation of farmers interacting via different types of social network. We find that the outcome of the scheme in early time periods is improved by providing more information to farmers. However, changing the structure of the social network by which the information is provided has no effect.

I. Introduction

THIS abstract contributes to the literature on the use of agent based simulation modeling to study the pattern of land use behaviour on privately owned geographical landscapes, specifically agricultural landscapes. Such landscapes deliver ecosystem services that are beneficial for mankind (Millennium Ecosystem Assessment Report 2005), including food and water provision, flood control, insect pollination services for crop cultivation, water quality maintenance and habitat and biodiversity protection. Land use behaviour pertaining to the provision of these ecosystem services is commonly incentivized with the help of conservation incentive schemes termed Payment for Ecosystem Services (PES) Schemes. These schemes entail financial compensation for private landowners, most commonly farmers, who adopt pro-conservation land uses on their property. The economic rationale behind such funds transfer is that many ecosystem services have public good features, leading to their under-provision by the private agent – thus increase in supply can be potentially affected by making targeted payments to farmers. Another rationale for these payments is that since the ecosystem services provided by the farmers have benefits for society, farmers should be compensated for producing these benefits. Examples of PES schemes include the Stewardship Scheme in the UK (Dobbs and Pretty 2004), the Conservation Reserve Program in the US (Ferris and Siikamäki 2009) and the Pago por Servicios Ambientales (PSA) in Costa Rica (Sanchez-Azofeifa et al. 2007).

In the domain of PES schemes, one issue that has received widespread attention is that adopting the same land use on parcels of neighbouring farms, or on parcels within a given distance of each other, can increase the delivery of many ecosystem services which have positive spatial synergies (Margules and Pressey 2000). The economic literature by Parkhurst et al. (2007), Warziniack et al. (2007), Watzold et al. (2010) and Banerjee et al. (2012 & 2014) has focused on the study of the Agglomeration Bonus (AB) subsidy, that incentivizes such spatially coordinated land use behaviour by neighbouring landowners. The AB is a two-part payment scheme with a base payment and a bonus contingent on spatial coordination of land uses by neighbours. In this format the AB takes the form of a coordination game with multiple Nash equilibria, each corresponding to a particular land use strategy, ranked in terms of their payoffs – under one Nash equilibrium situation, participants make more money than under the other. This is the Pareto efficient equilibrium. However, depending upon the payoffs, the equilibrium selection principle of risk dominance (Harsanyi and Selten 1988) may select equilibria other than the Pareto efficient one, resulting in coordination failure. Previous experimental work has analyzed performance of the AB scheme and coordination failure under various conditions such as repeated interactions with neighbouring farmers, or the possibility of communication before making land use decisions (Parkhurst and Shogren 2007; Warziniack et al 2007).

Banerjee et al. (2012, 2014) focus on behaviour on simple local networks where every farmer has two neighbours whose actions determine whether they receive AB bonus payments or not. Laboratory experiments are used to explore the performance of the AB scheme in achieving cooperation amongst farmers over repeated periods of strategic interaction. In this paper we build upon these experimental results, first by extracting from them a cognitive model of the farmers' decision-making behaviour in response to the scheme, and then by using agent-based simulation to investigate how the performance of the AB scheme is affected by the amount of information available to farmers and the source from which this information is received. Our model adds to the large body of agent-based modelling literature focusing on the study of land use change and decision making under various economic settings as applicable to environmental management and conservation (Berger 2001; Filatova et al.; Ng et al. 2011). We also contribute to the growing body of work on combining agent-based modeling with human-subject experimentation (Duffy 2006).

Our cognitive model combines imitative learning (Eshel et al. 1998) and myopic best response (Morris 2000), along with force of habit (Blume 1993, Kahneman 2003) and a non-specific, time-dependent learning effect. Simulations using this model show that giving farmers more information about other farmers' choices and payoffs leads to higher levels of cooperation during early periods. However, changing the source of that information – whether it comes from local neighbours only or from long-range contacts in a small world network – has no effect on cooperation levels.

II. Methods

A. Experimental data

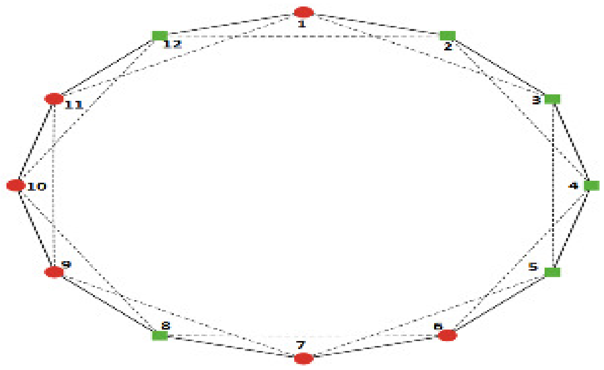

Fig. 1. Network structure in human subject experiments. The geographical network (solid lines) is a ring of 12 farmers. The information network is either a ring (solid lines only) or a ring lattice (solid and broken lines). Squares represent subjects adopting strategy M and circles represent subjects adopting strategy K.

The starting point of our work is data from human subject experiments by Banerjee et al. (2014). These experiments considered networks of 12 subjects representing farmers arranged geographically on a ring, as pictured in Figure 1. Each subject on this network is geographically adjacent to two neighbours, one on the left and one on the right, termed direct neighbours. From a conservation perspective a ring network is useful as it is representative of many geographical landscapes, such as riparian landscapes, but removes potential sources of confounding due to edge effects. Experiments lasted for 30 periods. During a period, each subject was asked to choose between two alternative strategies, M (the "efficient, cooperative" choice) and K (the "inefficient" choice), represented as green squares and red circles, respectively, in the figure. Subjects were provided with a payoff table (Table 1) informing them of the payoffs they would receive for each choice, depending upon the choices of their direct neighbours in the same period. For example, subject 1 in Figure 1 receives a payoff of 60 (the player's choice is K and the neighbours' choices are MM). In each period, subjects are informed of certain other subjects' choices and payoffs in the previous period. In one treatment, this information comes from directly linked neighbours only. In a second treatment, the information also comes from indirect neighbours, who are the direct neighbours of the subject's two direct neighbours on both sides (pictured as broken lines in Fig 1).

Experiments were carried out during 12 sessions (6 for each treatment), with 12 participants at each session. The experimental data (see for example, Figure 4) shows a relatively high initial level of cooperation which declines steadily over time.

TABLE I.
PAYOFFS IN THE AGGLOMERATION BONUS GAME

	Direct neighbors' choices		
Landowner choice	MM	MK	KK
M	**90**	50	10
K	60	70	**80**

B. Cognitive model

Many models of human decision making in iterated strategic interactions have been proposed in the literature. Myopic best response (Morris 2000) models cognitively sophisticated agents capable of strategic thinking. In this model, an agent's choice for the current period is the strategy that is the best response to the situation faced in the previous period. So for example, subject 1 in Figure 1 will choose strategy M in the next period, as that is the best response to the situation where both neighbours (subjects 2 and 12) having chosen M previously will do so in the current period as well.

Imitation (Eshel et al. 1998) is an alternative model which requires less cognitive ability on the part of agents. In this model, an agent simply considers the strategies and payoffs of its neighbours from the previous period, and copies the most rewarding strategy in the current period. Force of habit (Blume 1993, Kahneman 2003) is an even simpler model that captures the fact that human beings are cognitively sluggish and tend to repeat the same behaviour even when it might be in their economic interest to change.

Our cognitive model combines myopic best response, imitation, and force of habit, together with a period term intended to capture other, non-specific forms of learning over time that might take place (for example, growing apathy or cynicism leading to reduced willingness to cooperate). The model was derived by applying logistic regression to the strategic choices of the human subjects in experiments. The model gives the probability (p) that an agent will choose strategy M in the next period. The model includes three binary predictors, representing whether strategy M is the choice predicted by myopic best response (MBR), imitation (Imit), and force of habit (Habit), respectively. The time period (t) is the final predictor. Table 2 shows the details of the statistical analysis. The estimated regression equation is:

$$log\left(\frac{p}{1-p}\right) = -2.42 + 2.83\,MBR + 0.69 Imit + 2.88\,Habit - 0.05t$$

TABLE 2.
STATISTICAL DERIVATION OF THE COGNITIVE MODEL

Random-effects logistic regression
Number of observations: 4176
Number of agents: 144 (exactly 29 observations per group)
Random effects u_i ~ Gaussian
Wald chi^2(4) = 929.18 Prob > chi^2 = 0.00

	Coef	Std Err	z	P > [z]	[95% conf. int.]	
MBR	2.83	0.20	14.16	0.00	2.44	3.22
Imit	0.69	0.17	4.15	0.00	0.36	1.02
Habit	2.88	0.17	17.26	0.00	2.56	3.21
t	-0.05	0.01	-5.39	0.00	-0.07	-0.03
constant	-2.42	0.20	-11.97	0.00	-2.82	-2.03

C. ABM dynamics

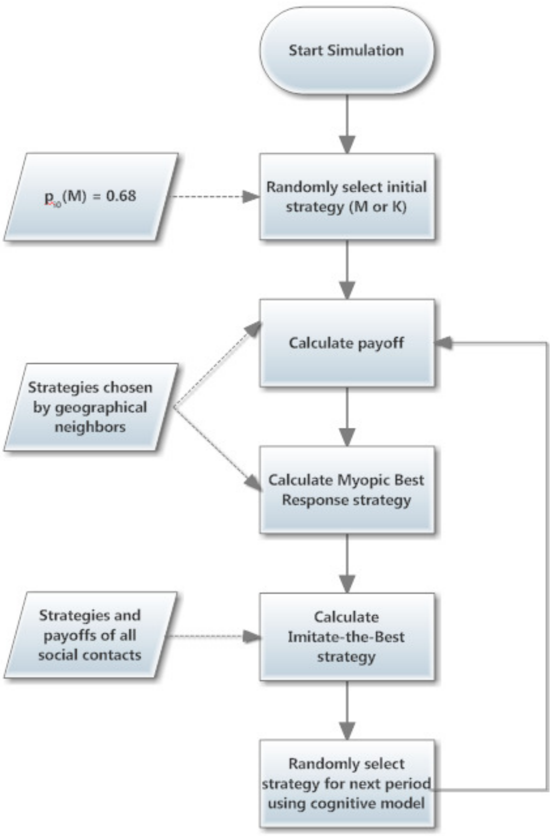

Fig. 2. Flow diagram for a single agent *i*.

Figure 2 illustrates the logic followed by a single agent *i* in the simulation. Initially, the agent will randomly select either strategy M or K, with a probability of 0.68 of choosing M. This probability reflects the proportion of times M was chosen by the experimental subjects in the initial period. The payoffs for the current period are then calculated. The strategies chosen by direct neighbours are examined and used to calculate the myopic best response prediction for the next period. The strategies and outcomes for all social contacts are examined and used to calculate the imitation-based prediction for the next period. Finally, these predictions are fed into the cognitive model equation, yielding a probability $p_{it}(M)$ that agent *i* will select M in the next period *t*, and the agent randomly chooses a strategy according to this probability.

D. Social network treatments

The literature on community natural resource management (Bodin et al. 2009; Prell et al. 2009) suggests that social networks within farming communities play an instrumental role in determining the success of natural resource management initiatives. In our model, the social network acts as the source of information about other farmers' strategic choices and consequent payoffs. We consider the impact of varying two aspects of these social networks 1) the number of social contacts per agent, which determines the amount of information the agent receives, and 2) the topology of the network.

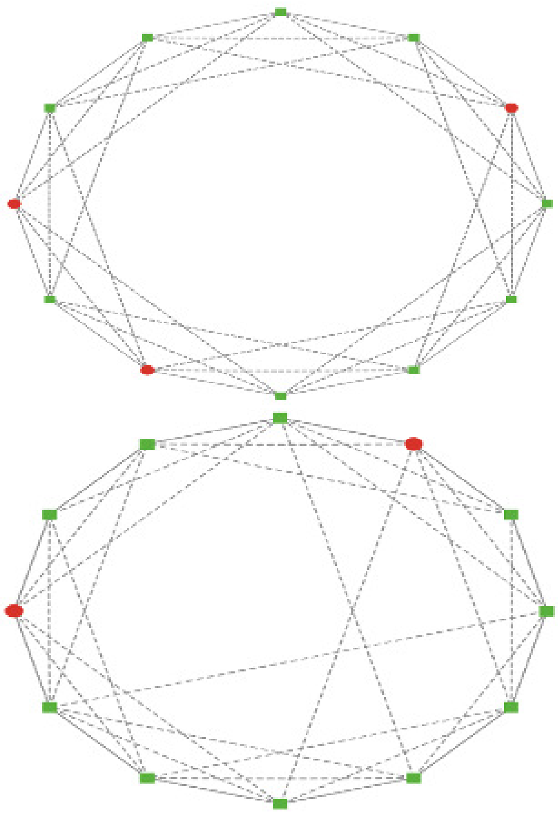

Fig. 3. Geographical network of a ring of 12 farmers with two different social networks. Solid lines represent the geographical network; solid and broken lines represent the social network. Top: regular social network where each agent has exactly 6 local contacts. Bottom: small world social network where each agent has on average 6 contacts which may be local or long-range.

Agents may receive information, not only from their two direct, geographical neighbours, but also from indirect neighbours, a situation referred to as information spillover. To study the impact of the amount of information received, we consider a range of information spillover setups, starting from the minimum setup where an agent's only social contacts are its two geographical/direct neighbours, to one in which the social network is a fully-connected clique. Figure 1 and Figure 3 (top) show two points on this range, illustrating the cases where each agent has, respectively, 4 and 6 social contacts. The social networks in this study are regular networks, of a ring-lattice type, with varying degree.

To study the impact of the network topology, we begin with the regular social networks of the previous stage, and rewire some of the links by replacing them with random links. The effect of rewiring is to replace some local links with long-range links. This reduces the diameter of the network, allowing information to flow more quickly between nodes that are geographically distant. The resulting networks have the small-world property, which has been observed in many real world social networks (Watts and Strogatz, 1998) and has been found to influence the dynamics of many processes that take place on those networks, e.g., epidemic spread and control (Maharaj and Kleczkowski, 2012). By varying the probability of rewiring, we create a range of social networks, from ones with only local links (Figure 3, top), to small world networks (Figure 3, bottom), up to fully random networks. (We note that rewiring, as implemented in our model, may cause links with direct neighbours to be lost, which is arguably unrealistic).

III. RESULTS

A. Comparison of cognitive model with experimental data

Figure 4 shows a comparison of the experimental data with simulations using our cognitive model with the same geographical and social network setups used in the experiments. Here, the information network is a ring lattice, as shown in Figure 1. We also show the results of simulating two simpler cognitive models: pure myopic best response and pure imitation. As the figure shows, neither of the simpler models yields results that resemble the experimental data, therefore it seems likely that the cognitive process employed by experimental subjects is more complicated than either of these. As a measure of model fit we can use the sum of squared differences between the model result and the experimental result at each time step. The imitation model scores 142471 and the myopic best response model scores 23938. Our cognitive model, which combines these simple models with force of habit and a non-specific time-dependent learning effect, captures the behaviour of the experimental subjects better, particularly in the early periods, having the best score (10737). The correspondence between the model and the experimental data is even better in the case of the simple ring network (not shown).

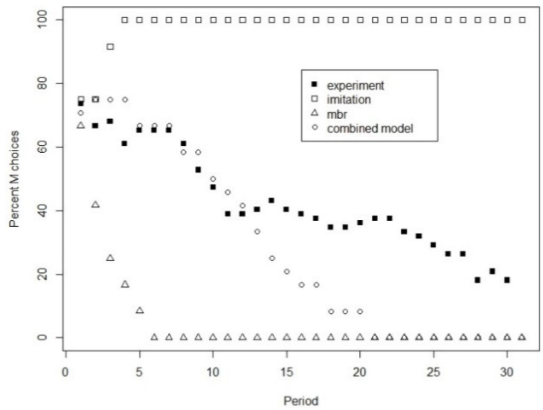

Fig. 4 Comparison of experimental data with simulations of myopic best response, imitation, and the combined model. The figure shows the percentage of cooperation (M choices) by period. The geographical and information networks are as in Figure 1. Simulation results show the median of 1000 replicates. In all cases, the information network is a ring lattice (direct and indirect neighbours) as shown in Figure 1.

B. Effect of information

Figure 5 shows the results of increasing the amount of information available to agents. In this figure, simulations are done on regular networks with local social contacts, of the form shown in Figure1 and Figure 3 (top). Our results indicate that given the current adverse payoff structure (whereby there is not much payoff difference between a player and neighbours choosing M or K) on a local network, increasing the information available to agents increases their likelihood of efficient coordination in the short term but does not prevent the inefficient strategy from becoming contagious in the long run. Thus performance of AB-based PES schemes should consider mechanisms to ensure that the efficient outcome can be obtained in the presence of more information even if repeated interaction has a tendency to transition the system to the inefficient outcome.

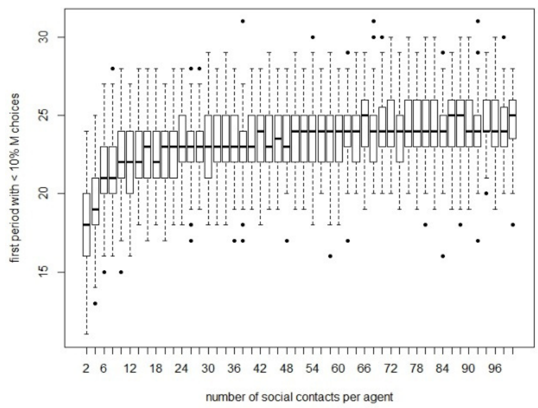

Fig. 5. Number of periods taken for the percentage of M choices to fall to 10% or less, against number of social contacts, in a regular network of 100 nodes with local information. Each box represents 100 replicates. Increasing information leads to greater cooperation in early periods

Surprisingly, introducing long-range, non-local links into the social network has no effect on cooperation. Figure 6 shows typical results. Here, the total number of links in the network is kept fixed at 200 (equivalent to a ring lattice as in Figure 1), but the probability of replacing a local link with a randomly chosen, possibly long-range link, is varied from 0 to 1. The time taken for cooperation to drop below 10% is the same, regardless of the structure of the social network. (Note that the result for the case where there is no rewiring differs slightly from the equivalent case in Figure 5; this appears to be due to stochastic differences between the simulations used in the two figures.)

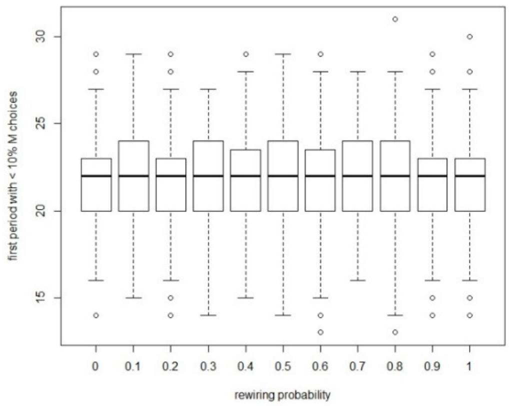

Fig. 6. Number of periods taken for the percentage of M choices to fall to 10% or less, against rewiring probability, in a Watts-Strogatz information network of 100 nodes. Each box represents 100 replicates. Replacing local with long-range information has no effect on cooperation.

IV. CONCLUSION

We evaluate spatial coordination of agents in an AB scheme when they are arranged on a ring and receive information about others' actions through social networks of varying topologies. We find that additional information and network structure play only a limited role in maintaining efficient coordination over repeated periods of strategic interaction. Future research in this context may thus involve devising and testing different ways of preventing contagion of the inefficient action. One option would be to evaluate agent behaviour when the payoff difference between efficient and inefficient equilibria is much higher than what we consider. Another option is to explore whether information about AB scheme decisions from neighbouring communities can influence agents' to coordinate efficiently. This is important since conservation agencies usually have access to this information that they can make available to farmers at minimal cost. Finally, noting that the network structure does not matter, it would be interesting to use a mean-field mathematical model to simulate behaviour and evaluate AB scheme outcomes.

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Human-in-the-loop simulation based system for more effective allocation and training of experimenters' groups in stimulation of biotechnological processes

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Abstract—**In the case of biotechnological processes, a proper conduction of experiments requires particular attention and skills. This is due to possibilities of causing irreversible damages to living microorganisms when making wrong decisions. In the considered case, two experimenters are enough to conduct a single experiment, but when taking into account the maintenance of process continuity (there is no possibility of stopping the process), then it is necessary to involve more experimenters working in sequentially changing groups. Due to the need to eliminate possible errors, the choice of experimental groups is crucial. In this paper, it is proposed to use human-in-the-loop simulation procedure for selection of experimental groups and for their training before making experiments on real process. For simulation purposes, the process simulator and the collection of processing data were used. This allowed to perform the human-in-the-loop simulations, and then, based on the obtained simulation results, to choose the experimental groups including social conditioning of experimenters.**

I. Introduction

INCREASING accuracy and precision of available measuring instruments, but also, increasing possibilities and functionalities of supervisory software for experimental, control and monitoring purposes make that the human becomes the weakest link in the whole system.

In the case considered in this paper, the major difficulty is related to the fact that there is a limited number of staff to perform laboratory experiments whose goal is to stimulate the biotechnological process in a proper way. At once, only two experimenters (process operators) can be involved in the performed experiments. The experiments are performed cyclically twenty-four hours a day and include various measurement techniques and procedures. Moreover, the complexity of experiments does not allow all the experimenters to perform all the experiments at same time. Therefore, for the realization of successive experiments on the real and continuous process, it is necessary to choose several working groups (two experimenters in each one), which has to be properly scheduled in the cycle of twenty-four hours a day.

An additional difficulty is the fact that it is not possible to stop the biological process (living biomass / microorganisms) and wrong decisions may essentially (often irreversibly) change biomass parameters. As a result, further supervision and maintenance of the process might be senseless or impossible. Because, social conditioning is also crucial factor, the choice of pairs of experimenters can be supported by the human-in-the loop (HITL) simulation technique. Then, the main criterion for selection of the experimenters' groups is mostly based on the social cooperativity.

The HITL simulations have been used for a long time mainly in the aviation industry for training pilots. However, a key barrier was the cost of simulators that based on expensive computer equipment. The development of cheap microcomputers, and especially, the IT revolution related to the development of small personal computers, has opened the way for the use of HITL simulations for training purposes of industrial process operators (although, it was still expensive), and then, in non-commercial applications (e.g. social and political).

One of the first papers dealing with the problem of supporting a process operator in the chemical or biochemical industry appeared in the last decade of the past century [1]-[4]. An application of the process simulation for the purpose of more efficient operation and process supervision was presented in [1], while the distributed access control schemes [2] were developed to make the operator's training and control easier. In the HITL simulations, colors of elements, which represent industrial plants in the control flow diagrams and the complexity of these diagrams, are crucial [3]. In turn, in the case of emergency situations, it should be possible to perform faster

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than real-time simulations [4] (this issue was highlighted in 1994 [4] and it is still under discussion [5]).

At present, the HITL simulation techniques are also used in solving various problems related to social issues. For instance, using methods known from control theory, human behavior in the HITL can be described in similar way as the behavior of PID controller in the closed loop control system [6]. In turn, a framework that provides experimenters and subject matter experts with useful tools to evaluate team performance in terms of task demands was presented in [7]. The HITL simulations are also used to describe human behaviors in emergency situations and in analysis of safety issues, e.g. in the case of fire in automotive manufacturing plants [8]. Another application of the HITL methodology in industry is a decision support system that allows an expert to make appropriate decisions in the case of delivery delays and to analyze risks caused by the unreliable suppliers [9]. Paper by Zenn and Lee [10] proposes the use of HITL approach to describe human-robot-interactions when designing assistive robotic systems. Another interesting example can be found in the paper [11] describing an automobile driving simulator. In order to evaluate characteristics of the human-automobile system, the HITL simulations were applied. Yet other examples are, for instance, HITL for a proper assignment of photos to appropriate groups on social networking Websites [12] or a novel automatic traction control algorithm by incorporating human behavior based on HITL testing. Finally, the paper by Shendarkar and co-workers describes the use of HITL to collect data on human behavior that can be used in crowd evacuation management [14]. In comparison to the existing solutions, the proposed approach in our paper is somewhat novel.

The paper is organized as follows. Section II discusses the problems related to experiments on a biotechnological process and the choice of experimenter groups including their social conditioning. The next section describes the architecture of HITL-based system. Finally, the last section discusses the main results and concluding remarks.

II. PROBLEM UNDER CONSIDERATION

Fig. 1 presents the structure of the system for monitoring, analysis and supervisory control of biotechnological process conducted in a continuously stirred tank bioreactor (CSTB). The main goal of the study is to determine a possible stimulation of the biotechnological process to improve its performance. The CSTB itself is fed with a mixture of several substrates with different inlet concentrations S_1, S_2, …, S_n. In the output stream of the process, a digital microscope camera was mounted to observe the structure of flocks formed by the biomass. Then, for extracting the data from small regions of microscopic images, the Contrast-Limited Adaptive Histogram Equalization (CLAHE) algorithm was used [15].

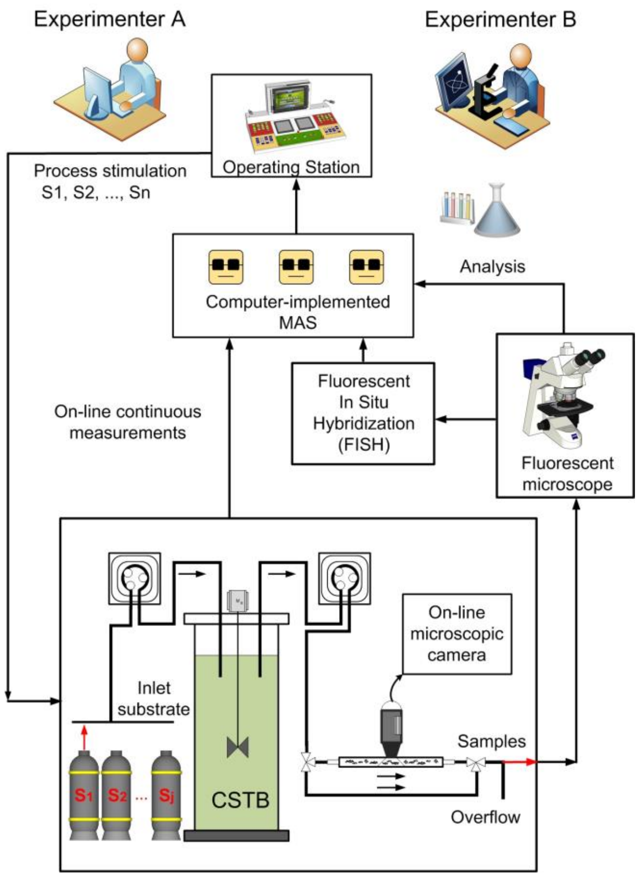

Fig. 1. The general structure of system for monitoring, analysis and control of the continuous flow bioreactor (CSTB) involving two experimenters

Moreover, additional samples of biomass are taken for further analysis including the Fluorescent In-Situ Hybridization (FISH) methods to detect RNA in the cells of microorganisms. Other necessary data (e.g. dissolved oxygen (DO) level, Redox balance or pH values) is provided in real-time by the standard measurement equipment. A multiagent system (MAS) supports the process operator in processing and analysis of the measurement data. More details on the structure and functionality of the MAS can be found in [16], whereas a survey of MAS applications in industrial process control in [17].

Monitoring and control system requires the presence of at least two experimenters (process operators): Experimenter A and Experimenter B. A pair of two experimenters is sufficient to perform necessary chemical and biochemical measurements including FISH analysis. Then, based on the obtained results and the data collected from the on-line measurements, the experimenters can suggest some changes aiming at a more efficient stimulation of the bioprocess. However, the preparation of a schedule of experiments for each experimenter group depends largely on the social conditioning between experimenters. Moreover, due to the presence of living microorganisms in the system, the biological process must be conducted continuously. As a result, the experimenter groups are required to perform their tasks at intervals ranging from four to eight hours depending on the current state of the process. It also means that each group of experimenters must be sufficiently prepared to perform various experiments and, if necessary, to change the stimulation of bioprocess by changing the composition of substrates and/or process parameters.

It should be emphasized that the performed experiments are difficult, laborious and require some expenditure. At the same time, any mistakes made during experiments, accidental omission of experiments and/or wrong decision made by the experimenters may disturb the course of the process and, in extreme cases, cause damage to the culture of microorganisms (biomass). Therefore, it seems obvious to train and instruct all the members from each experimenters' groups (see Fig. 2).

The problem of selection of workgroup members has already been analyzed in the literature, but in the majority of cases, from another point of view than discussed here. For example, the problem of group composition, taking into accounts the preferences of individual group members (i.e. with whom they want to work and cooperate), was presented in [18]. It should be clearly emphasized that in our case, the problem lies in the appropriate allocation of group members (experimenters) from among all the participants of the research project. It means that the composition of working groups cannot be accidental.

Due to above mentioned reasons, the training on a real process is impossible. Furthermore, it is necessary to take into account the behavior of experimenters working in pairs, i.e. their individual preferences (some of them may prefer to work alone and some in a group) and the relations between them. The use of the HITL simulation technique simplifies the incorporation of these factors. Hence, a system for testing and training the experimenter groups has been created. The real bioprocess has been replaced with its simulator and the analysis of the current measurement data has been replaced with the analysis of data from the real experiments.

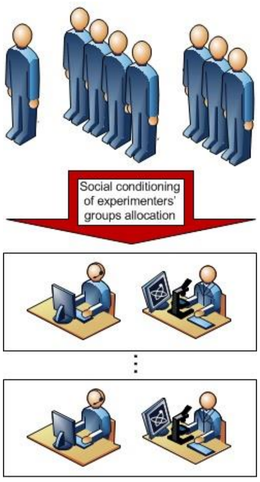

Fig. 2. The allocation of experimenters' groups

III. ARCHITECTURE OF THE HUMAN-IN-THE-LOOP SIMULATION

Fig. 3 presents the architecture of the training system, which is based on the HITL simulations technique. In this case, the HITL simulations use two sources of information: interchangeable bioprocess simulators and samples collected previously from the real experiments. Most of the experiment equipment is the same as in the real bioreactor system. Moreover, for the realization of HITL simulations, the experiment equipment is coupled with the process simulator. Depending on the goal of experiments, it is possible to update or change the structure of the mathematical model of the bioprocess and then to introduce necessary changes to the process simulator.

As shown in Fig. 3, the main feedback loop includes the Experimenter A and the process simulator. The Experimenter B is located in the second loop and, for data analysis training, appropriate measuring samples are chosen and displayed to the experimenter by the process simulator (depending on the current state of the bioprocess). According to the system architecture (Fig.3), both experimenters are located in each of the loops provided that the process simulator can select proper samples for analysis. However, this feedback information is limited to the available collection of samples.

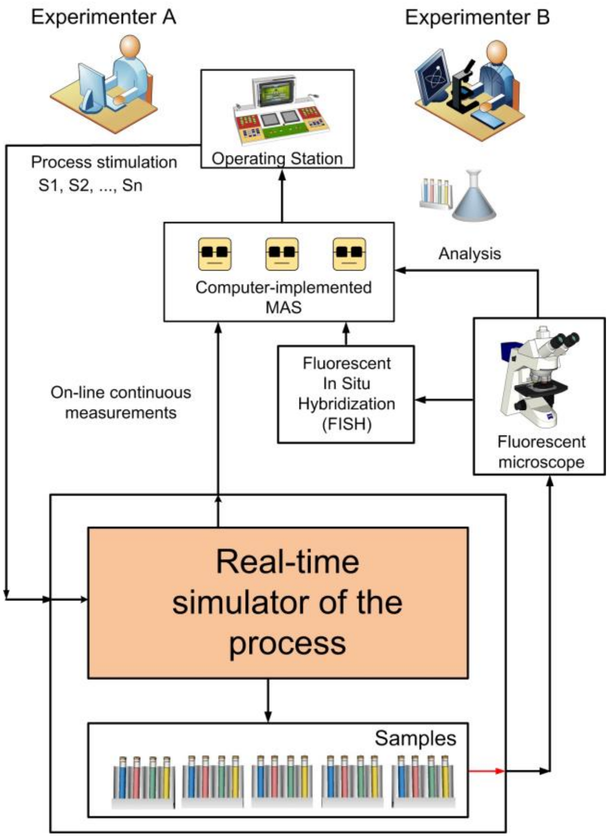

Fig. 3. The system architecture with two feedback loops based on the HITL simulations

If there are no samples that can be selected by the process simulator, then there is no feedback for the Experimenter B in the second loop. Nevertheless, the proposed system can still be useful in training and testing skills of experimenters.

IV. CONCLUDING REMARKS

Based on the HITL simulations, the system for selection and training of the experimenter groups can be very useful before starting the experiments on a real bioprocess. The system allows us to choose the experimenter groups without making expensive and time-consuming experiments, while at the same time incorporating the social conditioning of experimenters. The initial training on the process simulator and the possibility of choosing the pairs of cooperating experimenters can increase the effectiveness of their work when conducting real experiments.

By taking into account the social conditioning, the selection of groups may prove more effective than the classical approach, in which the pairs of cooperating experimenters are usually chosen arbitrarily. In our case, it is of great importance since the experiments are conducted twenty-four hours a day, several days in a row.

The most important social conditionings that were taken into account are: possibility of participation in experiments conducted at night, a distance between the experimenter's home and laboratory, and which are particularly important, the relations between experimenters and their individual preferences for work in a particular group.

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A Platform for Analyzing Access-friendly Transportations for Elderly People Using GIS on Agent-based Model

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***Abstract*— In this research, we construct a platform for analyzing access-friendly transportation for elderly people using GIS on agent-based model. Our interest is related to an aging world population and well-being of elderly people. We use GIS data of Ibaraki city Japan and study the outing rate of elderly people. We defined the number of times of outing per seven days as outing rate. The simulation is performed 63 times. It is comparable to 63days (nine weeks). As the results of simulation showed that the utility of experience from reaching destination and achieving their aim was more effective for next decision of old-old than that of young-old.**

I. Introduction

BACKGROUND of this aim is related to an aging world population and well-being of elderly people. Especially the ratio of Japanese elderly population is the most distinctive among the world [3]. In order to live a life worth living, it is important that elderly person can move easily to their destination. According to a report [2], there are strong relations with Subjective Well-Being (SWB) and opportunities of going out. In general, SWB is defined as the index that she/he evaluates the feeling of happiness and satisfaction of her/his own life. As the result of her research, a case of having many opportunities of going out showed high value of SWB. Also, communication with others enhanced a sense of well-being [4]. In this research, we aren't go into details of SWB, however, we discuss about utilities of their experience. The utilities are similar idea on this point of SWB.

Elderly people are categorized two groups, young-old (aged 65-74 years old) old-old (over75 years old). And that tendency going shopping is vary greatly depending on age. The citizens aged over 60 in Japan tended to rarely go out. On the other hand, less than 60 years showed tendency to often go out [1]. In this research, tendency going out are arranged by different from young-old and old-old.

A. Background of Construct Platform

Last year, we presented the result of optimized combination of local bus and DRT (Demand Responsive Transport) for elderly person using a simple model at WEHIA 2013. However, to solve several practical problems, we should revise our model from some aspects. One is modified field. GIS data should be implemented to revised model to deal with solving regional issue. The other is, function of decision making should be revised by implementing some mental factors. We use GIS data of typical Japanese city and study outing rate of elderly people.

B. Outline of Ibaraki City

A lot of Japanese people were concentrated around urban area by rapid economic growth in the1960's. Many residential areas called New Town were supplied by prefecture or government in the suburbs of urban area. And the car has been main transportation for residents in a long time. More than a decade ago, a lot of their children moved to more convenient place for live. The population is rapidly aging at New Town. And peoples who lives in new town let go of their car by their aging. Therefore, bus plays an important role in the aging society. One of a New Town named Sunny Town is on Ibaraki city in Osaka. Sunny Town was created 121 hectare in 1970's. In this research, we treat Ibaraki city and build a model.

Ibaraki city lies north and south about 17 kilometers, and east and west about 10 kilometers. According to the report of questionnaire of Ibaraki citizens (2013), elderly people who live the mountains area (35.7%) and hilly terrain area (21.8%) represent higher population aging rate than downtown (19.2%). And the ratio of going out at people over 70 years of the mountains area (every day 24.4%) and hilly terrain area (every day 36.0%) is lower than that of downtown (every day 52.4%). That is, people who live in the mountains area and hilly terrain area feel awkward to use of public transportations. Therefore, we construct a platform using GIS for analyzing access-friendly transportation for elderly people.

II. Outline of a model

A. Decision of people

In this research, for the sake of such improvements, we introduce the people's behavior is provided by the function for four variables as follows:

$$Dt=f(Tt,Wt,At,Ut), \quad (1)$$

where *Dt* is the value of elderly people's willingness of going out, *Tt* is time factor, *Wt* is the value of weather condition factor, At is the value of age factor, *Ut* is the value of utility on trip.

1) Time factor

Time factor is represented the length of time which is required reaching at peoples' destination from his home and returning his home. In our model, it is assumed to be used always the bus when the people move to shopping center, hospital and so on... If a person is going to move to shopping, he calculates the time it takes to walk to nearest bus stop, next bus schedule of the nearest bus stop, arrival time to the destination: shopping center, and the last bus from the destination to his home. The result of this calculation is used in decision making. If there is no schedule of the last bus, he decides cancellation of his trip.

2) The variable of weather condition factor

The variable of weather condition factor is represented that depending on the weather conditions, people will decide adjustment of schedule, transportation way, or cancellation of his trip [10]. And a literature survey shows the change of decision affected by weather change [11]. In this research, people's willingness to go out is given 40 percent in case of rain. And people's willingness to go out is given 60 percent in case of a good weather condition.

3) Age factor

Age factor is represented relations age between willingness of go out. Aged over 60 has gradually decreased in motivation of outdoor activity [1]. In this research, we treat the category of young-old and old-old. The ratio of willingness to go out on young-old and old-old are given each 60 percent and 40 percent.

4) The value of utility on trip

The value of utility on trip are represented that people receive a lot of satisfaction from achievement of his activities. For example, if he achieved his aim (shopping), his utility (degree of satisfaction) becomes high. In this research, Utility is changed by past (inexperienced) status and present (experienced) status. And the utility is referenced in the utility table. The utility is determined by the time spent at the destination. The utility is using the value of one tenth of the time experience. People is going to use 60 minutes at the library, 30 minutes for shopping and 40 minutes at the hospital,. The concept of time of shopping and library are based on [13]. The concept of time of hospital is based on [14].

In addition, the utility factor adds on shortage percent of the age factor. If value (e.g. 6) of utility is increased, the value is translated to additional percentage (e.g. 6%) of age factor. That is, the value of the utility is added to percentage of the willingness in age factor.

5) Outing rate

We defined the number of times of outing per seven days as outing rate. Outing rate is calculated as follows:

Outing rate is divided total number of times of outing in seven days by seven.

B. About GIS data

In our simulation, we use the data from the questionnaire results by Ibaraki City, which includes the actual status of the usage of bus schedule, citizen requests for service.

In this research, we implement the data of GIS to our model. The data of OpenStreetMap (OSM) is used for geographic information of Ibaraki City. OSM is provided that everyone can use easily on the internet. And we convert this data (osm formats) to shapefile formats using QGIS. In addition, we get coordinate data from shapefile formats using software "GIS Data Converter for artisoc". Loading this coordinate data, we use a part of program from GIS sample model which is provided by KKE Inc (see Fig.1). Lines represent road, river, and railway and so on. Dot represents people. In this simulation, local bus passes regular root and pick up peoples at bus stop and drop the people off at bus stop on the near destination.

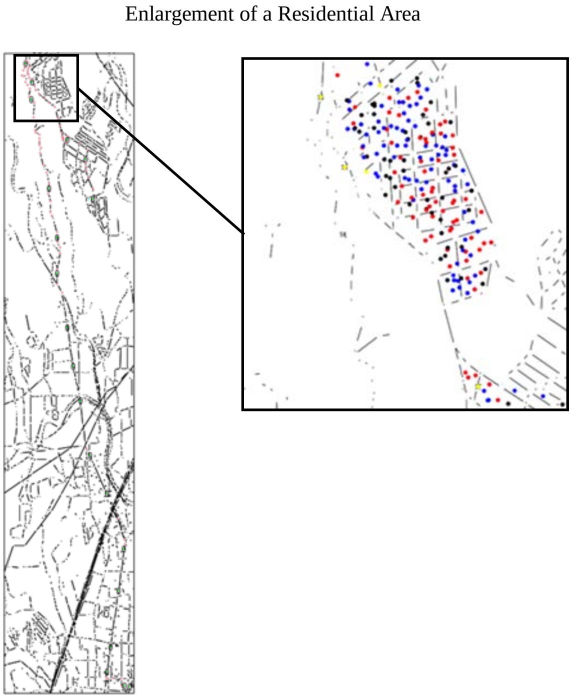

Fig. 1 Outline of Our New Model

C. The Role of Agents

Types of agent are as follows:

1) People agent: People agent differs in age. Population density is referenced on a map of Ibaraki city. The site of residential area is high density. The behavior of people agent is decided by function (1). People agent interacts himself for

decision making of achieving his trip. Total number of people agents is 1,000.

2) Local bus agent: local bus agents run downtown to hilly terrain area. The numbers of 80 buses run per a day. Travel distance is about 8.5 km. Bus speed is 18.2km/h (from downtown to a residential area), 20.4km/h (from a residential area to downtown).

3) Local bus stop agent: The number of 38 Local bus stop agents is located along the highway.

Simulation is performed 63 times. It is comparable to 63days (nine weeks). Utility of each people agent is taken over to the next time. Utility make up for the decrease of motivation going out associated with age. One trip using bus is limit of this model. One round trip is maximum number per a day.

D. Outputs of Agent Based Simulation

Data rerated to local bus agent

1. Time series of total fare (revenue) and the average number of people agent who used bus.

2. The number of people agent in each bus

TABLE I.
OUTING RATE OF YOUNG-OLD UNDER GOOD WEATHER CONDITION

Weeks	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Average of Outing Rate	50.57	64.76	75.42	76.94	77.66	77.83	77.59	77.06	77.42
Maximum	100.00	100.00	75.38	100.00	100.00	100.00	100.00	100.00	100.00
Minimum	0.00	0.00	75.38	28.57	28.57	28.57	28.57	28.57	28.57
Standard Deviation	21.31	20.84	75.44	16.48	16.04	14.94	16.08	16.34	14.84

TABLE II.
OUTING RATE OF OLD-OLD UNDER GOOD WEATHER CONDITION

Weeks	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Average of Outing Rate	22.91	31.89	38.98	50.30	59.31	69.23	73.00	76.56	76.91
Maximum	71.43	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	14.29	14.29	14.29
Standard Deviation	16.68	20.02	21.96	23.19	23.20	21.90	18.12	16.54	16.79

TABLE III.
OUTING RATE OF YOUNG -OLD UNDER RAINFALL CONDITION

Weeks	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Average of Outing Rate	22.48	27.68	31.52	33.24	35.92	37.52	39.11	38.99	38.58
Maximum	71.43	85.71	85.71	100.00	100.00	100.00	100.00	100.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	16.48	18.81	18.25	18.75	19.33	18.21	18.66	19.32	18.82

TABLE IV.
OUTING RATE OF OLD -OLD UNDER RAINFALL CONDITION

Weeks	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Average of Outing Rate	10.55	12.68	13.34	16.56	18.90	20.99	23.72	26.20	29.65
Maximum	57.14	71.43	57.14	71.43	71.43	85.71	85.71	71.43	85.71
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	11.32	13.96	14.22	15.84	15.94	16.38	18.79	18.73	18.72

Data rerated to People agent

1. The number of people agent which didn't use bus
2. The number of people agent which used bus
3. Outing rate of people agent

III. THE RESULTS OF THE SIMULATION

A. The Results of Outing Rate

Outing rate was the ratio of experience times of going out within 7 days. If a person went out 3 times in 7 days, the outing rate is calculated to be 42.86 percent.

Each peoples' outing rate was shown in TABLE I to IV. Fig.2 and Fig.3 shows that people agent which use bus after a week. The graph shows increase, same or decreases as compared with the first week.

The outing rate of young-old under good weather condition was represented in TABLE I. First week of an average of outing rate was 50.57 percent. And final week of an average of outing rate was 77.42 percent. Comparing the number of first week and that of final week, an average of outing rate was increased 26.86 percent.

The outing rate of old-old under good weather condition was represented in TABLE II. First week of an average of outing rate was 22.91 percent. And final week of an average of outing rate was 76.91 percent. Comparing the number of first week and that of final week, an average of outing rate was increased 54.00 percent. This extension percentage of difference on degree of change in case young-old and old-old, in case of old-old was larger.

Therefore, in case of young-old, people agent which increased outing opportunity was shown range among 70 and 80 percent (see Fig.2). On the other hand, in case of old-old, people agent which increased outing opportunity was shown more than 90 percent (see Fig.3).

The outing rate of young-old under rainfall condition was represented in TABLE III. First week of an average of outing rate was 22.48 percent. And final week of an average of outing rate was 38.58 percent. Comparing the number of first week and that of final week, an average of outing rate was increased 16.10 percent.

The outing rate of old-old under rainfall condition was represented in TABLE IV. First week of an average of outing rate was 10.55 percent. And final week of an average of outing rate was 29.65 percent. Comparing the number of first week and that of final week, an average of outing rate was increased 19.11 percent.

Therefore, in case of young-old, people agent which increased outing opportunity was shown less than 70 percent (see Fig.4). On the other hand, in case of old-old, people agent which increased outing opportunity was shown more than 70 percent (see Fig.5).

Compared with case under good weather condition and under rainfall condition, outing rate was increased at case old-old rather than that of young-old.

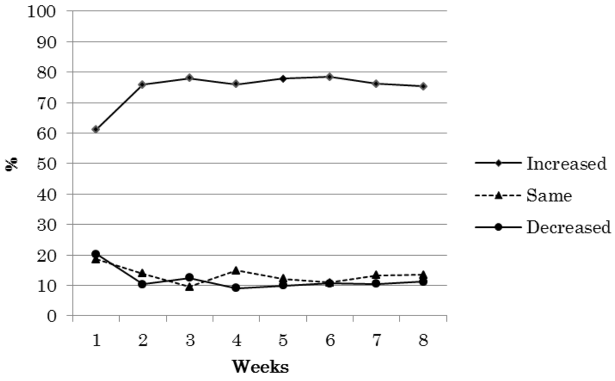

Fig. 2 Bus Users' Shifts Based on Comparisons with First Week (Young-Old, a Case of Good Weather Condition)

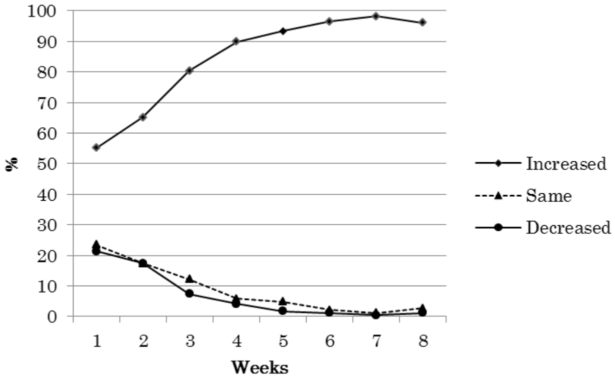

Fig. 3 Bus Users' Shifts Based on Comparisons with First Week (Old-Old, a Case of Good Weather Condition)

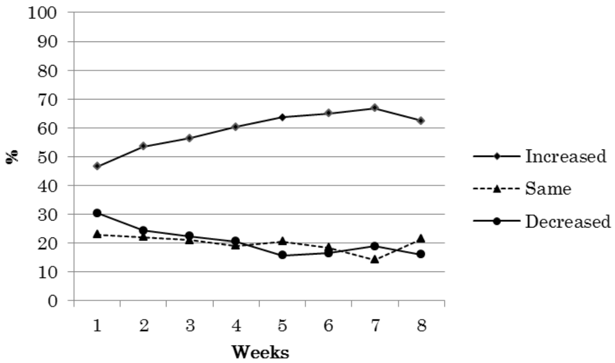

Fig. 4 Bus Users' Shifts Based on Comparisons with First Week (Young-Old, a Case of Rainfall Condition)

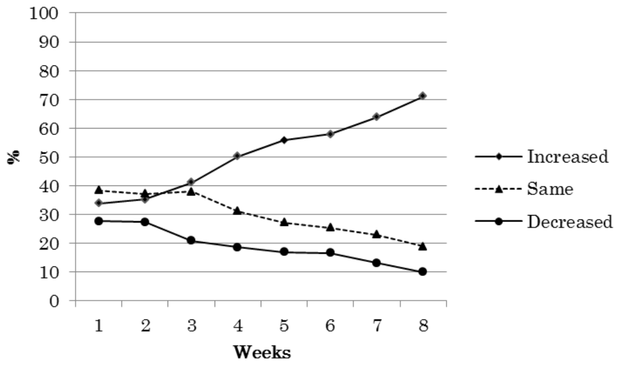

Fig. 5 Bus Users' Shifts Based on Comparisons with First Week (Old-Old, a Case of Rainfall Condition)

B. Case of Rainfall Condition

The repeat times of people agent under good weather condition were shown in Fig6. According to a polygonal curve of young-old, the range of repeaters was within 32 to 56. Maximum number of repeater (67 people agents) was 45 times.

According to a polygonal curve of old-old, the range of repeaters was within 8 to 49. The range was the number of 17 times wider than that of young-old. Maximum number of repeater (27 people agents) was 37 times.

From height of a polygonal curve of young-old, a lot of repeaters were concentrated around 45 times. On the other hand, a polygonal curve of young-old was not so high and wide. That is, there were together with high and low repeaters.

On the other hand, in case of under rainfall condition was shown in Fig7. According to a polygonal curve of young-old, the range of repeaters was concentrated within 5 to 36. Maximum number of repeater (63 people agents) was 22 times.

From polygonal curve of old-old, the range of repeaters was within 1 to 27. Maximum number of repeater (42 people agents) was 12 times.

The features of under rainfall condition were that most people agent existed near distance from the origin in Fig.7. The number of repeaters was fewer than in case of good weather condition. And a polygonal curve of old-old in case of under good weather condition was wide. However, a polygonal curve of old-old in case of under rainfall condition was not so wide.

From the number of repeaters, we were able to confirm that repeaters increased under good weather condition and decreased under rainfall condition.

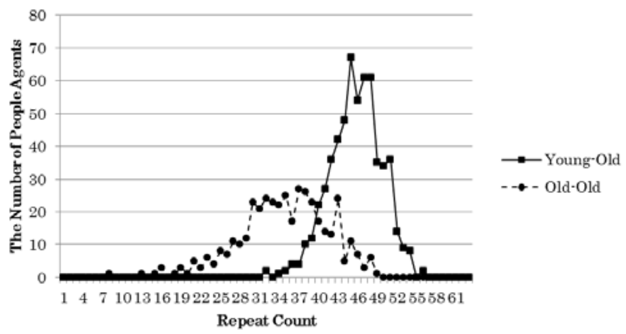

Fig. 6 The Number of People Agent which Repeater of Bus (Case of Good Weather Condition)

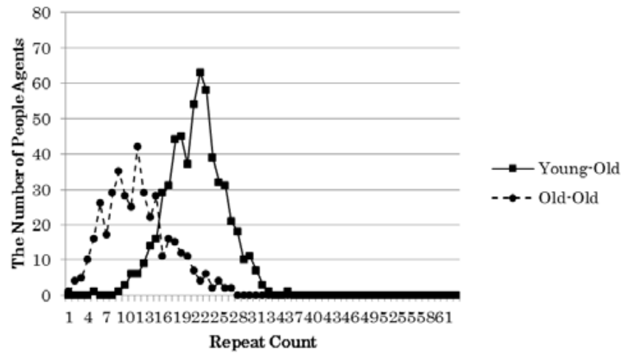

Fig. 7 The Number of People Agent which Repeater of Bus (Case of Rainfall Condition)

IV. Conclusion

As the result of the simulation, during the first week, young-old was using the bus relatively well. For this reason, the ratio of young-old of people agent which used local bus more than first week was significantly less than the old-old.

That is, utility did not affect enough to the next decision-making in case of young-old.

The finding is that the utility of experience from reaching destination and achieving their aim was more effective for next decision of old-old than that of young-old.

And, looking at this results from another perspective (policies of bus management), we understood that many people agent used local bus agent over and over again, local bus agents became well-established transportation. And we understood total fare was increased by getting many people agents who were repeaters.

The result implies that one of the policies may work well. For example, the bus company gives opportunity (e.g. discount, free) of riding bus for some people who has never use the route of bus or has been out of use for long years, the people is able to renew his awareness of buses' convenience. This policy requires a lot of initial costs. However, if utility of people increase, use of local bus will become well-established. And initial cost will be able to pick up from fare. Especially, from the aspect of outing rate, the policy is able to affect well for people of old-old.

Notice that, our model has no alternative way of transportation. Therefore, our offer is limited to only people who has no alternative way.

For future work, we will implement three cases which are mountains area (north side), hilly terrain area (center) and downtown (south side). And we will reflect data from previous study [5], [7] to new mental factor. And we will implement transportation's cost and the condition of budget constraints might be required in our model. We are going to carry out revised our model and discuss our simulation results at ESSA 2014.

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Cultural and genetic transmission in the Jomon-Yayoi transition examined in agent-based demographic simulation

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I. Motivation

The transition from the Jomon to the Yayoi period of Japanese Archipelago is an East Asian case of hunter-gatherer to farmer transitions. Drastic socio-cultural changes in subsistence, material culture and settlement structure occurred in the northern part of Kyushu Island around 10th -8th centuries BC. Major drive of this transition has been attributed to either immigrants from the Korean Peninsula or intentional adoption by native Jomon people. In reality, the Jomon-Yayoi transition is a complex process in which both human migration and cultural transmission played a major role.

Simulation studies can be very useful to understand the nature of the transition as we can examine various hypotheses with different parameters to see what combination would fit archaeological data. However, simulation researches have not developed for this prehistoric event except for a series of publications by Takahiro Nakahashi and Masaru Iizuka ([1], [3], [4]). Nakahashi and Iizuka suggested that the immigrant people were mainly responsible for the drastic cultural change based on palaeodemographic simulation in which higher population growth rate was assumed for immigrants. Nakahashi and Iizuka's studies demonstrate that even minor number of immigrants from the Korean Peninsula can lead to the dominance of continental physical features in the Middle Yayoi population in northern Kyushu as indicated by excavated skeletal remains.

Their model may provide a possible scenario concerning population dynamics in northern Kyushu, but its assumptions on demographic processes may be too simple to understand the real dynamics of intermarriage and resulting genetic spread, and cultural transmission process is out of its scope. Our research is the first application of agent based simulation to the Jomon-Yayoi transition with specific interest in the cultural transmission process in a realistic demographic dynamics.

The purpose of our research is not to replicate the actual processes of the Jomon-Yayoi transition in terms of genetic and cultural transmission, but to obtain useful insights to construct a model to explain the prehistoric demographic and cultural dynamics. We have considerably rich archaeological data thanks to the huge number of excavations most of which have been conducted by governmental institutions as a form of rescue archaeology. As for the Final Jomon to the Early Yayoi period, which is the critical period to understand the Jomon-Yayoi transition, more than two hundred sites have been excavated only in Fukuoka prefecture in northern Kyushu.

II. Jomon-Yayoi transition

The richness of archaeological information tell us that the actual process of the transition, i.e., the nature and extent of migration, adoption or rejection of cultural information, etc., varied from region to region even in western Japan, where it has once been suggested that the spread of Yayoi culture was quick and uniform. Interpretation of archaeological evidence also differs among researchers due to different assumptions concerning migration, cultural transmission, and the relationship between the two. As it is extremely difficult to calculate the long-term consequences of particular assumptions on genetic and cultural transmission, simulation study can be a very useful tool to experiment with particular set of assumptions.

Critical points of the Jomon-Yayoi transition which have been reconstructed based on archaeological data can be summarized as follows:

1) There was a certain amount of migration from the Korean Peninsula to northern Kyushu at the beginning of the Yayoi period [3].
2) Yayoi culture was formed by integrating traditional Jomon culture and Korean Early Bronze Age culture in northern Kyushu [2].
3) Major components of the Yayoi culture in northern Kyushu consist of wet rice agriculture, Itazuke type (Ongagawa-style) pottery, polished stone tools similar to the Korean Bronze Age culture, and new burial customs similar to that of the Korean Bronze age.
4) Immigrants from the Korean Peninsula and indigenous group of the Jomon tradition lived in the same settlements in northern Kyushu.
5) The spread of Yayoi culture to the other part of western Japan was achieved probably by both migration and

acculturation, but their actual conditions are still not clear.

6) Several cases of the discovery of skeletal remains with Jomon features accompanied by Yayoi cultural traits indicate that indigenous adoption of new cultural elements was not rare.
7) Some of the cultural elements such as placement of stone weapon as burial goods were dropped in the process of diffusion from northern Kyushu to Chugoku and Kinki regions [5].
8) Wet rice agriculture and Ongagawa-style pottery spread from the northern Kyushu to Chugoku and Kinki regions across about 500 km keeping considerable uniformity.

As pointed out above, the nature and extent of migration from the northern Kyushu to the east, and how different patterns of migration and acculturation may result in the distribution of genes and cultural traits, have not been well understood. Our simulation project intends to gain basic understanding of the relationships between the migration rate and the spread of genetic traits, and how social learning condition affect the spread of cultural skill in a realistic demographic dynamics.

III. Simulation system

The simulation system we developed is a multi-agent system. In the system, an individual is implemented as an agent. They are born, married, giving birth, and died according to calculated rates of these events would be happened. Population increase or decrease can be controlled to some extent by adjusting birth rate and death rate, although the results can be varied because of the stochastic nature of the simulation.

The system has areas that represent geographical divisions, or regional boundary of population. Areas are connected, and the connections of these areas can be logically represented as a graph in which an area is a node and a connection between areas is an edge. Individuals are born in one of the areas and can move through the connections between areas, if she or he decides to move. The system determines if the migration occurs for each individual according to the migration rate.

An individual represented as an agent in the system is born as a female or a male with 50% probability and has knowledge about her/his blood relationship, so that we can set incestuous taboo. An agent start finding her/his spouse at the age of 15, and females can give birth to babies only when she is married. Both female and male remarry when her/his spouse dies.

Each agent has two parameters: genetic value and skill value. The genetic value g represents a set of genes responsible for the morphological difference between the Jomon and the Yayoi phenotypes. The skill value represents the level of cultural skill like production of material culture.

Assume a population of N individuals, $i = 1, 2, ..., N$. Each has genetic value g_i and skill value s_i.

g_i is defined at the birth of $i-$individual according to the genetic value of parents. If the parents of $i-$individual are j and k, $g_i = (g_j + g_k)/2$.

s_i is 0 at the birth of $i-$individual. If $i-$dividual can grow up to be 15 years old, the $i-$individual choose her/his master m and copies the value of s_m to s_i. The system has three choice of the master to simulate the effect of social learning in a simplified manner. One of them is selected when the simulation runs.

L1. Choose randomly from all individuals in the same area who are more than 15 years old.
L2. Choose one with the highest skill value among relatives who live in the same area.
L3. Choose one with the highest skill value in the same area.

Here, relatives are individuals within the 3 degree of relationship.

In order to obtain insights about genetic influence and cultural transmission in the Jomon-Yayoi transition, we set 5 areas connected in series, as area A, B, C, D and E respectively. 300 individuals are generated in each area at the start of simulation, and data is taken after 30 years when population structure is normalized. At the start of the simulation, g_i of each individual who lives in area A is 1 and that of those who live in other areas is 0. s_i of the individuals living in area A is set according to normal distribution with a mean of 10.0 and sigma of 1.0. s_i of other areas are 0.0. We experimented with three sets of migration rate.

M1. An individual moves in 0.001 possibility per year.
M2. An individual moves alone in 0.03 possibility per year.
M3. An individual moves with her/his relatives within the 2 degree of relationship in 0.001 possibility per year.

Each individual can move to a neighboring area, that is, if an individual lives in area A, she/he moves to area B in a specified possibility. If an individual lives in area B, she/he moves to area A or C in a specified possibility for each year.

We ran five simulations for 500 years for each of the three versions of cultural transmission pattern and examined the results of population increase, spread of genetic value and spread of skill value. Birth rate and death rate were set as the population gradually increases.

IV. Results

Results of five runs are shown overlapped in the graphs so that basic patterns and variability can be assessed. The rate of population increase shows considerable variation (Fig. 1) . The smallest population at the end of simulation for 500 years is less than 2000 in some cases while the largest is over 10000. However, patterns of the spread of genetic value and skill value seem unaffected by such difference of population increase. The spread of genetic value is almost constant as the same marriage rules and move rate were applied to all runs (Fig. 2-4), while the spread of skill value showed definitely different patterns according to the ways to chose her/his master.

In the L1 condition of random selection, the skill spread very slowly (Fig. 5). Individuals who acquire skill value appear in the area B soon but only appear in the area C after about 100 years. The mean of skill values learned at the age of 15 slightly increases in the areas B and C while that in the area A gradually decreases.

In the L2 condition of leaning from the most skilled person among relatives, skill spreads much quicker, and the level of skill does not drop during the diffusion process. Individuals with skill appear in the most distant area E around 200 years after the start even in the M1 condition (Fig. 6). In the L3 condition of the extremely biased transmission, the graphs show similar pattern with that of L2 condition but the time needed for the skill to reach area E is about the half.

The number of people who move during the first 200 years does not differ very much between the M2 and M3 conditions, although the number of moving people per year shows much more variability in the M3 condition. Both gvalue and skill spread slightly quicker in the M2 condition (Fig. 3, 4, 7, 8) .

V. Conclusion

The following insights were gained from the analysis:

1) Genetic influence and culturally transmitted skill show clearly different patterns.
2) Cultural skill can spread quickly without much loss in the case of biased transmission, even when migration rate is very small.
3) The rate of population increase can considerably vary due to chance factors.
4) Nonrandom migration based on family relationship produce results different from those of random migration in the spread of gvalue and skill.

The result provides us with a possible explanatory model for the Jomon-Yayoi transition, where indigenous people are considered to have played more major roles in the areas farther from the northern Kyushu where Yayoi culture was born under the influence of immigrants from the Korean Peninsula. How to choose her/his master may be different according to the nature of cultural skill. For highly visible, easily transmitted type of skill, an extremely biased transmission as simulated here as case 3 may be possible. However, for the kind of skills that need long time apprenticeship is necessary, people tend to learn the skill from nearby relatives. It is expected that this type of cultural skill would spread much slower than more easily acquirable elements. However, in our simulation with L3 condition in which an agent learn from the most skilled relative within the 3 degree of relationship who live in the same area, the speed of the spread of skill was not significantly different from the results with L2 condition. We need to further examine the effect of social learning types on the spread of cultural skill, taking the nature of kinship structure and gender into consideration.

It should be noted that migration rate, birth rate and death rate are constant for all agents in the current setting, in order to examine the relationship between variables. In the case of the Jomon-Yayoi transition, migration could be more restricted and the movement was one-way. Although our simulation project is still at preliminary stage, further examination and comparison with detailed archaeological data would produce more sound results.

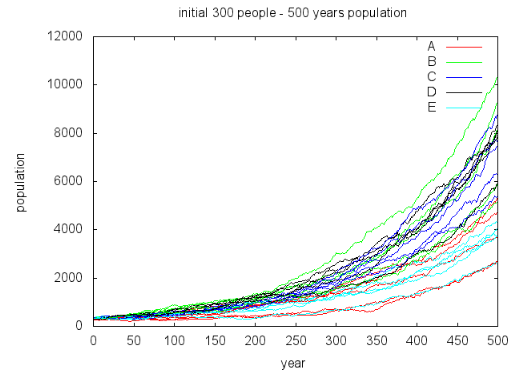

Fig. 1. Population increase: M3.

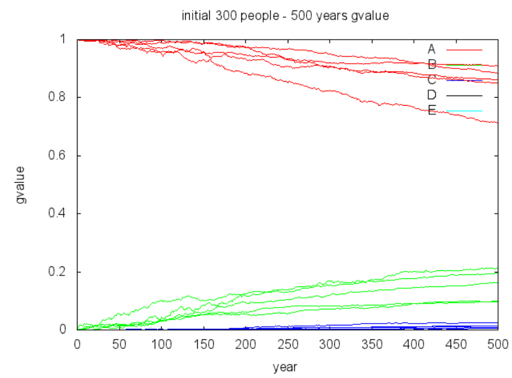

Fig. 2. Spread of gvalue: M1.

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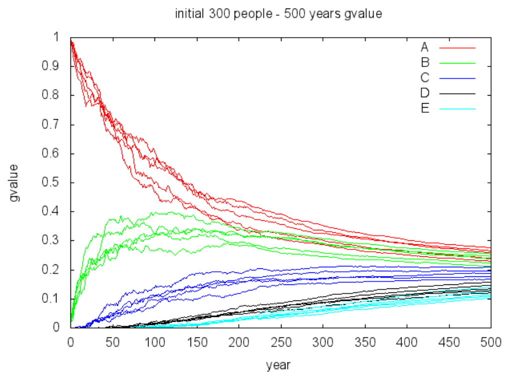

Fig. 3. Spread of gvalue: M2.

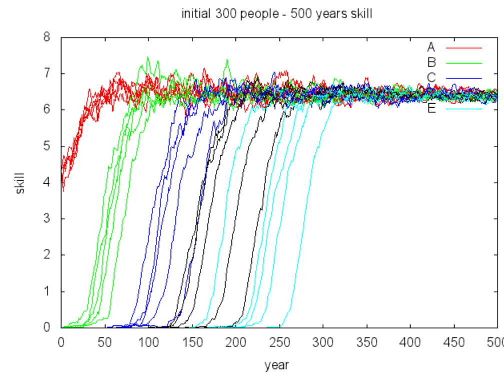

Fig. 6. Spread of skill: M1 L2.

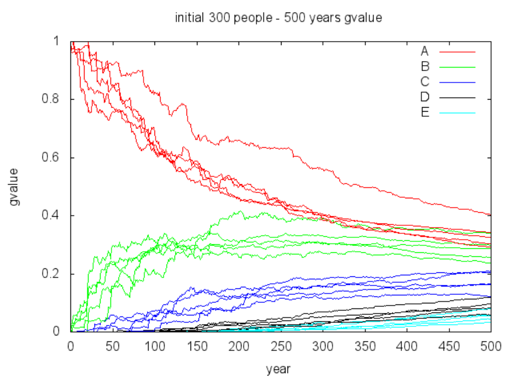

Fig. 4. Spread of gvalue: M3.

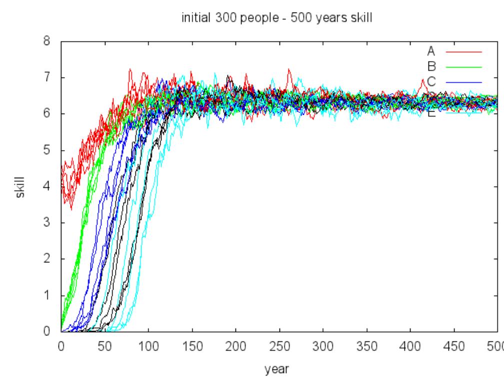

Fig. 7. Spread of skill: M2 L2.

Fig. 5. Spread of skill: M1 L1.

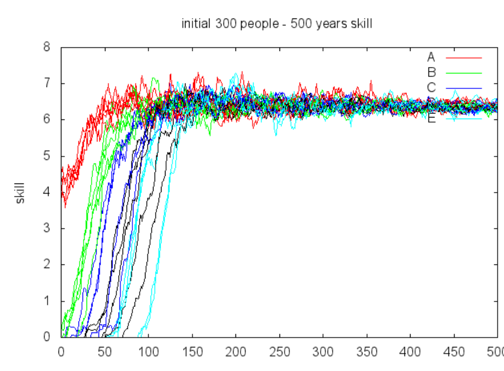

Fig. 8. Spread of skill: M3 L2.

Moderate and Polarized Opinions. Using Empirical Data for an Agent-Based Simulation

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***Abstract* — The selection of a potential site for a deep ground repository for nuclear waste in Switzerland is designed as a participatory process where the citizens' opinions play a central role. Understanding how Swiss citizens form and change their opinions over time on this specific issue is this study's main goal. For this purpose, different methodological approaches are needed. First, a longitudinal online survey based on an argumentative approach aims to show the main dynamics and changes of the opinions over time. Second, an agent-based model simulates opinion changes based on the empirical data and sociopsychological theories. Results of the online survey show the replication of a four-opinion cluster (i.e., in favor, opposing, ambivalent, indifferent) and the relevance of using the dimensions of valence and importance for the arguments. The implementation of the agent-based simulation is discussed.**

I. Introduction

In democratic countries, the opinions of citizens and major social groups are of central relevance for all sorts of political and social decisions. This implies that citizens need to form their own opinions about different topics. Various fields in the social sciences provide theoretical considerations about how people form and exchange their opinions. However, the question about the factors and the dynamics that people assume to form opinions on specific issues still needs to be clarified.

The storage of nuclear waste is an example of a controversial topic on which citizens of a country are asked to provide their own opinions [1]. For the purpose of examining the structure of opinions related to this issue, the prevailing method is to use polarized opinion scales that merely differentiate between proponents and opponents [2], [3]. An investigation on moderate positions (i.e., ambivalence and indifference) is mostly neglected [4].

More recent studies [5] showed that the opinions about a potential deep ground repository (DGR) for nuclear waste (the results of individual ratings on risk and benefit scales) can be clustered into four groups:

- high-risk ratings *opposing* a DGR;
- high-benefit ratings *in favor* of a DGR;
- *ambivalence* (high ratings on both risk and benefit scales and moderate opposition);
- *indifference* (moderate ratings on both risks and benefits, compared to the ambivalent cluster, and a moderate acceptance).

This risk and benefit approach provides aggregate results that are difficult to interpret in a more process-oriented view. Even though one might include moderate opinions, the mechanisms of opinion dynamics remain vague. For this reason, we need to examine more detailed structures of opinion formation and dynamics by using an argumentative approach [6], [7]. The rationale behind this is that in real life, people usually do not interact by sharing their mean values on risk and benefit scales on a topic, but by exchanging arguments that they value in a certain way. This manner of evaluation can occur using the dimensions of *valence* (i.e., how in favor or how against arguments are regarding the specific topic) and *importance* (i.e., how unimportant or important the arguments are rated regarding a specific topic).

Moreover, we need to explain how people build these structures and eventually adapt them after their interactions. Therefore, we require a review of psychological theories that can explain such mechanisms. A plausible, underlying sociopsychological mechanism for opinion formation is described by the Social Judgment Theory (SJT) [8]. This theory explains how an individual weighs new beliefs, attitudes, and/or cognitions by comparing them with his or her own current point of view. This process takes place among three judgmental *latitudes*:

- *acceptance*, including the positions that an individual finds acceptable. In this case, a shift in the direction of the advocated position (assimilation) is possible;
- *rejection*, including the positions that an individual finds unacceptable. In this case, a shift in the opposite direction of the advocated position (contrast) is possible; and
- *non-commitment*, including the positions that an individual neither accepts nor rejects.

As this theory posits, a change in opinion will more probably take place in the latitude of non-commitment and

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the proximate transitions to the latitudes of acceptance and rejection—which is comparable to the range of moderate opinions. The SJT has mainly been tested in small experimental settings, only rarely in more extended ways that include an investigation of opinion changes on a collective level in modeling studies [9]. Our study aims to operationalize this theory in relation to a specific issue (see below) and to integrate it into a simulation model.

From a methodological point of view, the investigation of *opinion dynamics* is limited if we rely solely on empirical methods such as single surveys and experiments. Many researchers pointed out the relevance and usefulness of computer simulations [10], [11]. These simulations have already found some significant applications in social psychology [12]. Specifically, some successful applications of opinion dynamics in the field of computer simulation, mainly based on agent-based models (ABMs), have already emerged [13], [9]. The ABM approach can be useful for testing the underlying mechanisms of both the change and the structure of opinions. This step can lead to a more complete investigation that can shed light on dynamic aspects on both individual and collective levels.

Our assumption is that moderate positions can be key elements for a deeper understanding of the formation and development of opinions. This leads to the questions: Where are the tipping points of public opinion that can lead to changes in individual opinions? How can we define the emerging patterns of public opinion in a heterogeneous population?

In our study, we address these research questions in relation to Switzerland's case. For several decades, Switzerland has been producing nuclear waste (e.g., nuclear power plants and industries) that is currently stored in two interim facilities in the country. However, for long-term storage, the best-known scientific solution relies on DGRs. The Swiss government is currently leading a process of geological selection for a potential DGR site for nuclear waste. This process is designed to be participatory in order to gain public acceptance; therefore, it places considerable emphasis on public opinion and the question of how citizens form and eventually change their opinions over time on this topic.

We present the first steps of a quantitative investigation about the different opinions on a DGR in Switzerland and the first attempts at an ABM that can simulate opinion changes over time.

II. METHODS

Our investigation's methodology includes an empirical part as well as an ABM. First, we provide an overview of the empirical part and then describe in detail the content of the multi-agent system.

A. Empirical Part: Longitudinal Online Survey

The empirical part consists of the first wave of investigation using a longitudinal online survey, in which 1,302 German-speaking Swiss citizens participated. After an introduction to the topic and the collection of demographic data, participants rated ten arguments (eight adapted from risk and benefit scales regarding nuclear waste and DGR used in past literature [4] and two referring to the ongoing political process) on a *valence scale* (i.e., against or in favor of DGR in Switzerland) and an *importance scale*. The ten arguments in the online survey are categorized into three types (see Table 1).

For the purpose of investigating the latitudes described in the SJT (i.e., acceptance, non-commitment, and rejection), participants completed an alternative ordered scale [8]. This scale allows the differentiation of the three latitudes by asking the participants to rate the arguments on a ranking from "the most acceptable" to "the most objectionable."

TABLE I.
THREE ARGUMENT TYPES

Risk-Oriented (RO) Arguments	**Benefit-Oriented (BO) Arguments**	**Process-Oriented (PO) Arguments**
Four arguments regarding the primarily risky aspects of a DGR.	Four arguments regarding the primarily beneficial aspects of a DGR.	Two arguments regarding the political process for the site selection of a DGR.

B. Computer Simulation Part: Agent-Based Model

To report our ABM we follow the overview, design concepts, and details (ODD) protocol put forth by Grimm et al. [14]. For the implementation, we use the NetLogo 5.0.3 software.

a) Purpose

This ABM's purpose is to simulate the opinion dynamics regarding the DGR and nuclear waste issue in Switzerland. The model shows how opinions can shift due to the interactions between agents. In such interactions, agents compare arguments on the basis of a sociopsychological theory; over time, they adapt (or not) their opinions, depending on the interactions in which they were involved. This process should offer insights into the dynamics that lead to changes in the opinions of individuals, as well as show how moderate and polarized opinions become influenced by these dynamics. The results should help explain potential opinion changes during the site selection process for a DGR in Switzerland.

b) Entities, state variables, and scales

Agents represent individuals from the German-speaking Swiss regions. Each agent possesses a given set of arguments, currently limited to three types (i.e., *risk-oriented [RO], benefit-oriented [BO], and process-oriented [PO] arguments*) for the purpose of simplicity. The three argument types are the same for every agent to make comparisons possible. Each argument type x is described as a function Arg_x [-1 – 1] of the mean values of valence V_x (on a continuum from positive to negative, representing the positions from -1 "absolutely against" to 1 "absolutely in favor" regarding the topic of a DGR) and the mean values of importance I_x (from 0 "not important at all" to 1 "very important"). The equation is shown below:

$$Arg_x = V_x * I_x \qquad (1)$$

One interaction between two agents occurs in one time step.

c) Process overview and scheduling

Agents interact randomly with each other and compare their argument types (i.e., *RO*, *BO*, and *PO*) in a one-directional interaction. Based on the SJT, each agent first decides whether it accepts or not the argument type of the other agent by checking if the value for Arg_x lies in the latitude of rejection. Depending on the position of the argument type compared to an agent's own latitude, it subsequently decides whether it adapts or not its own value away or toward the other's value. When it finishes the comparison, it exits the interaction and chooses a new agent for the next interaction (see Figure 1).

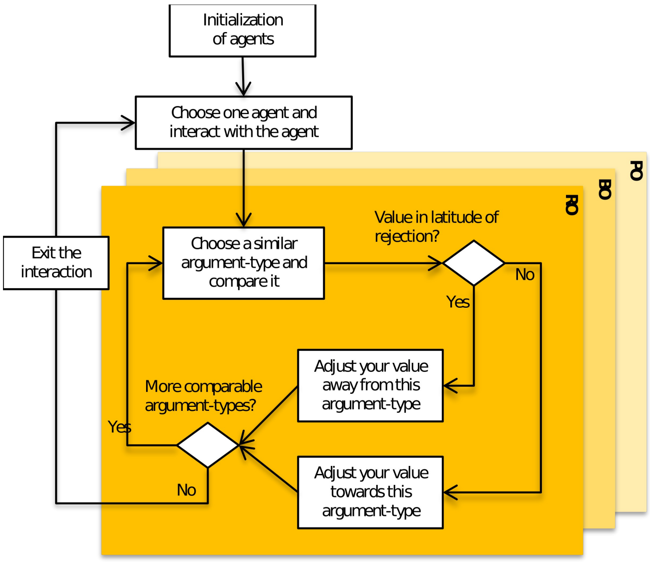

Figure 1. Flow chart of the interactions

d) Design concepts

This model aims to simulate the opinion dynamics based on the interactions between agents. During initialization, agents are randomly linked together in order to create a basic social network (i.e., small world). At each time step, each agent exchanges its argument type with that of a randomly chosen neighbor and changes its own opinion in response to its adaptation after an interaction. All the argument types possess two dimensions: *valence* and *importance* (see Equation 1). The *general opinion on DGR* results in the mean value of every argument type value Arg_x. During the interaction, the interacting agent compares the other's argument type with its own and evaluates how far these argument types are from each other. Depending on this distance (i.e., the latitudes), the agent decides to shift its own argument type value away or toward the other's argument type. This process is repeated for each argument type during one interaction.

As an objective, each agent strives to build its own solid opinion about nuclear waste repositories. This objective is related to the amount of adaptation the agent experiences; the less the agent adapts after interactions, the more its opinion becomes solid.

The social network is updated after every interaction (time step). New links are created (with agents holding arguments that mostly fall under the latitudes of non-commitment and/or acceptance), and others are broken (with agents holding arguments that mostly fall under the latitude of rejection).

e) Initialization

Each agent has its state variables assigned at the setup procedure, based on the empirical data from the online survey. The following variables are needed to set up the agents' profiles:

- values for the valence of each argument type (V_x);
- values for the importance of each argument type (I_x); and
- ranges for the latitudes of rejection, non-commitment, and acceptance of each argument.

III. Results

The first analysis replicated a four-opinion cluster solution that was observed in prior investigations. The four clusters represent different types of opinions (i.e., *opposing, in favor, ambivalent, and indifferent*), based on the evaluation of the arguments.

Concerning the latitudes described by the SJT, the results of the alternative ordered scale revealed that people evaluate the arguments on being on different latitudes across the continuum, ranging from rejection to acceptance. However, the process-oriented arguments were found to be predominantly in the latitude of acceptance.

The ratings for importance showed higher values for process-oriented arguments than for risk-oriented ones, and the lowest values for benefit-oriented ones.

A. Expected Simulation Results

Based on our simulation described above, we expect to have heterogeneous agents with different values for the three argument types. These values will result in the four types of opinions comparable to the empirically based, cluster analysis solution (i.e., opposing, in favor, ambivalent, and indifferent). Each agent with its own set of three argument types will then interact with another agent per time step and compare the values of the argument types using the latitudes described by the SJT. We expect a change of opinions from moderate to more polarized ones at the agent level, due to the evaluations of the argument types on the latitudes. Those agents with argument-type values that are predominantly in the middle position (around zero) are anticipated to adapt more than their counterparts with argument-type values that are primarily in the upper or lower ranges (either -1 or 1), depending on the other agent's argument-type value.

The argumentative approach should lead to more realistic dynamics that simulate the interactions among people who discuss the site selection process for a DGR in Switzerland, by tracking the changes in their opinions based on the comparison of different arguments.

IV. Discussion

This study provides results that can help define the dynamics and mechanisms of opinions regarding the specific issue of nuclear waste and DGR. The arguments that are rated on valence and importance, in combination with the sociopsychological assumptions of the SJT (although challenging to operationalize and investigate), constitute a valid and realistic approach for examining opinions on this specific issue. Together with the methodological combination of a longitudinal online survey and an ABM, this study allows the investigation of dynamic aspects that are often neglected in more methodologically homogeneous designs.

From our preliminary analyses, we observe that focusing on arguments, instead of mere risk and benefit evaluations, can provide more detailed insights into the underlying structures of opinions. By having two dimensions for each argument (i.e., *valence* and *importance*), we could provide a differentiation of the structure of opinions, which is important if we want to draw the investigation closer to the real process of opinion dynamics among the citizens of a country. Moreover, we can distinguish the set of arguments for different types (risk-, benefit-, and process-oriented arguments); this can offer in-depth knowledge about how people perceive the site selection process for a potential DGR in Switzerland, which is obviously of high relevance in the ongoing political process.

The implementation of the ABM provides a basis for investigating the dynamics that would otherwise be difficult to measure with common methods in the social sciences (e.g., questionnaires, experiments, etc.). The model will be validated with the upcoming phases of the longitudinal online survey.

A. Next Steps and Further Investigations

The next steps for this study concern an in-depth analysis of the empirical data and its implementation in the ABM. To obtain robust results from the simulation, further trials and analyses are necessary (sensitivity analysis). The next stages of investigation using the longitudinal online survey can provide additional data for the model validation, which is crucial for a powerful simulation. Additionally, a more differentiated initialization of the agents could lead to more precise process dynamics, by considering other traits, such as gender or age differences, expertise, or involvement. Exogenous processes (e.g., influences of the media) will also allow a further step for a more realistic representation of the model.

We are currently working on the next steps and have confidence in our ability to present more detailed results during the conference session in September 2014.

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Simulating the influence of socio-spatial structures on energy-efficient renovations

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Abstract—To meet climate protection targets it is suggested to increase the number of energy-efficient renovations. Homeowners are the main decision makers regarding renovations in their houses. It is hypothesized that socio-spatial structures affect the decision to renovate. Since it is crucial to consider all important aspects influencing the decision making of homeowners when designing policies to trigger higher energy-efficient renovation activity, we developed an agent-based model to examine the influence of socio-spatial structures on these decisions. The simulation results suggest that socio-spatial structures have a considerable effect on the type of renovation measures carried out. The distribution of socio-technical attributes, population density, social network properties, and residential segregation, affects the homeowners' decision to renovate. Additional research is needed to validate the model and make it applicable to evaluate policy instruments designed to promote the diffusion of energy-efficient renovations.

I. Introduction

Buildings are responsible for over one third of global greenhouse gas (GHG) emissions [1]. Despite the economic viability of many energy-efficient renovations (EERs) having a high potential to reduce greenhouse gas emissions and meet climate protection targets [2,3], the number of measures actually carried out is relatively low. In Germany, for example, the annual EER rate is less than one per cent [4]. Several climate protection scenarios at national, international and global level suggest an increase of the EER rate to meet climate protection targets [5–7]. It is the responsibility of the policy makers to introduce new or improve existing instruments to initiate and allow such transition to a climate-friendly building stock. Friege and Chappin (2014) point out that due to the decision-making processes of homeowners not yet sufficiently understood [8,9], present incentives lead to unsatisfactory results [10–12]. The authors conclude that a simulation model which maps the decision-making processes of homeowners is needed [13]. This paper presents an agent-based model (ABM), designed to investigate the influence of socio-spatial structures on EER decisions. The model is implemented in NetLogo v. 5.0.4 [14]. In the following we provide the theoretical background, present our research questions posed to facilitate the analysis and introduce the applied methodology.

This work was supported by the Heinrich Böll Stiftung and the Wuppertal Institute for Climate, Environment and Energy.

A. Theoretical background

A literature review on EER decisions of homeowners has shown that the economic viability of measures is only one motivating factor among others [13]. Wilson et al. (2013) even found that financial constrains do not prevent households from planning renovations, but they may make the decision more drawn out [15].

In order for individuals to perform EERs various wants and needs must be met [16]. Principal motivations of individuals to achieve energy efficiency are mentioned by Organ (2013): energy bill saving, increased comfort and reduced environmental impact [17]. Several studies indicate that the homeowners' social interaction influences their renovation decision-making processes [15–18]. According to Rogers (2010) communication of homophilous individuals (similar in certain attributes), which "usually belong to the same groups, live or work near each other, and are drawn by similar interests" [19], are likely to communicate more effective and more often. Wellmann (1996) shows that neighbors make up 23 per cent of a person's entire social network active ties while they are responsible for nearly two-fifth (38 per cent) of all contacts [20]. If one also takes into account that nearby houses are likely to be of the same type with similar renovation options, local socio-spatial structures possibly play a major role in homeowners' renovation decision to renovate.

B. Research questions

The following four research questions are posed to facilitate the analysis on how homeowners' social networks affected by local spatial structures influence the diffusion and in this way the share of EERs:

- Q_1: Does the population density and the density of social networks influence the diffusion of EERs?
- Q_2: Does the degree of homophily in neighborhoods influence the diffusion of EERs?
- Q_3: Does the distribution of socio-technical attributes amongst homeowners influence the diffusion of EERs?
- Q_4: Do the kind of renovations, most frequently carried out in the past, influence the diffusion of EERs?

C. Methodology

We developed an ABM to elaborate on our hypotheses. Establishing such a model requires the consideration of socio-demographic parameters, house type and condition, homeowners' interaction in social networks and several external framework conditions. One reason why we use this bottom-up methodology is its ability to capture complex emergent phenomena – in our case the diffusion of EERs. Homeowners' heterogeneity and social interactions can be modeled explicitly [21]: When transferring Rogers' theory of "Diffusion of innovations" [19] on our case, the likelihood that homeowners interact and that this triggers the adoption of EERs is dependent on baseline homophily and spatial proximity. Therefore, homeowners which share similar technical and socio-demographical attributes and live close to each other, have a higher possibility to communicate. Given the circumstance that homophilous individuals usually live near each other in houses that are likely to be of the same type, we expect a considerable diffusion rate of EERs in neighborhoods. Spatial structures, incomplete information and several other real-world phenomena influence the degree of homogeneity between homeowners and thus the diffusion of EERs. Holzhauer et al. (2013) state that spatial ABMs should consider "baseline homophily, i.e. the influence of local socio-demography on the composition of one's social network" and that "the probability of links (…) depends on geographical distance between potential partners" [22].

The structure of the present paper is as follows: Section 2 describes the creation and use of the spatial agent-based model. Section 3 presents the results. The paper closes with conclusions in Section 4.

II. The agent-based model

A. Purpose

This paper addresses the poor understanding of how the composition of homeowners' social networks influenced by local spatial structures has an impact on the share of EERs in self-occupied houses. A comprehensive review on scientific literature and several project reports was carried out to obtain an initial insight into the socio-technical system [13]. The review was complemented by expert discussions and five initial semi-structured telephone interviews with homeowners regarding their decision making on EERs. These steps resulted in a system description suitable for the design of the model. Several concepts were identified to be important when modeling the diffusion of EERs: the socio-technical system, consisting of agents with their individual attributes (see Subsection B), the socio-spatial structure (see Subsection C), and interactions between agents within their social network further described in subsection D. Decision rules in our model are as much as possible based on literature but need empirical validation or rather modification in the follow up process (see Section IV). Our model has the potential to lead to a better understanding of how certain spatial structures influence the diffusion of EERs. This knowledge may be used to design policy instruments targeted at existing local spatial structures.

B. Socio-technical system

The actors in the socio-technical system are represented as agents in the model. The main actors we are looking at are owner-occupier households with decision making regarding investments in renovation measures. Even though households may consist of several individuals (parents, children etc.) we treat households as single entities. They are represented as homeowners containing several social and technical attributes.

Homeowners' technical attributes refer to characteristics of the house they live in. In accordance to our modeling purpose the house type and age are considered. These attributes have a low or even no influence on the type of performed renovation [23] but affect the renovation occasion, the spatial structure and the interaction between homeowners. We consider detached, semi-detached and terraced houses, the typical housing types of owner-occupiers.

Social attributes are grouped into socio-demographical and psychological characteristics. Socio-demographical attributes, mainly the homeowners' age, highly influence whether a renovation will be carried out. Comparatively high income also has a positive influence on the decision to renovate [23]. Psychological attributes such as stubbornness towards the opinion of other people or attitude towards energy efficiency, together with knowledge on EERs, highly influence the type of renovation measure carried out [23].

C. Spatial structure

The socio-spatial structure is based on the preference of people to move to a neighborhood of like-minded people, similar in certain socio-demographical and psychological attributes. Residential segregation leads to the physical separation of groups into different parts of the urban environment [24]. Due to incomplete information and heterogeneity of homeowners, a certain amount of diversity sustains within the neighborhood. Since houses are mostly build in complexes and therefore have a similar construction age and type, clustering is based on these values as well. Zhao et al. (2013) point out that the Euclidean distance function can be applied to measure the similarity between two data points, e.g. in social networks [25]. Accordingly, that function is used to determine the degree of homophily[1] between two homeowners (ΔH):

$$\Delta H = \sqrt{\left(\Delta T^2 + \Delta H_a^{\ 2} + \Delta A^2 + \Delta O_a^{\ 2} + \Delta I^2 + \Delta S^2\right)} \quad (1)$$

with socio-technical attributes given in Table I. For simplification purposes, it is assumed here that all attributes are of the same importance. Exploring the influence of different weighted socio-technical attributes on the simulation results is recommended for further work.

[1] Here, a low degree of homophily between two homeowners means that they are very much alike.

Setting up the socio-spatial and technical structure is done in three steps: 1) setup agents, 2) distribute agents at random, and 3) start simulation.

1) Homeowners are created and socio-technical attributes are assigned to them. The number of created homeowners is dependent on the desired density of homeowners on the grid. The socio-technical attributes are normally distributed with a mean of 0.5 and a standard deviation of 0.15, except for the types of houses (see Table I). The distribution of the different house type is based on a report by the German Federal Statistical office [26].

TABLE I: DISTRIBUTION OF SOCIO-TECHNICAL ATTRIBUTES

Attribute	Distribution	Description
House type [T]	60%	Detached houses
	27%	Semi-detached houses
	13%	Terraced houses
House age [H_a]	Normal distribution with $N(0.5, 0.15^2)$	Young to Old
Attitude [A]		Negative to Positive
Homeowner age [O_a]		Young to Old
Income [I]		Low to High
Stubbornness [S]		Low to Extreme

2) Homeowners are at first randomly distributed over the grid.

3) Each of the homeowners check the degree of homophily towards their neighbors within a predefined patch-radius on the grid with a size of 60 x 60 patches. If the average degree of homophily is below or at a certain threshold (tolerance), they remain where they are. The initial tolerance is set to zero. If the average degree of homophily is over their tolerance, they move to another place and slightly increase their tolerance. This artificial process to generate a spatial structure is repeated until all homeowners found a place to stay.

D. Social network

The composition of a homeowners' ego network is dependent on the likeliness (regarding socio-technical attributes) of other homeowners they come into contact with. The chance of contact is dependent on spatial proximity. The following function, adapted from Holzhauer et al. (2013) [22], is used to generate the social network. It describes the likelihood that two homeowners link:

$$p_{link} = \frac{\Delta H}{\Delta D^{\varepsilon}} \quad (2)$$

where ΔH is the degree of homophily between two homeowners (see Function 1), ΔD the distance between two homeowners and ε an auxiliary parameter to vary the likelihood for the occurrence of links between homeowners with a distance greater than one. Network ties based on this approach, represent a relationship between homeowners that may communicate and mutual influence each other [19]. Homeowners interact through their ego network by exchanging information on renovations they have carried out.

E. Decision-making process

After setting up the spatial structure and generating the social network, it is time to implement the homeowners' decision making behavior. According to Wilson et al. (2013) homeowners run through three different stages in their decision-making process: 1) thinking about renovations in general terms, 2) planning a concrete renovation, and 3) executing renovations. In the following, the decision making of homeowners is described by looking at the different stages in detail. Before that, there has to be an occasion triggering the homeowners to start thinking about renovations.

When to start thinking about renovations

About half of a representative sample of 1,028 homeowners were not considering a renovation [15].

The precondition for homeowners to start thinking about renovations is that they did not think about or actually renovated their building for more than a year (cool-down). Homeowners start to think about renovating their property when the opportunity or need arises to do so. Stieß and Dunkelberg (2012) [27] list three occasions, 1) purchase of a building, 2) extensions/alterations and 3) maintenance which can trigger an EER. According to Stieß and Dunkelberg (2012) such particular situations are associated with a buildings' condition and homeowners' socio-demographic situation/phases of life. Since no precise data regarding the probability of occurrence of different occasions dependent on homeowners' age (purchase and extension/alteration of a building) or on house age and condition (maintenance) were found, the dependencies were based on suggestions derived from literature [28,29].

- Purchase of a building: After associating a normally distributed random number $N(0.35, 0.1^2)$ to each homeowner, it is checked whether their age attribute is equal to this number (accuracy of one decimal place). If this situation arises, the purchase occurs with a possibility of 30 per cent
- Extensions/alterations: Same procedure as for the occasion above. The linked numbers are normally distributed with $N(0.40, 0.15^2)$
- Maintenance: The third renovation occasion occurs with a probability of $(0.9 + 0.1 \times H_a) \times 30\%$

Therefore very young and very old homeowners are less likely to purchase a building or extend/alter it. Maintenance is more likely to occur in older buildings.

Thinking about renovations

Thinking about a renovation in general terms includes the exchange of information between homeowners. Stieß et al. (2010) found that 60 per cent of questioned renovators do not carry out comprehensive EER measures because they believe their house to be in a good energetic condition [23]. This significant finding was implemented in the model by only giving 40 per cent of the homeowners the knowledge that a comprehensive EER may be a useful option for their house. "Informed" homeowners were chosen based on characteristics of two different types of renovators given by Stieß et al. (2010), persuaded energy savers and open-minded skeptics: medium to high income and attitude, rather old houses, not middle-aged, low and quite high stubbornness. A homeowner, who is not in possession of such information, adopts it if:

$$\frac{N_I}{N} \geq S \qquad (3)$$

where N_I is the number of "informed" network contacts, N of all homeowners' network contacts and S is the homeowners' stubbornness. Furthermore homeowners can adopt the information through other channels such as media or energy consulting and repress or forget the information.

The previously mentioned circumstance that 60 per cent of renovators believe their house to be in a good energetic condition is stated to be the second most important barrier to prevent homeowners from carrying out a comprehensive EER [23]. Since it was not necessary to distinguish between simple and comprehensive EERs to address our research questions, we decided to abstain from doing so in the presentation of the results (see Section III). The distinction will become relevant in further research.

Planning renovations

Homeowners concretely planning a renovation decide whether to carry out a measure to increase the energy efficiency of their building in addition to a pure amenity renovation. The focus is set on this matter due to the findings of several reports on EER decisions:

- Efficiency measures are rarely done alone, they are commonly bundled with amenity-only measures [15]
- Since amenity-only measures dominate market activity, would-be amenity renovators "represent a largely unexploited opportunity to introduce efficiency measures into homeowners' decisions to renovate" [15]
- EER measures are more profitable if carried out additionally to amenity-only measures [30]

We adopted the approach for "a multiparameter model for innovation uptake" by McCullen et al. (2013) [31] to describe the adoption of EER measures subject to individual homeowner's characteristics. Thus the decision to additionally carry out an EER measure is "determined by the perceived usefulness, or *utility*, to the individual" [18]. The homeowner adopts the measure, when this utility outweighs the barriers, or *threshold*, to adoption. The total utility U for an individual homeowner is the sum of (additional) personal P_{Be} and social benefits S_{Be} [32]:

$$U = P_{Be} + S_{Be} \qquad (4)$$

In addition to the social motivation, Organ (2013) mentions three further motivations to perform an EER: reducing energy bills; increase comfort; and reducing environmental impact [17].

Accordingly, the personal benefit P_{Be} is a combination of financial, comfort and environmental benefits:

$$P_{Be} = \alpha\,(F_{Be} + C_{Be} + E_{Be}) \qquad (5)$$

where α is a weighting for the personal benefit, F_{Be} represents the financial benefit, C_{Be} is the comfort benefit and E_{Be} is the environmental benefit. The perceived financial, comfort and environmental benefits are dependent on the individual homeowners' attributes (see Table I):

$$F_{Be} = 1 - I + H_a \qquad (6)$$

$$C_{Be} = O_a \qquad (7)$$

$$E_{Be} = A \qquad (8)$$

So the perceived financial benefit F_{Be} decreases with increasing income and increases with increasing house age. The comfort benefit C_{Be}, namely thermal comfort, air quality and noise protection [33], is expected to be more important for older homeowners who are assumed to spend more time in their building than younger homeowners. Furthermore, homeowners with a positive attitude towards energy efficiency perceive a higher environmental benefit E_{Be} by reducing their environmental impact via an EER than homeowners who do not care about this matter. However, the degree of the different dependencies needs to be adjusted based on empirical data (see Section IV).

According to McCullen et al. (2013) the individual social benefit S_{Be} can be split into both the direct influence from a homeowners' ego network D_{Be} and the influence from society in general G_{Be} [34]. w_D and w_G are weightings for the social benefits.

$$S_{Be} = w_D \cdot D_{Be} + w_G \cdot G_{Be} \qquad (9)$$

$$D_{Be} = \frac{(1-S)\cdot(N_{M2} - N_{M1})}{N} \qquad (10)$$

$$G_{Be} = \frac{(1-S)\cdot(O_{M2} - O_{M1})}{O} \qquad (11)$$

where N_{M2} represents homeowners' network contacts which have already carried out a mixed (amenity-only and efficiency) renovation measure and N_{M1} are the network contacts to those where the last renovation measure carried out was an amenity-only measure. O_{M2} and O_{M1} are homeowners within the model to whom the last renovation measure carried out was amenity-only or mixed respectively. O stands for the number of all homeowners within the network. As can be seen the social benefit of performing a mixed renovation measure is only positive if more mixed measures other than amenity-only measures in the homeowners network or the society in general have been carried out. The degree of influence again is dependent on each homeowners own stubbornness towards the opinion of others.

The threshold to adopting the innovation consists of perceived financial F_{Ba}, socio-demographical S_{Ba} and technical barriers. Since there is no distinction drawn between different types of EER measures, the model lacks to map specific technical barriers. Technical barriers are partly considered by taking into account a necessary cool-down before a renovation occasion can trigger homeowners to think about renovations as introduced above. Homeowner's individual threshold θ is calculated as shown below:

$$\theta = F_{Ba} + S_{Ba} = 1 - A + O_a \qquad (12)$$

The financial barrier is therefore expected to decline with a more positive attitude towards energy efficiency and increase with the homeowner's age. Homeowners with a positive attitude towards energy efficiency are more likely to raise a credit for or spend the money they have on energy efficiency measures instead of spending it for something else. Stieß et al. (2010) found that the circumstance that most homeowners are unwilling to raise a (further) credit [23], is the most important barrier preventing EERs.

The socio-demographical barrier is high for elderly homeowners because they may not live long enough to experience the EER to pay back. This is especially the case if the homeowners do not have relatives who could inherit their property. Elderly homeowners are also expected to be more irritated by additional noise and dirt caused by the renovation. A homeowner decides whether to carry out a mixed renovation measure instead of an amenity-only renovation measure if the utility U outweighs the threshold θ.

Executing renovations

Finally, homeowners actually carry out the renovation they decided on. The time they spend on this and the other stages was estimated based on a survey carried out by Wilson (2012)[15].

III. Results

The aim of the model is to understand whether the composition of homeowners' ego networks influenced by local spatial structures has an impact on the diffusion of EERs in self-occupied houses. By means of a reference scenario (see Subsection A) various socio-spatial structures and parameters relevant in the decision-making process on EER activities were simulated (see Subsection B and C). Subsection D elaborates on the significance of the simulation results. Since the parameter variations result in different spatial structures, we were able to address our research questions (see Section IV).

A. Reference scenario

We develop a reference scenario to investigate the impact of various socio-spatial structures and parameters relevant in the decision making process on the share of mixed renovations (F_m). It is pointed out here that time frame and renovation dynamics over time are of secondary importance since the model is not developed to predict possible future states but to reconstruct potential present situations. Of particular interest is the share of mixed renovations after reaching a steady level. Therefore, the simulations are run up to a certain degree of stabilization of the share of mixed renovations. The parameters for the reference scenario are designed to sketch the present situation: At a cool-down time of one year, the shares of homeowners within the different decision stages stagnate at values found by the survey of Wilson et al. (2013)[15]. Therefore, the period of time before homeowners start thinking about renovations again (after their last decision-making process) is set to one year. α, the weighting for the personal benefit, is set to 1.4. At this value, the mean personal benefit of all homeowners towards mixed renovations is below the mean threshold. The other parameters for the reference scenario were estimated by the authors considering the results of several simulation runs with different parameter combinations. The following table (Table II) gives an overview of all relevant reference scenario parameters.

Table II: Reference scenario parameters

Parameter	**Value**
Socio-spatial structure	
Population density [P_d]	40%
Search radius of homeowners [R]	3
Distribution of socio-technical attributes [D]	See Table I
Likeliness parameter for links [ε]	3
Initial share of amenity-only renovations [J_a]	0%
Initial share of mixed renovations [J_m]	0%
Decision making	
Weighting of personal benefit [α]	1.4
Weighting of direct social benefit [w_D]	1
Weighting of benefit for society in general [w_G]	0.5

The influence of different socio-spatial structures (see Subsection B) and decision making parameters (see Subsection C) on the share of mixed renovations was tested by changing only one parameter at once while keeping the others constant. Since the model outcomes differ in each run, each parameter constellation was run a hundred times in order to be stochastically sure about the outcomes.

B. Socio-spatial structure

The following section introduces the framework used for the analysis, presents the simulation results and gives some visualization examples of different socio-spatial structures.

Analysis framework

A sensibility analysis was carried out to investigate the impact of different socio-spatial structures on the dissemination of mixed renovations after 120 ticks:

- Population density (P_d): 10% - 70% (10%/step)
- Search radius of homeowners (R): 1- 4 (1/step)
- Distribution of socio-technical attributes (D): Normal or uniform distribution of socio-technical attributes
- Likeliness parameter for links (ε): 2 – 4 (0.5/step)

Additionally, the initial share of renovations carried out before starting the simulation was varied:

- Initial share of amenity-only renovations (J_a): 0% - 100% (10%/step)
- Initial share of mixed renovations (J_m): 0% - 100% (10%/step)

Population and network density

The population density and the network density (affected by the likeliness for the occurrence of links) were found to have a major influence on the mean final share of mixed renovations in the reference scenario. The final share of mixed renovations decreases with increasing population density and increasing likeliness for the occurrence of links (the likeliness increases with a decreasing likeliness parameter for links) (see Fig 1). These patterns emerge since a low population density and a low likeliness for the occurrence of links leads to low network densities.

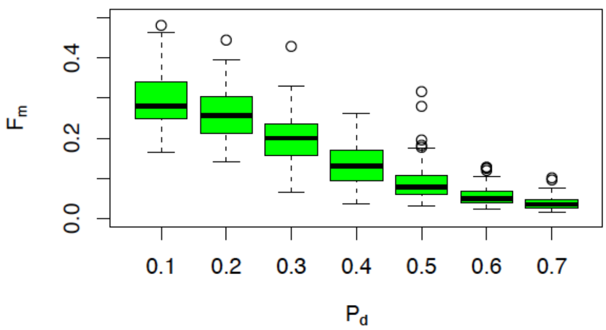


Fig 1: Final share of mixed renovations (F_m) dependent on the population density (P_d)

Here, clusters of homeowners with a positive perceived personal benefit towards mixed renovations are not as much affected by the generally negative perceived personal benefit as at high social network densities (see Fig 2). A population density of 10 per cent represents 360 homeowners on the grid with a size of 60 x 60 patches.

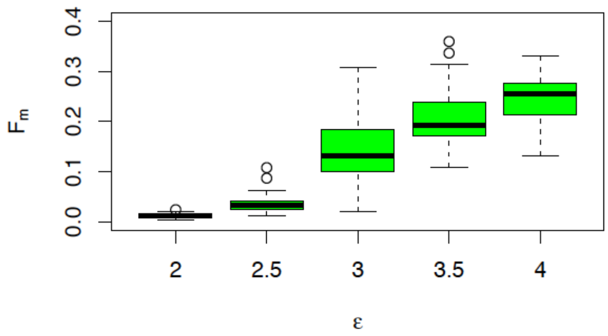


Fig 2: Final share of mixed renovations (F_m) dependent on the likeliness parameter for links (ε)

Size of clusters

The search radius has an effect on the size of clusters in the model, since homeowners consider the degree of homophily towards neighbors in a larger radius. Larger clusters have a positive influence on the final share of mixed renovations (see Fig 3). This is the case since larger clusters of homeowners with mixed renovations are better equipped against direct social pressure than smaller clusters. A search radius of more than one leads to cluster sizes which make it easier to resist against exogenous social pressure.

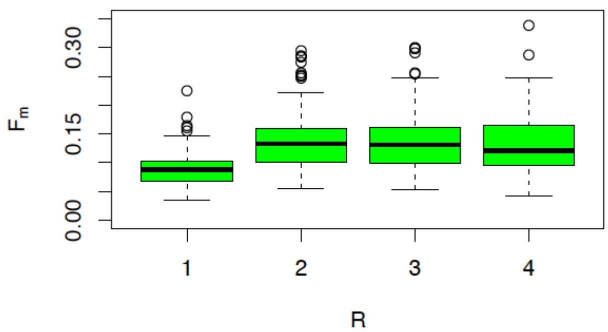


Fig 3: Final share of mixed renovations (F_m) dependent on the search radius (R)

Accordingly, when considering an initial share of mixed renovations of 50 per cent, the final share of mixed renovations is smaller if the clusters are larger (see Fig 4).

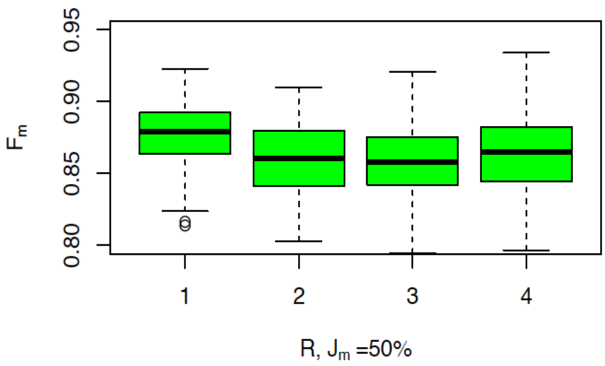


Fig 4: Final share of mixed renovations (F_m) dependent on the search radius (R) considering an initial share of mixed renovations (J_m) of 50 per cent.

Distribution of socio-technical parameters

How socio-technical parameters were distributed amongst homeowners was found to have a major effect on the final share of mixed renovations. A normal distribution of homeowners attributes leads to a higher share of mixed renovations compared to a uniform distribution if the average benefit of performing an EER is positive (at α=1.6, see Fig 5). If the average benefit (at α=1.4) is negative, the uniform distribution leads to a higher share of mixed renovations. Since more homeowners have a medium utility and threshold when their attributes are normally distributed, the marginal utility of increasing the personal benefit based on a medium personal benefit (at α=1.5) is higher compared to uniformly distributed attributes.

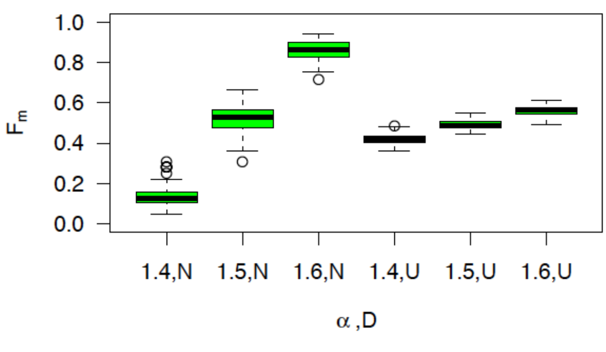


Fig 5: Final share of mixed renovations (F_m) dependent on the distribution (normal|uniform) of homeowners and different weightings of the personal benefit (α)

The greater diversity of attributes at uniformly distributed socio-technical parameters furthermore demands homeowners to be more tolerant in order to find a favorable neighborhood.

Path dependency

A share of already performed mixed, or amenity-only, renovation measures before starting the simulation highly influences the results (see Fig 6 and 7). Given the initial shares of performed mixed or amenity-only renovation measures, this is not surprising since the social benefit is not neutral at initialization of the model. This imbalance leads to a higher final share of mixed renovations at a high initial share of mixed renovations compared to a high initial share of amenity-only renovations.

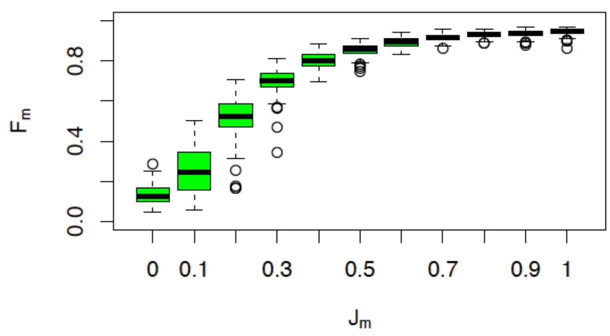


Fig 6: Final share of mixed renovations (F_m) dependent on the initial share of mixed renovations (J_m)

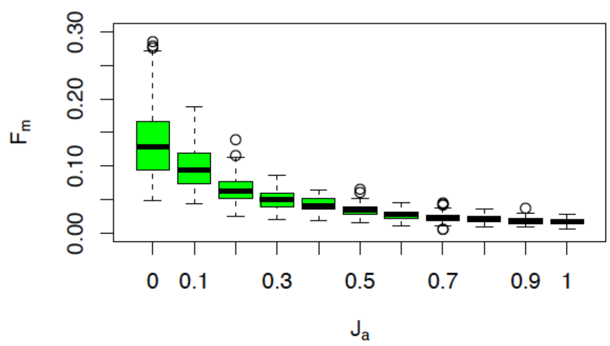
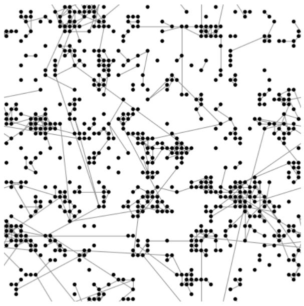
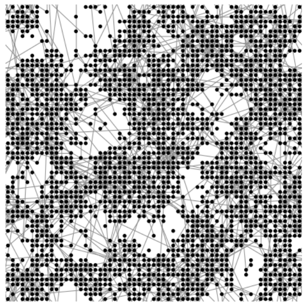
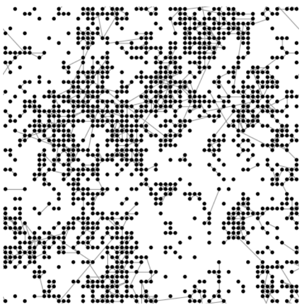
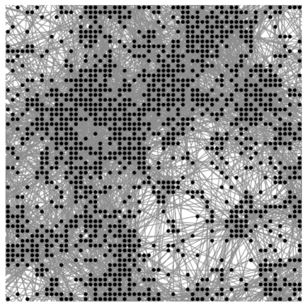
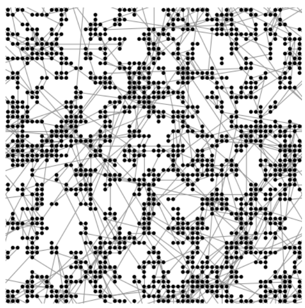
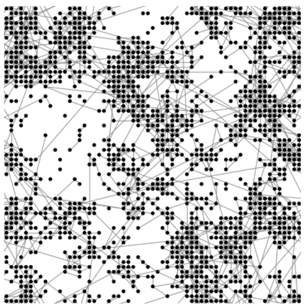


Fig 7: Final share of mixed renovations (F_m) dependent on the initial share of amenity-only renovations (J_a)

Visualization of different socio-spatial structures

Table III gives some visualization examples of different socio-spatial structures: low and high population and network density, and small and large clusters. Each figure is labelled with the parameter modified in comparison to the reference scenario.

TABLE III: VISUALIZATION OF DIFFERENT SOCIO-SPATIAL STRUCTURES

 Population density (P_d): 20%	 Population density (P_d): 60%
 Likeliness parameter for links (ε): 4	 Likeliness parameter for links (ε): 2
 Search radius of homeowners (R): 1	 Search radius of homeowners (R): 4

C. Decision making

The following section introduces the framework used for the analysis and presents the results of varying decision making parameters.

Analysis framework

Apart from analyzing the influence of several setup parameter variations on the results, we also looked at different decision making parameter variations. Besides varying the personal benefit of installing a mixed renovation measure, the perceived social benefit was modified. w_D represents the weighting for the direct benefit from a homeowners' ego network and w_G the weighting for the benefit of society in general. The following parameter variations were used in the analysis:

- Weighting of personal benefit (α): 1 – 2 (0.05/step)
- Weighting of direct social benefit (w_D): 0 – 1.5 (0.25/step)
- Weighting of benefit for society in general (w_G): 0 – 1.5 (0.25/step)

Personal benefit

The weighting of the personal benefit (α) has a high influence on the final share of mixed renovations (see Fig 8). The share of mixed renovations varies between 2 per cent and nearly 96 per cent at a range of α between 1.2 and 1.8.

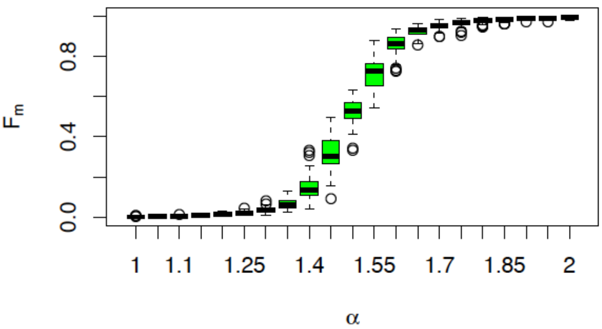


Fig 8: Final share of mixed renovations (F_m) dependent on the weighting of the personal benefit (α)

Direct social benefit and benefit from society in general

Since the reference scenario (w_D=1, w_G=0.5) results in a low share of mixed renovations (about 20 per cent), homeowners are confronted with a high social pressure to perform amenity-only renovations. Consequentially, the final share of mixed renovations decreases with an increased weighting of the influence from society in general (see Fig 10). Surprisingly, this is not the case looking at the weighting of the direct social benefit (see Fig 9). Here, the final share of mixed renovations decreases up to a weighting of 0.5 and increases afterwards. After analyzing the outcome of several simulations in detail, we suggest that this behavior emerges due to the circumstance that clusters of homeowners who performed mixed renovations hold together more strongly if the weighting of the direct social benefit is above a certain level. The clusters mentioned above have more links amongst each other than with the outside world.

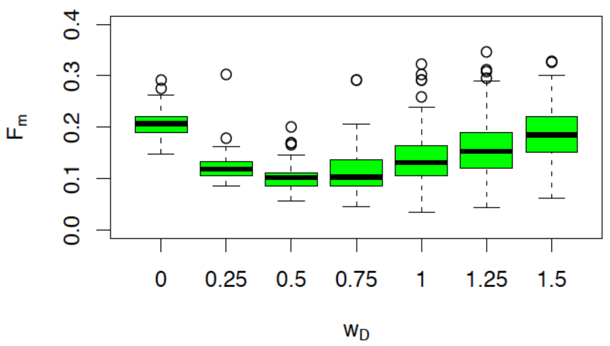


Fig 9: Final share of mixed renovations (F_m) dependent on the weighting of the direct social benefit (w_D)

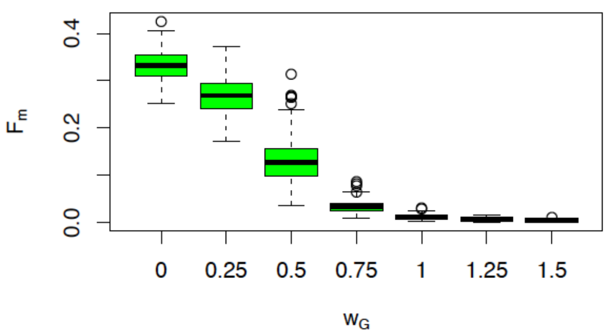


Fig 10: Final share of mixed renovations (F_m) dependent on the weighting of the influence from the society in general (w_G)

D. Analysis of Variance

An analysis of variance (ANOVA) of the simulation results was carried out to test the null hypothesis that data from all groups (different population densities, different likeliness parameters for links, etc.) have equal means. The one-way ANOVA (performed in R [35]) returns a p-value that takes into account the variance, the mean expression difference and the sample size. The p-value is a measure of how likely it is to get the spot data if no real difference existed. A low p-value indicates that the chance is very low [36]. Since the p-value is lower than 0.05 (confidence level of 95%) in every analyzed case, the difference in group expression data is significant. Therefore the null hypothesis of equal means in the groups is rejected.

IV. Conclusions

This paper presents a literature based ABM examining the influence of socio-spatial structures on energy-efficient renovation (EER) decisions. An analysis of variance (ANOVA) showed that the influence of parameter variations on the number of EERs in combination with amenity-only renovations (mixed renovations) is of significance in every analyzed case. The following conclusions regarding the posed research questions are complemented by an outlook on further work.

A. Socio-spatial structure

The influence of different socio-spatial structures on the number of mixed renovations was analyzed by using a spatial ABM.

We found that the population density and the network density have an influence on the share of mixed renovations (Q_1). A low population density and a low likeliness for the occurrence of links leads to low network densities where clusters of homeowners with a positive perceived personal benefit towards mixed renovations are not as much affected by the generally negative perceived personal benefit as at high social network densities.

The simulation results further show that homeowners in homogeneous neigborhoods (large clusters) are less likely to impose their own opinion (Q_2). In the reference scenario, the average benefit to perform a mixed renovation measure is negative. Here, spatial structures with larger clusters lead to higher shares of mixed renovations. This is the case since larger clusters of homeowners with mixed renovations are better equipped against direct social pressure than smaller clusters.

The distribution of homeowners' socio-technical attributes affects the number of mixed renovations carried out (Q_3). Since more homeowners have a medium perceived utility and threshold when their attributes are normally distributed, the marginal utility of increasing the personal benefit based on a medium personal benefit (A=1.5) is higher compared to uniformly distributed attributes.

Initial shares of amenity-only or mixed renovations affect the future type of renovations carried out (Q_4). An initial share of renovations not including energy efficiency improvements, leads to a lower number of renovations including EER measures.

B. Decision making

The influence of relevant decision making parameters on the number of mixed renovations was analyzed as well. The final share of mixed renovations increases if homeowners have a greater personal benefit to do so. An increased weighting of the influence from society leads to less mixed renovations measures carried out since the majority of homeowners do not perceive mixed renovations to be beneficial compared to amenity-only measures in the reference scenario. In case the direct social benefits become more important for the homeowners, clusters of homeowners who performed mixed renovations hold together more strongly when the weighting of the direct social benefit is above a certain level. This results in a higher final share of mixed renovations in the reference scenario.

C. Further work

Assumptions on agent's behavior in the presented model are, inter alia, derived from a comprehensive literature review [13]. Nonetheless the model as a whole needs validation in order to assess accuracy of the experimental outcomes and to prove that the model answers the research question posed. Traditional validation techniques consist of comparing experimental results and real-word data [37]. Due to the exploratory design of the model it must be examined whether this technique is applicable to our case. Other validation techniques such as face validation through expert consultation or literature validation [37] might be more appropriate: Nikolic et al. (2013) state that the validation through expert consultation "is the most commonly used validation approach in agent-based modeling" [21]. Performing an expert validation would include workshops with larger groups of experts or interviews with individuals, systematically going through the model. Besides deriving modeling assumptions from literature, studying academic literature may also serve to validate the model as a whole. Accordingly, the confidence in the outcomes of the model can be increased by comparing these with both theoretical research and other models. The involvement of potential users and stakeholders in the model specification, design, testing and use could be considered to support the development of the ABM [38].

We also aim to extend the model to evaluate policy instruments designed to harness social networks to promote the diffusion of EERs. Collecting further data on homeowners' ego networks and decision-making processes and implementing it in the ABM will lead to a better representation of the real-world system.

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Recent progress on formal and computational model for A. Smiths Invisible Hand paradigm.

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***Abstract*—The recent economic crisis has boosted a very strong demand for quite new tools to analyze and predict the behavior of quasi-free[1] markets. The paper presents our effort to build a formal theory of A. Smith's Invisible Hand [5] paradigm (ASIH) and simulation model for a selected case. It proves that ASIH is not only an economic idea, which conflict on ways to govern [16], but something that really exists, for which formal a theory can be built. Moreover, ASIH can be measured [17], and in the future probably utilized for quasi-free market analysis and prediction. In advance, we want to state, that ASIH according to our theory, can generate both correct and incorrect decisions. For this, we use the theory of computational Collective Intelligence [18] and a molecular model of computations [1], [2]. Our theory assumes that ASIH is an unconscious meta-inference process spread on the platform of brains of agents. This meta-process is: distributed, parallel, and non-deterministic, and is run on a computational platform of market agents' brains. The ASIH inference process emerges spontaneously in certain circumstances and can vanish when market situation changes. Since the ASIH platform is made up of brains of agents, conclusions of this inference process affect the behavior of agents and therefore the behavior of the entire market. Our research unveils that ASIH is in fact a family of similar meta-processes; thus ASIHs for different economic eras are different because corresponding models of brains of market agents are different. The paper will present and explain, on the basis of a simulation model, a case of powerful ASIH response at the end of the 15th century due to a blockade (taxes and the Dardanelles sea-route cutoff) of spice trade by Turks and Arabs. ASIH also responded to the discovery of America, the emergence of a sailing route around Africa, the establishment of plantations (sugarcane, spices) and modern galleons[2] technology. This case demonstrates how powerful and with far-reaching consequences, ASIH can be.**

I. Introduction

Secondary schools textbooks define Economics as a study of human behavior.

Our research effort to build a formal computational theory of ASIH under the assumption that it is a form of Collective Intelligence of a quasi-free market, perfectly fits this point of view. In our research, we abstract from widely used terms such as money, production, consumption, inflation, etc. Instead, we concentrate on large scale inference processes collectively run in the brains of market agents. The molecular model of computations applied here, starts to be efficient when computations are: parallel, distributed, multi-threaded (many interleaving calculations are run at the same time), non-deterministic; with at least tens of thousands of information molecules representing participating agents. This approach perfectly fits the observed behavior of a quasi-free market.

We model the information molecules[3] representing market agents, with the help of an abstract Virtual Machine (automate) denoted by VMa. This approach is to some extent similar to a Java Virtual Machine concept. VMa architecture will be given further on. Depending on the era in economics, this virtual machine is equipped with a corresponding model of economic behavior, a corresponding inference and calculation engine and a corresponding ability to displace (to carry out a business trip) in computational space, thus modeling the whole market. Such an approach is necessary, because agents in a pre-monetary era will carry out business inferences in a different fashion than for example a 15^{th} century Venetian merchant would, to a modern derivatives trader. It is also difficult to observe occurrences of ASIH in different markets in different eras. When we analyze real, live agents from a mental and inference/computational point of view, we see how far this agent is mentally redundant. This redundancy allows unconscious, parallel, distributed and multi-threaded inferences to emerge, run and to conclude in their brains. Results can have a kind of landslide/shake effect on a given quasi-free market - what we perceive as ASIH.

Now, some statements regarding considered meta-inference process should be given to make our theory more intuitive.

<u>I. Observability:</u> Many physical processes can serve as local computers (e.g. analog computers) and we observing it can be unaware about real nature and function of this computer for the environment.

It is quite natural that computational processes which are the basis of ASIH remain unnoticed until now. A perfect example of this is an analog computer (Fig. 1) constructed of

[1]Quasi-free means that markets are subject to restrictions of political, ethnic and environmental nature e.g. during the **15**th century in fact, only the Arabs were able to trade in the Levant.

[2]In only a few decades, European ship displacement had increased from approx. 100 tons (Columbus' ships), to almost 2000 tons (Manilla galeons).

[3]For an extensive discussion on the information molecule concept see [1], [2], [8].

strings and bags of sand, by architect Antonio Gaudi, used to calculate the structure of the Sagrada Familia cathedral (Fig. 2) in Barcelona, Spain. Even computer science students will not realize - without special explanation - when looking on it, that this is a problem oriented computer.

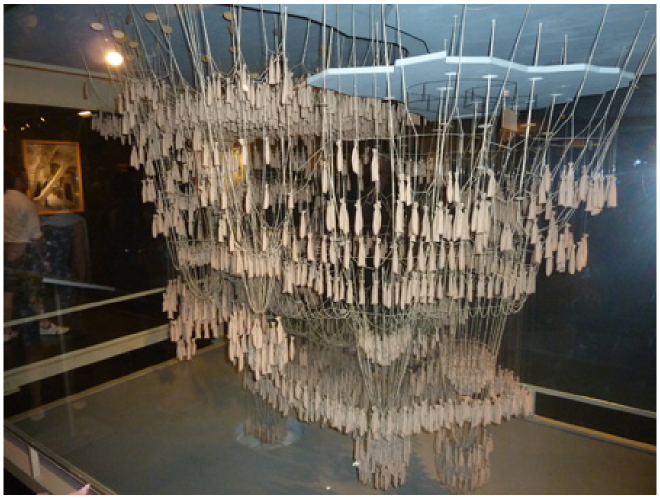

Fig. 1. **Gaudi analog computer.** Source: http://www.sacredarchitecture.org

Fig. 2. **The Sagrada Familia cathedral, Barcelona, Spain.** Source: Google pictures.

II. Unconscious: A market agent can be unconscious about the fact that "doing his business as usual" the agent participates in a distributed meta-inference process. Conclusions of such inference can affect a different agent, or profits from inference conclusions can be appropriated by other agent(s).

A perfect example of this is academic and/or, scientific world. University staff receive salaries for teaching students, whereas usually two good publications per year are a must for contract renewal and promotion. It is usually unimportant for the chairman what the publications are about. Instead, it is the quotation index that is important, which is a guarantee that a researcher participates in the global, common research effort. A given scientist can be quite unaware, that in the end someone, not even related to his study will put together even partial results of the study, and will build an inference chain profiting from the conclusion[4].

III. Implied computations: Building a certain tool to reach a given goal, we are almost always unable to define what the real domain of possible applications is. It is true for hardware tools, for programs, as well as for algorithms.

A good example is the A* algorithm which has a double nature: can serve to find an optimal path between two points and find a path from a start to finish, in-between obstacles. Thus the A* algorithm - built into a VMa of agents trading spices to optimize (from an economic point of view) their sea routes during a stable trade period; will unveil it "second nature" as a path finding algorithm, when path optimization is impossible due to new obstacle (Arab's taxes for example).

All three above mentioned statements perfectly interact together in our formalization of the ASIMH case analyzed in this paper.

Perhaps the best way to provide an intuitive insight into our theory and the nature of ASIH, is to tell a short tale.

...suppose that somewhere, at some time, a small, anonymous city is rapidly growing. Because of the ignorance of the inhabitants and greed of developers, houses are built close together, using timber, and covered with straw making them cheaper. Garbage lay commonly between the houses. Some foreseeing inhabitants protested because of spreading epidemics and a constant threat of fire, but they are being ignored. Fate seemed to observe this and finally an overturned candle caused the city to burn down (London 1666 ?). Residents blamed destiny for this disaster, however, they drew the right conclusions. While rebuilding the city; wider streets with greenery were introduced to separate blocks, fireproof separating walls between buildings were made obligatory and several other regulations were introduced...

Now, if we replace the fire jumping from building to building, to the outbreak of distributed inference transferring between brains of residents, the result will be similar...

II. State of Art

For years now, the notion of the *Invisible Hand* of the market has been stirring controversy. In everyday life, it is customary to put all economic processes for which no other reason can be found down to the operation of the invisible hand.

So where has this notion, that has been used in both science and daily life for years, come from?

The source of this notion can be traced back to the 18th century, when Thomas Hobbes, having fled the civil war-

[4] It is demonstration that our theory extends beyond problem of ASIH. Most probably the phenomenon of universities can be explained. Teaching layer corresponds to business layer, whereas university research corresponds to ASIH. It will be the subject of upcoming publications.

torn England to hide from his political opponents in France, formulated his concept of the Leviathan [7], [8]. Hobbes, assuming that the human nature is egoistic, argued that it was necessary to establish absolute power. He believed this to be the only way of taming the egoistic human nature, or else humanity ran the risk of irreversibly drowning in chaos. To better illustrate this concept, he used the metaphor of a sea hybrid[5], the aforementioned Leviathan[6]. Over a century later, the thesis of the egoism of the human nature was elaborated further by Adam Smith, who explained its reasons as follows [5]:

> „As every individual, therefore, endeavours as much as he can both to employ his capital in the support of domestic industry, and so to direct that industry that its produce may be of the greatest value; every individual necessarily labours to render the annual revenue of the society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an **invisible hand** to promote an end which was no part of his intention."

This quote represents the essence of the thoughts of this Scottish thinker and economist. It was an attack of a kind on the mercantilist trade philosophy (dominating Europe then), according to which unregulated aspiration to private profit inescapably had to lead to anarchy. A. Smith used the *Invisible Hand* theory to try and describe a mechanism characteristic for capitalistic economies, whereby activities of particular individuals, driven by their egoistic intention to satisfy their own needs, actually contribute to meeting society's needs as well. By ASIH, A. Smith proved that the market mechanism is able to self-regulate the process of satisfying social needs, and thus rejected the need for state interventionism and protectionism as the condition for achieving public interest.

The central theme of the work by A. Smith is the operation of the *Invisible Hand*, the essence of which is that it is not from the benevolence of the baker, that we expect our bread, but from his regard to his own self-interest. A. Smith saw the perspective of a promising analysis, discovering that in certain social conditions, which are nowadays often called the functional competition, private interests are in fact harmonized with the social interest. Without collective regulation or a common plan, market economy still operates in accordance with orderly rules of behaviour. Every individual, being one of many, can only exert insignificant impact on the overall situation on the market. As a result he/she accepts prices as given and only has the freedom to choose the quantities bought and sold at these prices, driven by the motive of maximising his/her personal benefits. However, the sum total of these isolated actions determines the prices. Every person, considered separately, follows the prices in his/her choices, however the prices themselves are governed by the sum total of the individual reactions. The *Invisible Hand* of the market thus produces a social effect independent of the will and intentions of individuals.

In 17^{th} and 18^{th} century Europe, wages, prices, interest rates, employment, foreign trade as well as the quantity of goods and services were subject of strict controls by the governments. The purpose of these controls was to ensure the achievement of the vision of social justice as understood by the governing class by way of managing what was produced as well as the method of producing and distributing it. An idea was widespread that every action motivated by aspirations to private profit must be antisocial by this very fact. Even today, Keynesian economics says that free market economy cannot satisfy public interest because it is governed by the profit motive rather than by consciously planned social objectives.

Yet for A. Smith, self-interest was an obviously constructive and coordinating force. In striving to meet their own needs, people taking care of their interest had to refer to the interests of others. Self-interest is a stimulus, a reason for cooperating and coordinating one's own activities with those of others [10].

Critics of the market system perceived profit as an unjust charge on employees wages, but A. Smith saw it as a stimulus, a gratification which persuades a producer to strive to meet the needs of others. He felt that competition between producers would keep profits and prices low so that consumers would not be overcharged. In his reasoning, he also presented a simple proof of the benefits accruing from free trade. It is not profitable for anyone to produce something they can buy cheaper from someone else. He proved that *„what is prudent"* in the private life of every family (in the micro scale) cannot really be crazy in the life of a great kingdom (in the macro scale). A. Smith knew history, politics and economics very well. When he pronounced his famous words about the *Invisible Hand*, he was using his extensive knowledge, and not just a deductive reasoning [5]:

> „It is not from the benevolence of the butcher, the brewer or the baker, that we expect our dinner, but from their regard to their own self-interest. We address ourselves, not to their humanity but to their self-love, and never talk to them of our own necessities but of their advantages."

If this passage from A. Smith's book is taken out of context, as it very often is, it may suggest a very narrow, cynical view of human behavior.

However, if we read it in the whole context, A. Smith's thesis is simply logical. In a complex, internally complicated society, prosperity simply cannot rely on the benevolence of others to satisfy all our desires and needs. People are given

[5] In the sense of something composed of different, often mismatched parts.

[6] The title of Hobbes book, which is the source of the above metaphor, is taken from the Old Testament, in which Leviathan (which in the contemporary Hebrew means a whale) is mentioned, inter alia in the Book of Job, as one of sea monsters, and in the Book of Psalms, where it has a more negative connotation.

to charity at least the majority of them but they also feel restrictions. As A. Smith said, an individual person [5]:

> „...stands at all times in need of the cooperation and assistance of great multitudes (of people), while his whole life is scarce sufficient to gain the friendship of a few persons. (...) He will be more likely to prevail if he can interest their self-love in his favour, and show them that it is for their own advantage to do for him what he requires of them."

The essence of the *Invisible Hand* is the conviction that individuals' striving to further their own interest within the free market lead to an allocation of resources efficient from the perspective of the entire society. This turned into a legend that the entire Wealth of Nations is based on such naive reasoning, on the so-called doctrine of the spontaneous harmony of interests [3]. It sometimes seems that this only means the ability to arithmetically adding instances of individual satisfaction with meeting ones needs: if everyone is maximising their satisfaction when they are only allowed to, a laissez-faire system [21] will maximise the satisfaction of the entire society's needs. In fact, in his proof of the maximum satisfaction doctrine, A. Smith went much further.

In Book I, Chapter 7 [5] he demonstrated that free competition contributes to bringing prices down towards production costs, thus leading to the optimum allocation of resources inside an industry. In Book I Chapter 10 [5] he showed that free competition in the means of production market aims at equalising the net benefit stemming from using those means in all industries, and thus to achieving the optimum allocation of means between industries. He did not prove that various means are combined in the production process in the best proportions or that the product sold is distributed in the best way between individual consumers. Neither did he prove that economies of scale and external effects in production and consumption often hinder achieving the competitive optimum, although his analysis of public facilities does contain a kernel of such reasoning.

However, he did make the first step towards a theory of the optimum allocation of specific resources in the conditions of perfect competition [10]. The *Invisible Hand* is nothing more than an automatic equilibrium mechanism of a competitive market - A. Smith claimed. If competition is perfect and the market is not deficient, it will squeeze as many useful goods and services out of the available resources as possible. However, if monopolies, environmental pollution or similar market deficiencies spread, the efficacy of the *Invisible Hand* may be destroyed [4], [10], [20].

The paradox of the Invisible Hand is that even if every person separately behaves in a non-cooperative fashion, the economic result is socially efficient. What it more, competitive equilibrium says that no individual can improve their situation by changing their strategy if all others resolutely stick to their strategies [10].

The law of supply and demand [4], [20] indicates that the quantities of a given product that are purchased and offered for sale change in different directions as a result of a price change: as the price increases, the quantity purchased falls, but the quantity offered for sale increases. If these two regularities are put together, we find that at a given time and in a given market, there is only one price of a given good at which the quantity purchased is equal to the quantity offered for sale. This is the so called equilibrium price [4], [20].

Market prices get set under the influence of mutual competition, as a result of the interplay of supply and demand in particular markets [11]. In free competition markets, supply curves are determined by the marginal cost [4], [20]. A. Smith perceived the market as a method of forging cooperation between strangers. Give me what I want and I will give you what you want is the offer which forms the cornerstone of every market deal [3], [10], [20]. However, it is true that A. Smith's personal belief in the benefits stemming from the *Invisible Hand* was only to a limited extent due to a static analysis of the allocation efficiency in the conditions of perfect competition. He deemed the decentralised pricing system desirable due to its dynamic impact of broadening the market and increasing the benefit of labour division, or in simple words, because it was a powerful machine stimulating the accumulation of capital and a growth of income.

Although he never said this in so many words, A. Smith was deeply aware of the imperfection of the market system. He also conceded that the market often adjusts to changes slowly and may not maintain the appropriate quantities of certain goods without government intervention. The Wealth of Nations did not try to prove that the free-market system is perfect. It was rather a classical impression of the relative advantages of a free market system compared to alternative economic systems [3].

Smith was definitely on the side of the ordinary people. He believed that replacing monopolistic enterprises with state regulation of the economy would probably spoil the economy and not improve it. A. Smith's views opened the way for the industrial revolution and the golden age of capitalism. His book, published in 1776 [5] still remains a classic economic work today [3].

Making economics mystical with the Invisible Hand of the market had far-reaching consequences. Even the terms market and economy themselves are so imprecise and ambiguous that they cause a lot of misunderstandings. All the more so the term Invisible Hand of the market. In the simplest sense this expression should be synonymous to the word people. In this situation, requesting that the Invisible Hand of the market be allowed to work should be equivalent to allowing people to act.

The *Invisible Hand* of the market was also understood as **the hand of God**. It can be understood even more generally, as a self-organising general harmony, an abstract property of the reality. In that situation it can mean anything, or in other words nothing. The emptier a concept, the more useful it can turn out to its user, when they use it to justify solutions favourable to themselves. One could even be tempted to draft a law on using this metaphor. It would say [3]:

> „demand that all industries with the exception of

your own be subjected to the power of the Invisible Hand of the Market"

In the conclusion, it is worth noting that A. Smith is also the point of reference for one of the main contemporary currents in business ethics utilitarism. A. Smith's theory aimed at demonstrating that the market and market economy are most natural, consistent with human nature and the Creators intention. The same is true for the concept of *homo economicus*[7]and the *Invisible Hand* of the market as well as the laws governing the socio-economic life. In A. Smith's opinion, in the conditions of a free market, if a person aspiring to maximize his utility function follows the law and moral principles, he/she automatically contributes to achieving social objectives, as it were. In a sense, the market system itself is a kind of educator in virtue and an effective way of bringing up a person of integrity.

The concept behind the metaphor of the *Invisible Hand* is often used as an argument for economic liberalism and has been criticized numerous times by supporters of state interventionism. They have been proving that there are many circumstances which prohibit the public interest from being achieved as part of the market mechanism, which they believe to justify the regulatory action by the state.

A doctrine that has undermined the assumptions of the classical economics was Keynesianism [12]. According to this doctrine, state interventionism is necessary to correct the operation of market forces. Unlike the classical economics, Keynesians claim that there is no complete flexibility in the adjustment of the prices and there is significant price sticking (particularly downwards). The private economy does not achieve equilibrium as a result of the market forces in the conditions of a given state policy, whereas market deficiencies lead to forced unemployment and excessive GDP fluctuations. According to Keynes' followers, the *Invisible Hand* of the market cannot convert egoistic, private interests into the social optimum. Although they believe that competitive markets can fully utilise means of production, they cannot determine the optimum values of employment and production this must be done by the government.

Stiglitz is among the more important contemporary critics of the concept of the Invisible Hand of the market. The main argument against the *Invisible Hand* is the existence of *public goods* [14]. Their characteristic feature is that they can satisfy the needs of many people at the same time, but the cost of their generation is greater than the individual benefits that a single individual can reap. For this reason, the *Invisible Hand* of the market will not lead to such a good being created, even though its existence is beneficial at the level of the whole society. Thus supplying it will require the action of a public institution. Examples of such goods are public national defense, an efficient court system, scientific research on a new type of drug, roads, schools etc.

Another argument against the autonomy of the market mechanism in meeting social needs is the existence of external effects or the information asymmetry in the market [20]. The tobacco industry is frequently given as an example here: although it produces goods desired by a part of the society, the actual social effects of its operation are very detrimental. In this case, the *Invisible Hand* of the market leads to a situation in which there is an overproduction of specific goods above the socially desirable level (called the production of anti-goods, which include cigarettes, illegal drugs, alcohol and gambling).

An important argument of interventionists is the imperfect competition in the economy, particularly the existence of monopolies. The *Invisible Hand* of the market ensures the socially desirable level of production of a given good only if strict assumptions of perfect competition are met, which almost never happens in real life [10].

Another issue is many peoples fear of the *Invisible Hand* of the Marked due to their ignorance of the essence of this phenomenon. If something is allegedly so powerful as to be responsible for all matters of the economy, then it is likely to cause fear, which can be easily used as a pretext by all sorts of *saviours*. The defence they propose against this threat is to limit personal freedoms. Thus the *Invisible Hand* of the market becomes useful not just to entrepreneurs or corporate officers, but also to government officials. By effectively manipulating people and their fear of the menacing *Invisible Hand* of the market, they can boost their power. They will then claim that the wage cuts or price hikes are not caused by human action reflected in the law of supply and demand [4], [20], but by some *Invisible Hand* of the market. So when the state fails to meet its obligations, this apparently has nothing to do with the errors made by politicians, but is the consequence of the operation of the evil *Invisible Hand* of the market, which in this case becomes its own caricature.

Mark Blaug also mentions in the Economic Theory [3] that the *Invisible Hand* of the market is not an uncritical rule. He claims that the theory of „solutions worse than the best" leads to one of the objections against the rule of the *Invisible Hand*: the inability to create a partial economics of prosperity solving its problems „piecemeal". He reaches the conclusion that the „public" nature of certain goods significantly reduces the accuracy of the *Invisible Hand* theorem in a way that A. Smith had never dreamt of.

In a milestone article published in 1956, Lipsey and Lancaster [9] proved that if the optimum conditions are not met on at least two markets, the Pareto prosperity theory [20] cannot justify a policy aimed at eliminating the imperfection on one of these two. The movement towards the optimum in the Pareto understanding is not enough: either we reach the best solution the first of the best or there are no grounds to choose between the following worse that the best solutions: of the second, third etc. grade. Lipseys and Lancasters proof, greatly simplified, is as follows: lets assume that we have a certain overall equilibrium system with constraints expressed by two equations and that we solve this system for the second

[7]In the free translation this means the *economic human* – this is a concept of the individual assuming that a human, as a rationally acting being, always strives to maximise the profits he/she earns and make choices due to the economic value of the results of those choices. In the colloquial sense, a „homo oeconomicus" is a person acting in accordance with this principle.

grade optimum using a normal technique of maximisation with the given constraints. Let us assume that one of these two constraints concerns a certain political parameter, e.g. a customs duty, and the problem consists in detecting whether reducing that duty would improve social prosperity. Proving that this must happen is impossible and this is what the general theory of the second grade optimum as the authors call it is all about [9].

Today, the *Invisible Hand* term is understood much more broadly. In the contemporary perspective, the *Invisible Hand* of the market is a meta-process whose results are achieved in a decentralized way without overt agreements between its participants [Joyce01]. In addition, this process is unintended and the goals pursued by individual market players are neither synchronized nor identical with the results of this process: the result is achieved by the way as it were. However, this process has a strong impact on the market in the regulation sense. Its participating agents may be unaware of it: this is why this process is called invisible. This process is visible if the market is analyzed from a higher level. It is assumed that this process occurs in a free market.

III. Controlling computations with the help of an abstract value.

In a digital processor, computations are driven by a hardware control layer, which fetches (from instruction cache) and decodes lines of program. In the ASIH model of computations, calculations/inferences are controlled and thus driven by an abstract parameter: ”*value*”, which labels all business objects being processed by an agent. It is assumed that the agent is able to label any given object with this subjective *value* on the basis of fixed business rules or on the basis of his private considerations. Thus, *value*[8] in our theory is not a price: *value* is abstraction of logical nature[9] used to label objects; whereas the price (measured with the help of money) is of an economic nature. Locally however, *value* of a given object can be projected onto specific exchange instruments, e.g. money. In our theory, *value* must be transitive. It means that agents performing business e.g. based on barter - must be able to directly compare two goods in terms of *value*, with the ability to analyze change and to evaluate/estimate this *value* for the last element in the exchange chain. In the example of ASIH given in this paper, *value* is expressed with the help of money on the basis of a simple decision table. Individual costs (of agents) are based on the length of a trip of an agent and local taxes (if any). When defining resale price, small individual overhead for mediation is added. Another approach[10] to problem of calculations, costs and *value* can be found in [6].

[8]The difference between value and price is also explained and dissected in the book: K. Marx: Das Kapital.

[9]Predicate calculus style inference rules are applicable.

[10]Eberbach: ...In fact, it can be considered as a new cost programming paradigm, where each statement of the language has its associated cost, and instructions with the smallest cost are those selected for execution (i.e., the execution is cost-driven in contrast to control-driven, data-driven, demand-driven and pattern-driven control)...

Observation of our simulation model (which is under development to obtain more cases of ASIH) demonstrates, that it is an astonishingly powerful and universal computational mechanism, which we can not fully comprehend at this very moment... Most computational algorithms (if not all, no proof as yet[11]) can be redefined by applying *value* abstraction, and can be found to still function properly. Labeling with *value* must be done in such a way that advancing computations provides benefit for the involved elements (agents, processors, etc.) with maximum benefit for those who finish computations. It must be done dynamically by agents.

The above discussed situation, including that in part VI, is relatively simple, because there are no relations between objects; beyond the fundamental, business question if $\exists$ somebody, somewhere, wanting to sell and if $\exists$ another agent somewhere wanting to buy.

Now suppose that agents are ”more intelligent” i.e. they can not only use integer calculus to calculate money, profit, trip costs, etc. but also they can analyze relations between business objects they trade. Let this ability will be on the propositional calculus level[12]. Example is given below.

Example

Suppose that the case of fire discovery is formally defined by set of facts and rules, using propositional calculus as given below. Let us also assume (for the moment) that fire is temporarily not necessary (e.g. for agents trading spices), and therefore all items in the set below are labeled by agents with *value=low*.

$$\left\{ \begin{array}{l} \langle tinder.\rangle^{value=low}, \quad \langle fire\_striker.\rangle^{value=low}, \\ \langle flint.\rangle^{value=low}, \quad \langle fuel.\rangle^{value=low}, \\ \langle tinder \wedge fire\_striker \wedge flint \xrightarrow{making-small-fire} \\ \qquad temporary\_fire.\rangle^{value=low}, \\ \langle temporary\_fire \wedge fuel \xrightarrow{making-permanent-fire} \\ \qquad permanent\_fire.\rangle^{value=low}, \\ \langle permanent\_fire \xrightarrow{heating} heat.\rangle^{value=low} \end{array} \right\}$$

Now suppose, that all of the above facts and rules are randomly spread (as business items: goods, skills or knowledge) among agents and treated in the same way as other business items are. Some items will exist in parallel in different locations, e.g. $\langle fuel.\rangle^{value=low}$. Agents will not trade above items (e.g. they will continue trading spices), because there is nobody expressing the will to buy even one item from the list.

Now, leta strong demand for heat emerge, expressed as below:

$$\langle ?heat.\rangle^{value=veryhigh}$$

Assuming that agents are be able to process value according to inference rules (a, b, c are business items):

$$\frac{a, a \Rightarrow b^{value=high} \quad \vdash}{a^{value=high}}$$

[11]Under research.

[12]We should not assume, that businessman are philosophers.

$$\frac{a \Rightarrow b, b \Rightarrow c^{value=high} \quad \vdash}{a^{value=high} \Rightarrow c^{value=high}},$$

the system of agents will discover fire in the background of doing usual business.

This is probably (currently under investigation) the gateway to proper analysis on how in certain situations, ASIH can act as a universal inventor in terms of new technologies, which can also overturn the present state of quasi-free market as a consequence.

We can therefore risk the following statement; that perhaps sometimes, the real inventor of scientific and technological progress is not always one, devoted researcher or scientist, but ”the anonymous world of business”.

IV. Structure of Virtual processor representing agent

The assumed business structure of a single agent and corresponding Virtual Machine (VMa) is given in Fig 3. and Fig. 4. As mentioned before, in the ASIH model of computations, a single VMa does not take a fixed position (in terms of interconnections) in abstract computer architecture, but moves in an abstract *computational space* reflecting a given quasi-free market. This implies a permanent and unpredictable change of ties. Movements are random or are driven by a business plan which is the result of business conclusion.

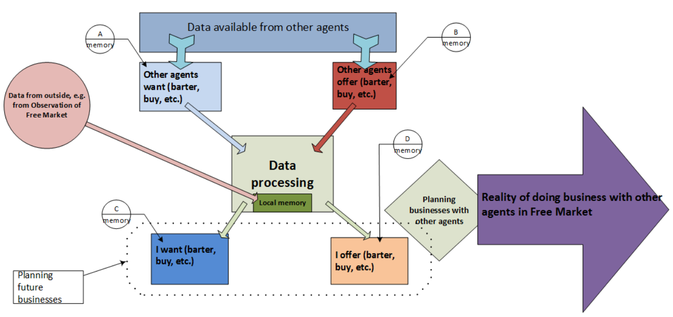

Fig. 3. **Model of business agent.**

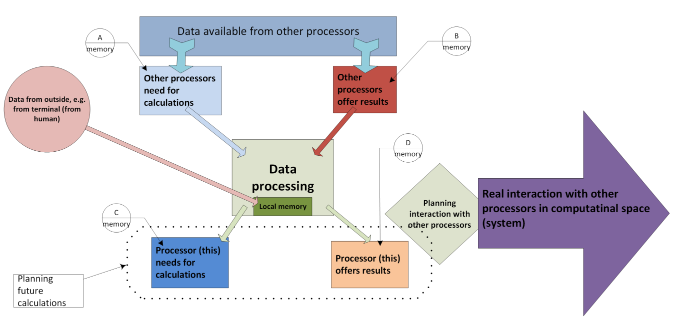

Fig. 4. **Virtual machine representing single business agent.**

V. Mental and computational abilities implemented on the VMa of an agent.

Our research strategy is based on the modification of business, mental and computational abilities of agents (implemented on VMa); until ”great discoveries” happen in the modeled environment. All agents are the same in terms of abilities. The only difference is that a class of agents called ”townsmen” do not travel (they represent settled agents in, for example, cities). Similarly, for Europeans, Arabs, Indians there exist specific areas where each do not or cannot travel. Agents incomplete knowledge of the surrounding geographic world is therefore assumed. As an example, we can give Europeans (poor) awareness that Spice Islands (Moluccas) where located somewhere in the East.

It was necessary to equip agents with only elementary abilities such as the ability to trade, infer about present business situation, build business plans and finally to implement them. This includes the ability to travel in an optimal fashion. Thus, agents behave according to the following specifications:

1) When two agents A and B rendezvous, they mutually exchange information: what they want to sell, buy, what others according to agents' knowledge want to buy, sell (where, amount, price);
2) When agent A finds, that agent B wants to sell a certain item, which he wants to buy, allowing agent A to infer a reasonable profit; a transaction will be carried out;
3) When agent A finds that there is an item on his *OthersWantsToBuy* list, which agent B wants to sell, and that the profit minus travel costs (to deliver item to the future client) is sufficient, a transaction will be carried out. Next, a business plan is generated to deliver the item and to make a profit;
4) When agent A does not have a business plan, the agent moves/travels randomly along sea-routes of the known world. For all agents (except Columbus and Vasco da Gama) a traveling range of the agent‘s ship is imposed, which will limit the search tree. Columbus and Vasco da Gama (at the beginning) do not participate in trade because their costs (a flotilla of 3-4 ships) which exceed the expected profit threshold. Restrictions are also imposed. For example: the Europeans (and Indians) cannot travel through the Levant Barrier (Middle East) and Arabs fear sailing the Mediterranean Sea. However the Arabs sail and trade on their dhows as far as the Moluccas.

Thus, to perform the above mentioned activity, mental abilities of agents must include integer calculus for evaluating costs, profits and an inference engine to generate a business plan. The implementation of ability 3 requires in addition, another algorithm to find the shortest path between two geographical points[13].

We decided to base the traveling behavior of agents on the A* algorithm, for several important reasons. Firstly, this algorithm uses ”a set of nodes already evaluated”, ”a set of tentative nodes to be evaluated” and ”a map of navigated nodes” in such way, that they can be used in parallel like a blackboard by many agents. An interpretation can be assigned to all these sets e.g. ”a map of navigated nodes” can be

[13] T. Szuba has yacht sailing experience in the Mediterranean, thus we are aware, what were real conditions to travel that time.

interpreted as portolan charts[14]. A definition of the algorithm is based on the minimization of function $f(x) = g(x, y)+h(y)$ where g function is a past path-cost function and h function is a future path-cost function, which is an admissible "heuristic estimate" of the distance from x to the goal. This easily allows us to include Arab taxes as well as hypotheses about an alternative path to India bypassing the Levant. It can be done in such a way, that the A* node generator can produce starting nodes (Lisbon and Palos), and abstract neighbor nodes (West-Indies and Indies) with extreme high cost associated $h(y)$; equivalent to cost of 3 or 4 ships equipped for 3 months of non-stop oceanic sailing. Such nodes will be not taken into account by the algorithm as long as the costs of importing spices through the Levant remain reasonable. This was a key-point in building favorable conditions for ASIH, because the A* algorithm also unveiled its pathfinding abilities. Animations[15] demonstrating how the A* performs its pathfinding, can be found at http://en.wikipedia.org/wiki/A*_algorithm

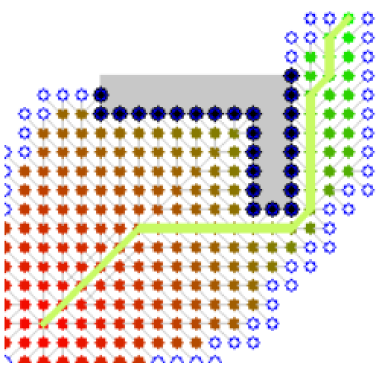

Fig. 5. **A* agorithm in action. Cost of edges are same as their Euclidean lengths. The gray shape represents an obstacle. The filled circles in red and green represent expanded nodes (nodes in closed set). The color indicate the g-score (red: lower g-score, green: higher g-score). The empty nodes with blue boundary are the ones in open set. The nodes of the graph are generated on the fly, and nodes falling inside the obstacle are discarded as inaccessible.**

VI. The structure of the simulation model

During our research process, it has been found that a simulation model is key to both understanding what ASIH really is, and building its theory. On one hand, a very precise historical description of 15^{th} century the spice trade crisis prevented us from making some non-realistic assumptions, but on the other hand, it allowed the removal of all unnecessary elements from the process. This way we managed to build an abstract model of a single agent and a model of business cooperation so simple, that the agent has become almost automatic in operation, while ASIH was still functioning. This resembles the research approach which has led to the construction of the ant colony algorithms (ACO)[16], which explain Collective Intelligence of a colony of ants, using an automate model of a single live ant and a pheromone-based model of communication.

At the lowest level of our model, the QGIS system is used to allow editing of all necessary geographical data, basic for the 15^{th} century spice trade. Important cities (trade centers, with their geometric properties and relation), important sea-routes and a map of the then-known (15^{th} century) world have been defined, with the help of QGIS. QGIS[17] is powerful, user friendly Open Source Geographic Information System (GIS).

A basic structure and behavior of agents has been programmed in the Mason system. Mason[18] is a fast discrete-event multiagent simulation library core in Java, designed for large custom-purpose Java simulations. It is a joint effort by George Mason Universitys Evolutionary Computation Laboratory and the GMU Center for Social Complexity.

Since agents interact and move in a geographical environment, it was necessary to use GeoMason[19] also. This is a geospatial support for MASON, also designed at George Mason University.

As mentioned in the introduction, business items are labeled with logic expressions (predicate calculus) and abstract *value*. This SWI-Prolog[20] (University of Amsterdam) was used to equip agents with an inference engine. For this, JPL[21] (Java-Prolog interface) was necessary.

The size of the model is more than 4500 lines of code as counted in the Eclipse environment.

Constructing a set of procedures for a single agent in our model, while keeping consistency in-between databases: *WantsToSell*, *WantsToBuy*, *OtherWantsToSell*, *OtherWantsToBuy* appeared astonishingly difficult and complex in our model. Every single rendezvous and contact between two agents, resulting with information exchange and a real transaction, forced reshuffling of all these databases. Moreover, the flow of time forced keeping only up-to-date records in *OtherWantsToSell*, *OtherWantsToBuy* databases.

VII. ASIH as a computer: nature and flow of computations

On the basis of our simulations, natural properties and behavior of computational process, which are at the basis of ASIH, will be explained. A common digital computer and computational processes will be used as reference.

- In order to calculate something, a digital computer must a priori be programmed (initialized) by a human programmer. After such an initialization, computations must be started by execution of the first line of the program. In contrast, ASIH is self-programming computer, i.e. quasi-free market activity provides continuous influx of data

[14]http://en.wikipedia.org/wiki/Portolan_chart

[15]A* Progress Animation by Subhrajit Bhattacharya, used under CC BY 3.0 license.

[16]http://en.wikipedia.org/wiki/Ant_colony_optimization_algorithms

[17]http://www.qgis.org/pl/site/

[18]http://cs.gmu.edu/~eclab/projects/mason/

[19]http://cs.gmu.edu/~eclab/projects/mason/extensions/geomason/

[20]http://www.swi-prolog.org/

[21]http://www.swi-prolog.org/packages/jpl/prolog_api/overview.html

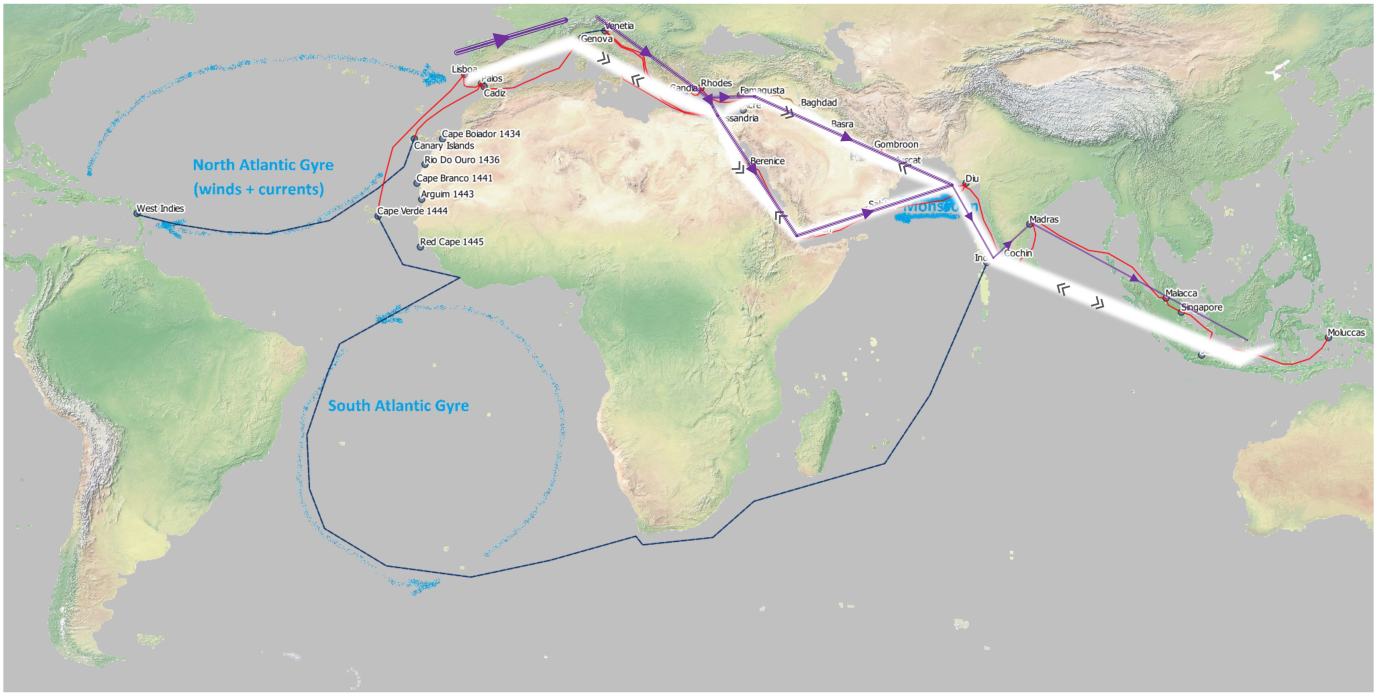

Fig. 6. Basic elements of computational behavior of ASIH.

for computations. In our formal model of ASIH, data items are represented with the help of predicate calculus expressions. It is not even necessary to use the term ”start of computations” because ASIH processes available data continuously, and computations will conclude when all components are available.

- In a digital computer, a given real-life problem can be solved, if a program is written to solve this problem in and automatic fashion. The situation with the ASIH Computer is somewhat similar; a given real-life problem can be solved if it can be translated into a business problem. As mentioned before, the ASIH Computer is self-programming, thus as soon as problems are translated into a business form, they will emerge naturally for the ASIH computer to be solved.
- The ASIH Computer is vast (spanning over a quasi-free market) and requires some time to conclude computations - in some cases, even several years.
- In a digital computer, data processing modules e.g. RAM memory or FPU, take fixed positions in computer architecture. Only data is transferred between them for processing. In case of the ASIH Computer, data is still transferred for processing, but agents as data processing modules move around a quasi-free market scene. Moreover, they move in an intelligent way to such locations where they can do business, which affects data processing. For example, they will cycle between two business points, providing significant speed-up of computations. Cities such as Venetia, Genoa, Alexandria will start to be important nodes of data processing.
- When used to watch and/or control and industrial process, a digital computer must be equipped with some hardware interface e.g. sensors, servos, etc. In contrast, the ASIH Computer does not require such hardware, because brains of agents are actual components of the computer. Agents respond directly to conclusions which emerge in their brains. Moreover, conclusions can emerge in many brains of many agents almost simultaneously, at different locations. This can resemble the bahevior of super cooled water rapidly changing its state. For example; agents can quickly conclude, that an expedition to the Spice Islands to bring back prescious spices, will result in higher profits when selling them later on in say, Lisbon.
- In case of the ASIH Computer, several basic flows, which constitute computations can be identified (see Fig. 6). First (white) is a bidirectional flow of information: what/where/price/amount, and who has/wants. It is a flow of pure information. The second flow (purple) is a flow of goods (in our example: spices). In general, if agents start to trade e.g. know-how (like in example on discovering fire) it will also be a flow of information. The third flow (not shown because is exactly like flow of goods (in this case), but in the opposite direction) is the flow of money. However, if trade will have a form of barter or cash-free turnover; it will not exist, or will also take the form of a flow of information. These flows are interrelated through the inference process: the flow of business information (from agent to agent) regarding high prices of spices in Lisbon, and a flow of business information about low prices of spices in the Far East, will cause a flow of

spices westwards, because the Arab traders will buy all spices from Indian producers for resale to the Europeans. After some time, the first supply of expensive spices will arrive in Lisbon via Genoese and Venetian traders. All information accumulating in the brains of Portuguese and Spanish, will ultimately result in a conclusion that it will be a good idea for business to sail around (bypass) Arab world, to get directly to Spice Islands (Moluccas) to buy cheaper spices directly from producers.

- All digital computers have the same architecture based on von Neuman architecture, the same semiconductor physics and the same 0/1 calculus used for computations as a constant common denominator. Similarly, for different manifestations of the ASIH Computer, the human, trade and profit is also a constant common denominator. The rest is different: communication abilities in terms of mutual data transfer, physical travel and goods transfer abilities, personal calculation abilities of agents, etc.
  Thus, as we can see, the presented model of ASIH is tuned for the 15^{th} century spice trade.

VIII. Reconstruction of the Invisible Hand‘s response to the crisis in spice trade at the end of the 15^{th} century

Before we are able to offer a reasonable new tool to analyze and predict the complex behavior of todays free markets based on our theory; we must concentrate on the reconstruction of historical events, which can be considered as the landslide/shake, from a market point of view, and can be considered as a symptom of the activity of Adam Smith‘s Invisible Hand (ASIH).

This way, we can also develop and validate our theory in a practical way; building convincing examples one by one.

Such historic events are perfect from research point of view, because they are sufficiently documented, their analysis is finished and completed, therefore the possibility of questioning or different interpreting of conclusions is restricted.

When simulations are started, at the beginning, the situation is as follows:

1) Townsman in Lisbon offers a high price for: pepper, cinnamon, nutmeg, cloves. Indians from Madras offer pepper, cinnamon for sale very cheaply. Molluscan in Moluccas also offer nutmeg, cloves for sale very cheaply. Portuguese, Venetians, Genoese, Arabs, Indians are sailors and traders. At the beginning of simulations, they move about randomly (doing e.g. local business) inside areas they are allowed to (or can) sail. However, they also come into contact with agents residing in the cities (trade intermediary), as well as other sailors arriving to the given city‘s harbor. This way, knowledge is spread of business items offered elsewhere for sale and business items somebody (somewhere) wants to buy. Thus, the knowledge about demand and supply is spreading slowly between the East and West.
2) In Lisbon, Vasco da Gama with his fleet of 4 ships and an idea (+ navigation plan) that it is possible to sail around Africa the Indies, is waiting for the right moment/circumstance. The same is with Palos where Christopher Columbus with his fleet of 3 ships is waiting; with an idea (+ navigation plan) on how to sail to Japan, sailing Westwards. The costs of executing both expeditions are so high, that the A* algorithm will take into account routes to the West Indies and Indies, as the absolute last resort, *iff* all other possibilities in searching graph are be exhausted.
   Vasco da Gama and Christopher Columbus are considered in our model of ASIH as positive examples of breakthrough ”government intervention” on a quasi-free market. A regular business willing to maximize profits and minimize risk, will hesitate to endow a small fleet of 4-5 ships and to send it on a high-risk, nonprofit voyage. However, in both cases, the monarchy should be considered as a selfish super-agent looking for own profit, and not as a government investing money for public good. The task to find maritime route to India was offered to Vasco da Gama by King Manuel I of Portugal in 1497. He was aware that the uncharted coast of Africa stretched away to the northeast after Bartolomeo Dias returned in 1488 from rounding the Cape of Good Hope, having explored as far as the Fish River (Rio do Infante) in modern-day South Africa. Columbus speculative proposal, to reach the East Indies by sailing westward, has received the support of the Spanish crown, which saw in it a chance to gain the upper hand over rival powers in the contest for the lucrative spice trade with Asia.
3) As a consequence, after a certain amount of simulation time, the Arabs (able to sail to the Far East) start to buy pepper, cinnamon, nutmeg, cloves from Indians and Molluscan for resale to Europeans in Alexandria and Acre. The real availability of spices start to shift Westwards, until first supplies of spices reach Lisbon.
4) After a certain amount of simulation time, the global flow of spices will stabilize, i.e. the A* algorithm in connection with simple business plan generator, will replace random displacements of agents, into regular, geographically optimal business trips of agents, buying spices and returning to resale them e.g. in case of Europeans: Lisbon $\longrightarrow$ Alexandria and back.
5) Now, very high taxes are imposed on spices in all cities where Arabs supply spices, i.e. in Alexandria and Acre. This will increase the costs of spices for Europeans to the level of negative profits (loss), thus the spice trade will (almost) cease.
6) In response, after a certain amount of simulation time, townsmen in Lisbon will start to raise their price offer for spices. However, from previous periods they will know, that Indians and Molluscan offer cheap spices, but the location of India and Moluccas Islands (Spice Islands) is not known to them (Arabs took care of this ...). Only the general direction (go East) is known.
7) Europeans will start again to behave in a chaotic way. At

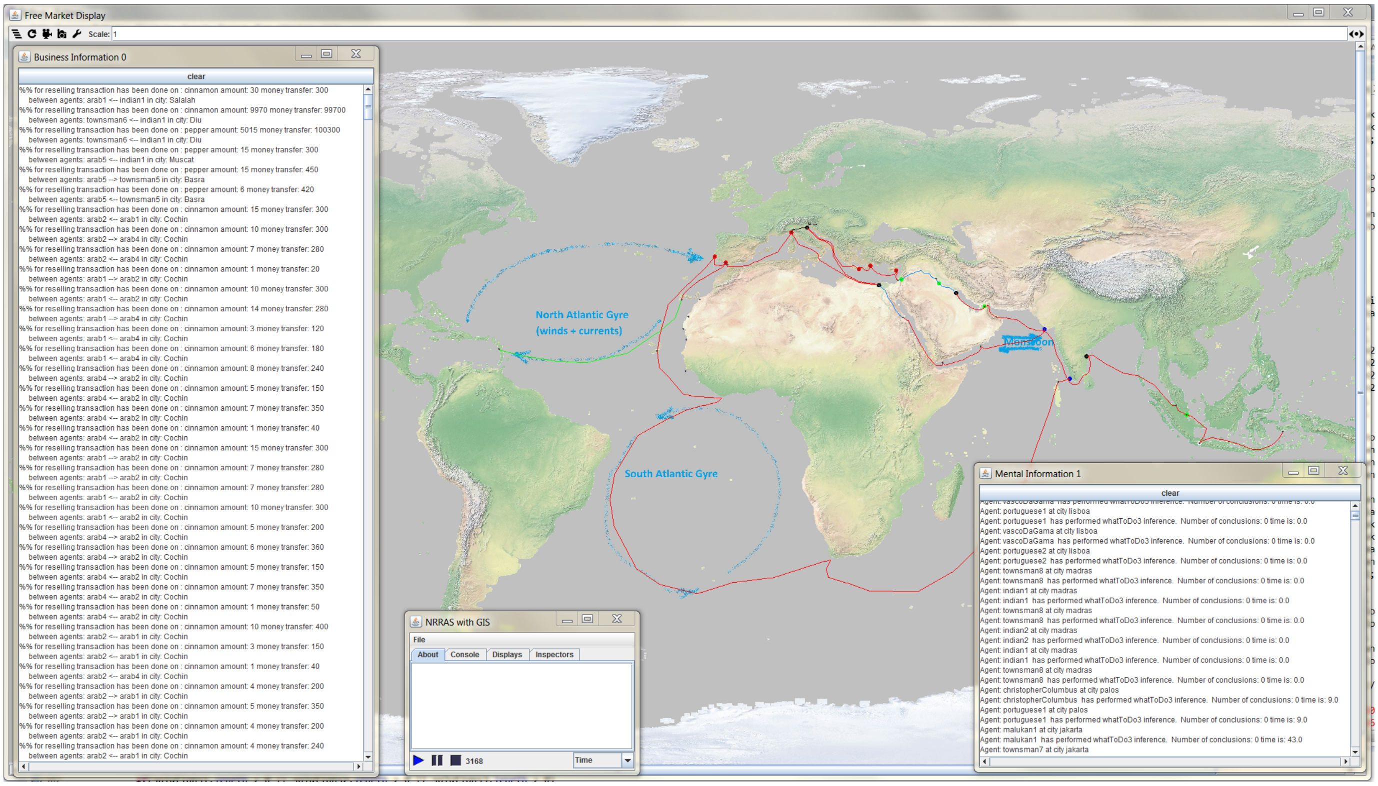

Fig. 7. Environment for simulations of ASIH response to Turkish and Arab blockade of spice trade at the end of the 15^{th} century.

a certain moment, prices offered by townsmen in Lisbon will be so high, that they will cross the threshold cost of expedition to find a sea-route to India. At this moment, the A* algorithm will also take into consideration "expensive nodes". This will result with Columbus and Vasco da Gamas expeditions. **It will also be the success of our simulations.**

Thus, equipping 15^{th} century agents with:

1) Basic ability to buy/sell/resell;
2) Ability to calculate costs and profits;
3) Ability to optimize costs of trips from A to B on basis of A* algorithm;

was sufficient to create the basis for ASIH, as a response to excessive taxation of spice trade by Arabs ⇒ resulting with discovery of America and sea-route around Africa. Further consequences for spice trade, like creation of spice plantation in India, Ceylon, Indonesia, and islands in the Caribbean, can be noted.

IX. Conclusion

Our theory presents ASIH as a parallel, distributed, non-deterministic inference process over agents participating in a quasi-free market. Since the inference process takes place in brains of agents, conclusions stay there and affect the behavior of the market, usually in a soft, optimization kind of way; however in many cases in a landslide/shake way.

In the considered case of ASIH, these aspects can be depicted as an interruption of the flow of goods from Europe to the Far East through the Levant, and a rapid emergence of a large flow of goods around Africa (by the Portuguese) and to America (by the Spanish) as well as the Philippines.

Such inference process can emerge (will be started) if the market situation is favorable, i.e. necessary logic expressions (describing market situation) are present in distributed way, in the brains of agents, and (brains of) agents are able to perform required computations. A state of gradual emergence of sets of building blocks in the brains of agents, for their further global inference, is analogous to the programming of a digital computer, before computations begin. The output in case of ASIH is also different - it is the state of market; not printout or print-screen, etc.

As introduced in the abstract of this paper, we are showing that ASIH is not only an economic idea, but something that exists, for which a formal theory can be built. Computational processes creating ASIH can be measured and probably utilized for quasi-free market analysis and prediction in the future. Measuring can be done in such a way, that a simulation model will be created for a given quasi-free market. Our simulation model's complexity is comparable to weather forecast models, due to the number of agents. It may require variations on personal behavior. Such a model will be investigated with regard to how some global, social and economic parameters influence the behavior and economic output of quasi-free markets. There is a wrongly belief that that ASIH always take optimal and correct decisions over quasi-free market. Since ASIH is inference process of Collective Intelligence style, it can be always provided set of data which will lead ASIH to wrong decisions. We plan to play with simulation model, to find what was necessary to stabilize spices trade without discovering America and sea routes to India around the Africa. Interesting is also question on how far single agent (genius investor or ruler) provided with partial information about free-market is able to compete with ASIH solutions.

Powerful response of ASIH to the Turkish and Arab blockade of spice trade, had the nature of ”discovery” (America, sea-route to India around Africa, big galleons, etc.). Thus, our research plan for the coming future, is to work on the emergence of money in the Phoenician era. As demonstrated before, the concept of *value* labeling business items is one of the basic components of the ASIH theory. However, an abstract *value* assigned arbitrarily by agents to items (convenient form individual inference point of view) is not convenient in more complex business contacts.

Our hypothesis is, that at the end of a barter era, ASIH has discovered money and integer calculus as a tool to deal with the problem of *value*. We will simulate barter trade and analyze what must be present (in terms of the structure and abilities) in VMa representing agents, to arrive at the situation where money and integer calculus emerge.

The second research direction, is to analyze what will be the nature of ASIH in a business environment, where agents can also perform logic analysis of relations between business objects they trade (see part II). It will be important to identify a historical event which can be assigned to ASIH (in terms of cause) allowing us to perform an in-depth analysis.

The third research direction for our research team, is to use our methodology for a formal description of a ”university” phenomenon. Nothing better was found in terms of joined education and research institutions since the medieval times when universities as we know them now had emerged. Perhaps we will be able to propose some formal tool to analyze the efficiency of a university from scientific progress point of view.

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Innovation, Demand, and Finance in an Agent Based-Stock Flow Consistent model

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I. Extended Abstract

We present an **a**gent **b**ased **s**tock **f**low **c**onsistent macroeconomic model with heterogeneous agents interacting through a decentralized matching process across multiple markets with multiple assets. The model is consistent across both the micro and macroeconomic levels, by providing a detailed, comprehensive, and rigorous accounting of real and financial flows and stocks. We implement the model using a brand new Java programming platform, explicitly designed for AB-SFC models.

Our **j**ava **m**acro **a**gent **b**ased platform JMAB exploits the opportunity of object oriented programming in order to ensure the accounting consistency of any model from the very bottom layer, that is by tracking through generic procedures all the variations in the balance sheets of agents generated by different types of transaction or transfer. Decisions undertaken by individual agents result in variations of their balance sheets which also affect the balance sheets of other agents both directly and indirectly, adding a new layer of complexity to be explored, and we can track these interactions.

We analyze the endogenous emergence of growth, business fluctuations, and financial instability. The model we build explicitly takes into account innovation dynamics, and using JMAB we can analyze the impact of innovation on the structure of production processes, the evolution of industrial market structures, and employment dynamics.

The economy at hand is composed of:

- Households selling their labor to firms, consuming and saving, with their savings being allocated between cash and deposits.
- Firms, divided into consumption and capital firms. Consumption firms produce a homogenous consumption good using labor and capital goods produced by capital firms. Capital firms produce different 'vintages' of capital out of labor only and invest in R&D, hiring people to perform this research activity. When innovations are successful, capital firms can produce more productive vintages of capital, starting from the following period. Each capital vintage is characterized by a specific level of productivity.
- A Government sector which hires public workers (as a constant share of the workforce), collects taxes and issues bonds to cover any deficit between current expenditure (wages, interests on bonds and repayment of bonds reaching maturity) and revenue from taxation. Government bonds are purchased by banks.
- Banks, collecting deposits from households, granting loans to firms and buying bonds issued by the Government. Basel III constraints apply so that, at the end of the period, banks may ask for cash advances to the Central Bank in order to restore the mandatory capital adequacy ratio.
- A Central Bank, which issues legal currency, holds banks' reserve accounts and accommodates banks' demand for cash advances at a fixed discount rate. [1]

These groups of agents, or sectors, are characterized by bounded rationality and follow (relatively) simple heuristics in an incomplete and asymmetric information context.

During each period of the simulation agents interact on five markets through a common decentralized matching mechanism, following [10]:

- A consumption goods market: households interact with consumption firms;
- A capital goods market: consumption interacts with capital firms;
- A labor market: households interact with government and (both types of) firms;
- A credit market: firms interact with banks;
- A deposit market: households interact and firms with banks,

In each of the markets we implement the following matching protocol, where two classes of agents interact in demand/supply space. One side observes a list of potential

[1] The primary objective of the model is not to analyze the dynamics and stability of public finance, so in the Baseline Scenario we assume that the Central Bank is not allowed to buy government bonds (i.e. a "UE scenario"). Nevertheless, we try to keep the structure of the model open to the implementation of a different scenario in which the Central Bank is part of a consolidated government sector, along with the treasury (i.e. a "USA scenario").

counterparts and chooses the most suitable partner according to some market-specific criterion.

At the beginning of each period the list of agents on the demand side–households in the consumption market, consumption firms in the capital good market, capital and consumption firms in the labor market, capital and consumption firms in the credit market, households and firms in the deposits market–is randomly shuffled.

Then the first agent in the list observes a random subset of potential partners whose size depends on a parameter χ which proxies the degree of imperfect information, and chooses the 'best' one: the cheapest counterpart for the consumption interaction, labor and credit markets, the capital vintage with the best trade-off between productivity and price on the capital market, and the bank paying the higher interest rate for the deposit market. After that, the second agent on the list performs the same activity on a new random subset of the updated potential partner list, and so on until we reach the end of the demand side list. The agents on the demand side are 'deactivated' when they have fulfilled their demand or if they have not enough liquid resources to buy further. Agents on the supply side are deactivated as soon as they have placed all their orders.

Given this iterative process it might be the case that agents on the demand side end up being supply constrained if the chosen partner does not have enough output to satisfy their demand, or agents on the supply side may not be able to place all their supply orders on the market. In the case of the consumption market, we allow interactions to take place several times during the same period, thus giving the opportunity to agents on the demand side to find new partners in order to fulfil their demand.

As mentioned above the model implements for the very first time in the field of innovation economics stock flow consistency [8] at both the micro- and macro-economic levels, by providing a detailed, comprehensive, and rigorous accounting of real and financial flows and stocks. The aim of the SFC framework is to provide a comprehensive representation of both the real and financial sides through the adoption of rigorous accounting rules based on the quadruple entry principle developed by Morris Copeland [4]. The adoption of an SFC approach will help agent based models to establish themselves as an alternative theoretical paradigm in economic thinking and as a powerful tool for policymakers. A growing number of scholars within the agent based modeling and post-Keynesian schools of thought have argued in favor of AB-SFC models (see [9], [1], [11], [10], [2], [3], see also the EU-funded Eurace Project[5]). The existing literature still provides only a few examples of truly AB-SFC models, characterized by a high degree of heterogeneity concerning both the economic issues addressed and the solutions adopted. This limits their generality, while making it difficult to compare them and to assess their effective consistency. Efforts to embed stock flow consistency in the bottom-up grounded framework of AB models have also proceeded along a number of parallel paths pursuing specific solutions to common problems, rather than establishing a common set of concepts, rules and tools as we have. One of the objectives of the present work is thus to foster a methodological advance by implementing a brand new Java programming platform, explicitly designed for AB-SFC models. JMAB exploits the opportunity of object oriented programming in order to ensure the accounting consistency of an AB model from the very bottom layer, that is by tracking through generic procedures all the variations in the balance sheets of agents generated by different types of transaction or transfer.

By combining the AB and SFC approaches, we are adding a fundamentally new layer of complexity. In addition to agents' interactions in shaping individual and aggregate behaviors, we can now model the fact that, in a monetary economy, agents are closely interrelated through a network of interacting balance sheets. Decisions undertaken by individual agents result in variations to their balance sheet, which also affects the balance sheets of other agents, both directly and indirectly. Tracking these relationships is absolutely crucial in order to understand the functioning of our highly financialized economies, and we do this here for the first time in a tractable and scalable manner[2].

We sketch out the basic structure of our model by verbally describing each agents' behavioral equations. In each period of the simulation, the following sequence of events takes place:

1) *Production planning*: both consumption and capital firms set their desired level of production based on their individual sales expectations in order to attain a target level of inventories, expressed as a share of sales, that they hold as buffer stock in order to face unexpected demand swings (and avoid frustrating customers with undue supply constraints).
2) *Pricing*: consumption and capital firms set the price of their output based on a simple adaptive rule. The price is revised downward by a stochastic amount whenever the level of inventories at the end of the previous period is above the target set by the firms, and vice-versa. Capital firms then send a 'brochure' to a random subset of consumption firms advertising both the price and the productivity of the capital vintage produced in order to spur production and consumption.
3) *Demand for workers*: based on their desired output, firms evaluate the number of workers needed for productive activities. For capital firms this amount depends on labor productivity, while for consumption firms it depends on the productivities of the respective capital vintages employed in the production process at any moment.
4) *R&D investment*: capital firms define the desired investment in R&D for the current period. Since we assume that R&D is performed by hiring people to perform research activities, desired R&D investment can be thought of as a desired nominal demand for R&D

[2]We view this feature, as already explained in [2] is crucial in order to analyze the inter-linkages between the real and financial sides of an economic system.

workers, which sums up to capital firms' demand for workers to be employed in production.

5) *Investment in capital accumulation*: the desired rate of capacity growth of consumption firms is defined as a positive function of their past profitability, and a negative function of the current debt burden, which is being expressed as the ratio between the overall flow of interest payments on past loans divided by profits. Consumption firms chose the capital vintage to invest in by comparing the price and productivities advertised in the 'brochures' (randomly) received from capital firms. Here we follow a logic similar to that presented in [6]. Consumption firms may also decide to invest in order to replace some of the old vintages in their stock, even though they might still be working, if the advantage brought about by the new vintage in terms of lower expected unit costs of production is higher than the cost of purchasing the new vintage (that is, we have a 'payback period rule');
6) *Credit demand*: in accordance with the dynamic trade-off theory of firms' capital structure (see [7]) firms' credit demand at time t depends on their net worth and their leverage target. In each period, this leverage target is adaptively revised according to each firm's debt burden and past sales.
7) *Credit supply*: banks set their total loan supply based on their expected variation in reserves in order to attain, by the end of the period, the mandatory capital adequacy ratio (CAR, hereafter) without having to refinance through the central bank's liquidity auctions. The interest rate on loans depends on a bank-specific component and a borrower-specific component: the bank-specific component is revised adaptively according to the gap between past period desired and realized credit supply. When positive, the interest rate is lowered to make banks' loans more attractive for borrowers, and vice-versa when the gap is negative. The borrower-specific component proxies firms' perceived reliability, and it is determined as an increasing function of the borrower's leverage. Banks and firms then interact in the credit market through the matching mechanism specified above.
8) *Wages and labor market interactions*: Workers adapt their asked, or market, wages according to whether they were employed or not during the previous periods following [9]: if over the year (assumed to be four periods) they have been unemployed for more than two quarters, they lower the asked wage by a stochastic amount. In the opposite case they increase their asked-for or market wage, provided that the aggregate rate of unemployment is sufficiently low. The government hires a constant number of (randomly chosen) workers. Workers still unemployed then interact with firms in the labor market trough the matching mechanism specified above.
9) *Production*: capital and consumption firms produce their output, the actual amount being potentially different from the desired one if labor (and capital, in the case of consumption firms) constraints apply.
10) *R&D activity*: capital firms perform R&D. The probability of success in each period is defined as a positive function of invested resources. In the case of a successful innovation, a new level of productivity is drawn and the innovation (i.e. the higher level of productivity) is embedded in capital goods produced from the following period onward.
11) *Consumption*: households consume out of income and wealth with fixed propensities. They interact with consumption firms through the matching mechanism specified above.
12) *Capital goods market*: The actual transaction takes place once the matching mechanism between agents on the demand and supply sides is finished, and with consumption firms having already decided the type of capital they want to buy. If after this matching process the consumption firms remain financially constrained, or if supply constraints apply, they might end up with less capital than desired, forcing an automatic need for bank financing of their activities.
13) *Loans repayment and interests*: firms pay interest on loans, and repay a (constant) share of the principal.
14) *Taxes*: taxes on profits (of firms and banks), income (of households), and wealth are paid to the government.
15) *Government bonds interests and repayment*: the government pays interest on bonds held by banks and repays bonds at maturity.
16) *Deposits market interaction*: banks set the interest rate on deposits following an adaptive rule, which mirrors the rule used to determine the bank-specific component of loans and interest rates. When the gap between desired and realized credit supply in period $t-1$ is positive, banks will tend to lower the interest rate on deposits by a stochastic amount in order to maintain their profit margin, which depends on the spread between interest charged on loans and interest paid on deposit. Otherwise, they will increase the interest rate in order to attract more deposits. Banks then interact with households and with firms through the matching mechanism explained above. We assume households maintain a constant share of their wealth in cash, with the remainder being held in the form of deposits. We assume firms deposit all their cash revenues into their deposit accounts, reflecting the reality that firms holding of cash is negligible compared to their stock of deposits.
17) *Bonds purchases*: the government issues new bonds to cover any deficit between expenditure (for wages, interest payments on the stock of debt and repayment of bonds which have reached maturity) and revenues (taxes). In the simplest scenario, we assume that the interest rate on bonds is fixed and banks buy all newly issued bonds, in proportionally to their relative size. Banks pay bonds by making a transfer from their reserve account at the Central Bank to the government's account, asking for cash advances from the central banks if

needed. We assume the repo rate fixed and equal to the interest rate on bonds.

18) *Cash Advances*: banks ask the Central Bank for cash advances when they need to fulfil mandatory CAR constraints.

Firms may default during the simulation when their net wealth turns negative after having paid interests or principal repayments on loans, or taxes. The default by a firm implies a loss for banks whose loans have not been completely repaid yet. This loss in turn may result in the bankruptcy of some banks in exceptional cases. This situation must be carefully managed to ensure the Stock Flow Consistency of the model. We assume that a bank in default is taken over by the wealthiest bank in business at time t, which inherits all its assets and liabilities. In order not to induce a loss for the acquiring bank (which would make the operation unreasonable), deposits held at the defaulted firm are lowered in the measure required to restore the parity. In the simplest case this acts as a bail-in type of buffer stock. The shock is absorbed by depositors (households and firms), the loss being distributed across deposits proportionally to their original amount.

The investment by capital firms in R&D triggers a process of ‘Schumpeterian competition’ between both capital and consumption firms. The capital firms compete by producing capital goods which entail different levels of productivity, while the consumption firms compete in an homogeneous good market trying to lower their production costs through capital investment in newly created vintages. The role played by ‘selection mechanisms’ operating in both markets leads to the default of some firms. Capital firms may default as a consequence of bad innovative performances, which make their output less attractive for consumption firms. On the other hand, consumption firms may default if, through the matching mechanism, they come to invest in less profitable vintages. In both cases strong cumulative effects are at work: capital firms which are fast enough in obtaining innovations may gain an advantage over their competitors resulting in them being more profitable, investing more in R&D, and thus enhancing their probability of achieving further innovations. Similarly, consumption firms that invest in the most profitable capital vintages (for given prices and productivities) may grow faster and invest more in the future periods, further increasing their productive capacity and improving their production process. In turn, these defaults imply a non-performing loan for banks who granted credit to defaulted firms, that is a loss on banks’ balance sheets. This may affect banks’ credit supply and, in some extreme case, it may even result in a bank’s bankruptcy. Shocks related to the endogenous default of firms may thus propagate in the economy through contagion effects across agents’ balance sheets, possibly generating a cascade of failures which affects employment and demand dynamics. Furthermore, by affecting labor productivity in the consumption sector, technological innovation may exert an impact on labor demand by consumption firms even in the absence of traumatic events, thus possibly affecting also demand patterns. In turn, a weak demand can induce a drop in firms’ sells, depressing R&D investment and slowing down innovation dynamics.

In conclusion, this paper analyses the endogenous emergence of growth, business fluctuations, and financial instability in an agent based stock flow consistent framework which explicitly takes into account innovation dynamics, analyzing their impact on the structure of production processes, the evolution of industrial market structures, and employment dynamics. The adoption of an AB-SFC approach helps us study the effects of technological change on both the real and financial economy by tracking the flows of funds resulting from the rise of innovations in the system in a novel and comprehensive framework. The model aims to build a bridge between the Keynesian and Schumpeterian schools of thoughts by studying the inter-dependence between supply and demand factors in shaping business fluctuations. s

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An empirical economic model to reveal behaviour characteristics driving the evolution of agriculture in Belgium

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***Abstract*—Effective design of agricultural policies requires an understanding of the drivers behind the evolution of the agricultural sector. This project builds an evolutionary economic model of the Belgian agricultural sector, as a testing ground for new policies. This agent-based model simulates the dairy, cow and pig sector. The model is calibrated to historical data of production and farm diversity during the period 2003 – 2013.**

Profit maximising agents cannot replicate the historical trends. When assuming heterogeneous behaviours, the actual evolution can be reproduced much more closely. The calibration reveals key behaviour variables. The evolution in the agricultural sector can only be explained when accounting for a resistance to change at farm level or at market level. However, this approach cannot determine the exact location of this resistance. The resistance to change can result from personal convictions of the farmer or from market rigidities and learning effects.

I. Introduction

Multiple agricultural policies and instruments are created to direct farmers towards more innovation, higher sustainability and efficiency. This requires in practice a far-reaching transition in the sector. Currently, the European Common Agriculture Policy (CAP) focuses on three objectives. First, enhanced competitiveness of agricultural markets is promoted by reducing production constraints and encouraging modernisation. Secondly, the CAP pursues a more sustainable agriculture with intense rural development. And finally in order to achieve this, the CAP wants a more effective and equitable framework of support policies for agriculture. Unfortunately, the creation of effective policies is challenging, given the complexity of agriculture and its relations with the environment and society. New policies influence an on-going evolution of the sector, though these policies are not always designed taking their evolutionary effects into account. Historically, policies are often designed based on a neo-classical understanding of the farmer's situation. There are concerns that this approach, founded on static equilibriums or general optimisation principles is too constrained [1]. It is not equipped to deal with uncertainty, lack of knowledge on diversity or complexity effects between markets. Evolutionary economics offers a more appropriate starting point to analyse economic transitions and to design policies [2]. Evolutionary models can also incorporate different behaviours. This can be an additional step in agricultural research to bring models closer to reality, given the complexity and diversity in behaviour of farmers [3, 4]. This project builds an empirical evolutionary model of the Belgian agricultural sector. We compare two types of modelled behaviour with the evolution of the sector between 2003-2011. The results indicate that rational profit-optimising behaviour cannot always explain the past evolutions.

Evolutionary economics have seen a growing interest since the second half of the last century. The evolutionary approach engages in the study of a phenomenon over time. The models include imperfections, non-equilibrium and selection mechanisms over time. There is a large focus on group effects, complexity and learning [5]. A specialised strand of evolutionary economics focuses on the development of agent-based modelling of economic evolutions. This approach models economies as decentralised, complex and adaptive systems. The models are founded on groups of autonomous agents, that have individual behaviours, technical characteristics and communication possibilities [6]. Such agent-based models (ABM) directly provide possibilities to investigate interactions and relations in detail. An ABM model is built from the bottom up: the individual agents being each represented with their decision process and historical pathways. This leads to research on co-evolution of markets, dynamics in consumer demand, emergence of innovations, historical path-dependence, environmental impacts and effects or co-evolution with institutions and policies [7-9]. Especially the translation of this approach to empirical research unlocked new methods to investigate economic and social phenomena [10].

This approach has also been applied to study evolutions in agriculture on multiple occasions. The first models have been created by Balmann [11], studying structural change in an abstract landscape. Further developments have elaborated this model to study impacts of new policies and CAP changes in different regions in Europe [12-14]. Berger [15] continued this approach and integrated detailed submodels for farm-level innovations, water management and irrigation. Other models included the effect of forest clearing by farmers to model regional land use changes in Indiana [16].

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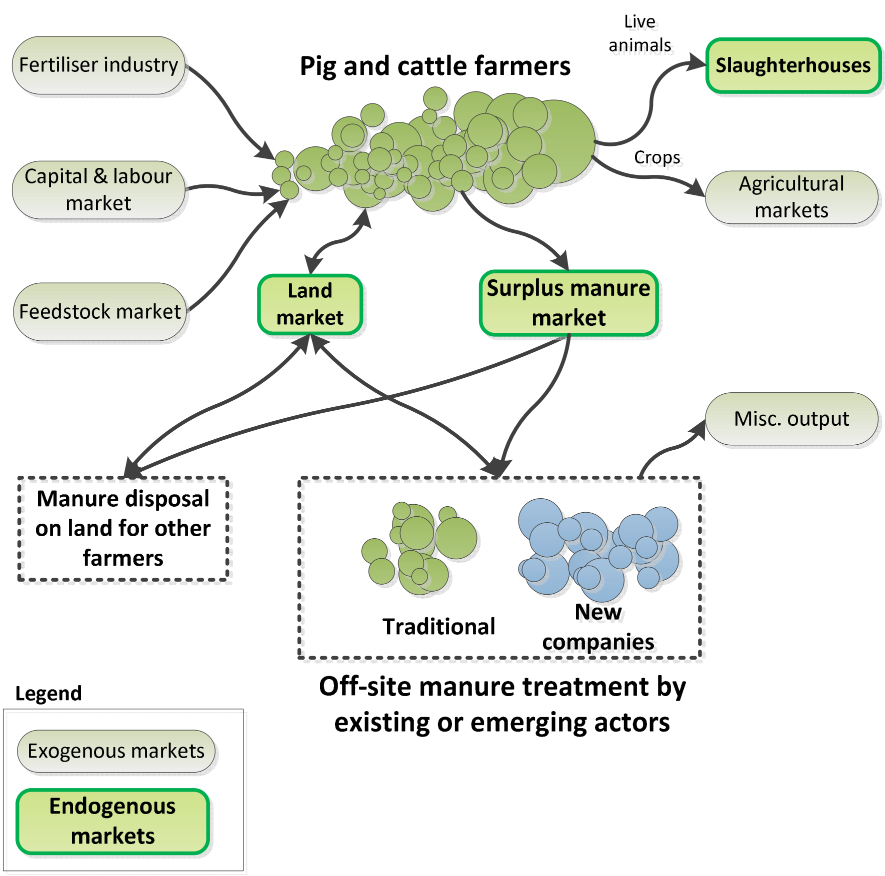
There are even initiatives to standardise farm models in this context [17].
A particular strength of this approach is the openness to interdisciplinary models. Several applications combine for instance technical, geological, and behavioural submodels. In the context of evolutions of the agricultural sector, the inclusion of behaviour is very important. Farms are often modelled at household level. The behaviour is related to the household directly and this implies influences from personal risk adversity, off-farm labour, work preferences, resistance to change or limited information availability. The behaviour, the bounded knowledge and the adaptation capacity of the agents confronted with new developments are all hidden drivers of agricultural transitions. Many models incorporate particular behavioural rules such as heuristics or constrained maximisation [18]. These decision rules are already more developed than the standard profit-maximising procedure from neo-classical models. However, most models exert the same decision procedure for every agent. Decisions ultimately vary due to differences in technical and historical characteristics. But the heuristic process remains the same. Empirical applications demand a method that also relaxes this requirement for a similar behaviour for all agents. Other research projects include an intrinsic diversity of behaviour rules in the construction of ABM.
The increased application of evolutionary modelling has also nurtured the debate on the robustness of ABM-modelling. There are several reasons to control carefully an ABM-based analysis. First of all, this is a new development. Neoclassical models can present a long historical range of applications and scrutiny, as well as regular modes of operation. These new evolutionary models are being developed in a new and burgeoning discipline. Agreed standards of construction and application have not yet been developed and the knowledge on the limitations of this approach is restricted. Secondly, compared to standard neoclassical economic models, an ABM can display several times the number of degrees of freedom. This implies that validation and calibration of empirical models is a crucial step to demonstrate the robustness and credibility of the results [20-22].
This paper reports advances in a project focussed on the Belgian dairy, cow and pig production sector. This sector is confronted with multiple problems such as low profitability of animal farms, high environmental impacts and high price volatility. The model needs to provide a testing ground for new policies and future scenarios. One particular focus of the model is the integration of new sustainable innovations for manure treatment in the current economic structure. Excess of manure constitutes an important economic and environmental problem in Belgium. The excess of manure leads to water pollution, high costs for disposal and important changes in local ecosystems. This urgency has led to the creation of new innovative methods to treat manure in a more sustainable way. These innovations are intensively researched and provide new production methods for fertilisers, algae-based products, feedstock or water purification. The potential influence on the overall sustainability of agriculture is large. However, the integration of these new technologies encounters multiple structural barriers. The current project builds an ABM model to test different scenarios of support policies for agriculture and for related sustainable technologies.
This paper develops the calibration of the ABM model according to the Werker-Brenner approach [23]. The calibration is aligned to the historical evolutions in dairy, pig and cattle production during the years 2003 – 2013. We compare two different models of farm agent behaviour. A first model follows uniform behavioural rules for all agents, based on profit maximisation. A second model implements a structured behavioural diversity. The calibration method allows the determination of several behavioural variables.
This paper is structured as follows. In the second section, the structure of the ABM model is described. This comprises the architecture and the behaviour submodels. The third section reports the calibration results for the initial benchmark situation and for the historical evolution. The fourth section discusses and interprets these results. Section five concludes.

II. Choices in the model construction

The main research orientation looks at the evolution of the agricultural sector in Belgium, and the influence of new manure-treatment methods on this evolution. More particularly, the focus is directed towards the investigation of structural change in agriculture. Structural change has been investigated as shifts between different types of producers (Baumol et al., 1985) or shifts in labour allocation per sector (Ngai and Pissarides, 2007). Generally, structural change can be regarded as shifts in productive assets at the level of an economic sector. The definition of the farm agent should thus include different types of productive assets, and allow to see modifications in asset compositions over time. The main answer to this requirement is the inclusion of different types of animal stocks, investments and land types for each individual farm agent. The farm agent can therefore specialise on one type of production, or he can choose to combine multiple stocks and create a mixed farm.
Mixed farms are an important part of the Belgian agriculture. Multiple economic studies focus on specialised farms (Berentsen, 2003; Meul et al., 2007; Nevens et al., 2006; Van Passel et al., 2007; Van Passel et al., 2009). But the Belgian agriculture contains different forms of mixed farming. This combination of different animal products and crops can be historical, but can also be strategic in response to economic adversity or low productivity (Meert et al., 2005). Mixed farms keep different production options open, allowing for more evolutionary pathways than specialised farms. So co-production and mixed farming should in principle remain possible for the farm agent. The chosen farm model allows for a simultaneous production of crops and animals. However, the categories of production do not detail specific crops or products. The different types of crops are divided in four groups (i) Forage : cultivation of plants destined for animal nutrition, (ii) Pastures and grasslands, (iii) Horticulture and (iv) Crops : all other types of crops. The animal products are grouped in three broad

categories : (i) Pig products : The output of this category consists mainly of live pigs, (ii) Dairy products : This output does contain raw milk, but also live reform cows for sale, (iii) Cattle products : All other live cattle are grouped in this category.
Pastures and grasslands constitute a particular category, as in this model the farmer cannot directly draw profit from the grassland. The available grassland is integrated in the production for dairy products and cattle. The production of the other categories can be used internally or can be sold, leading to six potential types of revenue for each farm. Specialised farms will focus on one category only. Mixed farms can combine different revenue streams.
A second field of detailed investigations is the agricultural land. The level of detail in the description of the agricultural land is highly dependent on the objectives of the study. For instance, many projects incorporate geographical data of land parcels to study local characteristics and geographical proximity as determinants of land transactions. This can be spatially explicit in a theoretical land framework (Epstein and Axtell, 1996; Happe et al., 2004), or based on real geographical information (Smajgl and Bohensky, 2013). This has been used to study water management options, regional farm structure, or management of common resources (Matthews et al., 2007; Parker et al., 2003).

Figure 1: Schematic overview of the agent-based model



In this case however, the focus is not on the geographical characteristics of the farm. The main objective is to study the emergence on the market of new technological solutions for manure treatment. Given the small size of the region under consideration – Belgium – differences in regional characteristics can play a role in reality, but are not preponderant. The emergence of these technologies is studied as a results of technology evolution, learning, acceptance by farmers and related policy measures. Other studies also investigate agent-based dynamics without geographical specification (Möhring et al., 2010).
If geographical information is not included in the land market, then this requires specific assumptions for the land market model. Because in reality geographical limitations impose specific dynamics on the exchanges of land between farmers, the implemented market model ensures that these are preserved.

III. The Model Architecture

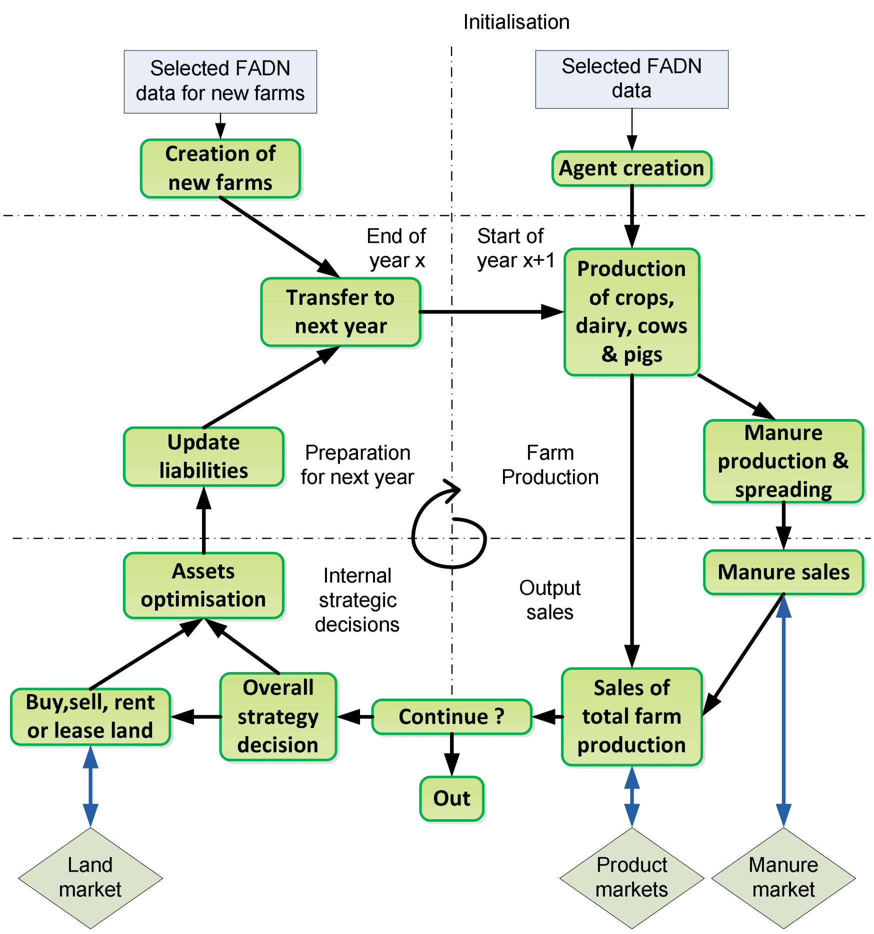
Figure 1 present a schematic overview of the model. It illustrates the group of farmers in relation with different markets. The exogenous markets are capital, labour, fertilisers, investments and output markets for different products. Their prices are fixed and given by external data. The endogenous markets react to the quantities and prices requested by the farmers: for land,for manure, and for live animals. The market for live animals considers the exchange with slaughterhouses. The price determination is based on an econometric model of market power in the slaughterhouse market. The other two markets, for land, manure and feedstock, are implemented as double auction markets [24]. In these markets, any party has the possibility to enter bids for either the purchase or the sale of a good, combined with a requested price. The double auction mechanism combines sales bids with purchase bids and establishes a negotiated price for the transaction. For the purpose of the calibration, the manure treatment sector is fixed. Existing technologies are present and unchanging, new technologies are not yet introduced.

Other external evolutions are set according to the historical prices in terms of market prices. Hence, the current application focuses on the dynamics within the agricultural sector itself. No external shocks are applied during the calibration.

The evolution of a farm agent during the course of one year is illustrated in Figure 2. The annual process in divided in four steps : (i) After the initialisation of the model for the first year, the agent starts producing. Whenever possible, the manure is first spread on the fields of the farm itself. The remaining manure has to be sold in the manure market. (ii) The second step is the sales of output products and manure. After the sales, the total annual turnover can be calculated and farm agents decide whether they want to continue farming or not. Reasons to cease activity are bankruptcy, passing of the farmer or a decision to leave animal farming and to focus on crops only. (iii) If the farm agent continues, he optimises assets for next year. This step contains most of the behavioural decisions. (iv) Finally the farmer updates his financial liabilities and new starting farmers enter the group for the next year.

The third quadrant of the annual cycle combines all steps to decide on the future lay-out of the Farm Agent. The decisions concern a number of variables that cover assets and efficiency investments. This part of the annual cycle also gathers all aspects related to adaptation and learning of the farm agent. The decisions are split between three steps, each changing several production variables. The first step of the decision process is the overall strategic decision, allowing the farmer to review the types of animals on his farm. This means that the agent can decide whether or not to continue raising a certain type of animal. The agent can also decide to invest in an innovation to improve production efficiency.

Figure 2: The different steps for every farm agent in the evolution of one year.



In the second step, the farm agent can change land surfaces, and interacts on the land market. Consistent with the choices of the land market rules, this second step is not entirely available to all Farm Agents every year. On an annual basis, only a small percentage of the Farm Agents (according to the ‘Land Access Factor’), can carry out this second step to buy land. Finally in the third step, the farm agent optimises the production assets by minor de- or investments and allocates different crops to the remaining available land surfaces. Based on the type of animals and the land surfaces available, the farm agent can adjust the amount of livestock with a maximum of ± 20%. Increases in animal stock are accompanied by investments for additional stables and machinery, and the farmer has to respect a minimum surface of grassland per cow at all times.
The third quadrant of the annual cycle assembles the different parts of the decision framework of the farmer. In this paper, we compare the results of two different behaviour submodels each applying a different set of decisions for the agents : a profit-maximising model and a diversified behaviour model. As all other input data remain equal, the results show the impact of the decision heuristics on the simulated evolution.

The evolution of the farmer’s community is subject to the following variables in each case :

- Transaction costs : Changes at farm level do not immediately yield their optimal return. The farm agent has to adapt to the new specialisation or investment. This learning period is implemented as a transaction cost, proportionate to the investment cost of the change, separately for each of the three animal productions.
- Adaptability: The general framework provides the option for the farmer to change his overall strategy every year. In reality there are several reasons that induce a farmer not to change his strategy every year. First of all, large strategic changes require willingness to change and a learning capacity. Secondly, large changes are disruptive at farm level. They reduce the options for future production and render some past investments obsolete. Finally, there can also be a form of persistence or stubbornness that explains why farmers continue production with an existing configuration rather than ‘giving up’ one type of animal or crop. The model integrates this lack of adaptability. The overall adaptability of the farmers’ community is defined as the percentage of the farmers that review their strategy in one year.

IV. Adaptation and Learning

Three aspects that determine the adaptation and learning capabilities of the Farm Agent, are historical path-dependence, the ability to forecast and the individual objective function. Adaptation of an agent requires the maintained link with the historical evolution of the agent. The agent follows a path during its development, and the effects of learning are determined by the past experiences of the agent. The second obliged concept in relation with adaptation is the ability to forecast. Even in situations where high uncertainty is prevalent over future trends, agents are obliged to determine forecasts for future productions and prices [33, 35]. Finally, adaptation obliges the definition of an objective function or fitness measurement. The agent will then adapt his situation in order to maximise his fitness [36]. These three aspects are reflected and implemented at different instants during the decisions taken in the third quadrant of the annual cycle.

First, historical path-dependence is present in the decisions taken in the third quadrant of the annual cycle. As such, path-dependence is a standard characteristic in agent-based models. Each agent starts an evolutionary cycle with an individual situation as a result of choices and experiences in the past. The starting situation determines to a large extent the possibilities that the agent has for the future. This is also the case in this model. At the start of the cycle, the Farm Agent begins with the results of the past cycle. The choices of productive assets indicate the present productions. Also, the past expenditures determine the present production efficiency and characteristics. Finally, the starting situation also limits his future choices for coming cycles. Farm Agents can choose to reduce the types of animals they raise, but they cannot choose to increase them. This means in practise for instance that a specialised dairy farmer cannot decide strategically to discard all dairy production and to turn to specialised pig farming instead.

Secondly, the farm agents display an ability to forecast. Each farm agent individually optimises his annual income based on personal price predictions. These price predictions are formed by averaging the prices the farmer received for this output during the last three years. External trends that could influence future prices are not taken into account by the farm agent. This is narrow foresight, similar foresight methods used in other projects [12].

V. Objective Functions and Optimisation Constraints

The final aspect of adaptation is the objective function and the related optimisation constraints. Multiple models use an objective function based on various forms of profit-optimisation. In these models, every farmer decides on his strategy and assets while optimising his annual profit. Profit-optimisation has been applied before in agricultural agent-based models, but rarely in the strict neoclassical sense. Several adaptations to this basic decision model have been applied to bring the behaviour closer to reality. The Agripolis model [12, 13] utilise a farm income maximisation decision module. This maximisation is based on limited information and personal prediction of future output prices. Similar constrained and bounded rational optimisation of annual farm income is found in agricultural models such as MP-MAS [18, 25] or CATCHSCAPE [26, 27], the latter combining optimisation with linear programming.

In this model, the objective maximisation of the farm agent is constrained by the availability of loans and by the level of financial risk the farm agent is willing to take. New investments in land, animals, farms or installations require loans. Banks will not base the restrict the maximum amount of the loan on the future business plan, but to the value of the land of the farm that the farmer can give as a guarantee. The financial risk of the farm agent is defined as the ratio of liabilities over owned assets. Every farmer disposes of a unique maximum level of risk he is willing to take. This maximum financial risk level RF is age-dependant. The fixed level RF_0 is normally distributed among the agents with parameters N(0.32; 0.224), corresponding to risk levels in 2003. With growing age, the risk preference of farmers decreases and falls to zero at the age of 65 :

$$RF = RF_0\left(1 - e^{\frac{x-65}{10}}\right).$$

Because two different behaviour submodels, of which one with behavioural diversity are used, as explained in the next section, three different objective functions are integrated. A first objective function is based on profit. This is similar to the projects mentioned above. Constrained by limited choices and loan availability, the farm agent decides on the optimal quantity of land, animals and animal types for a maximum profit next year. A second objective function expands this to farm value. Annual profit maximisation is a very short-term planning horizon for the farm agent. In order to incorporate a focus with a longer time-frame, farm agents maximise the entire value of the farm rather than solely their profit. This entire value includes liquid and fixed assets and agricultural land. This type of farmers does not pursue the largest profit for next year, but they pursue the creation of a large and rich farm, yielding important annual profits each year.

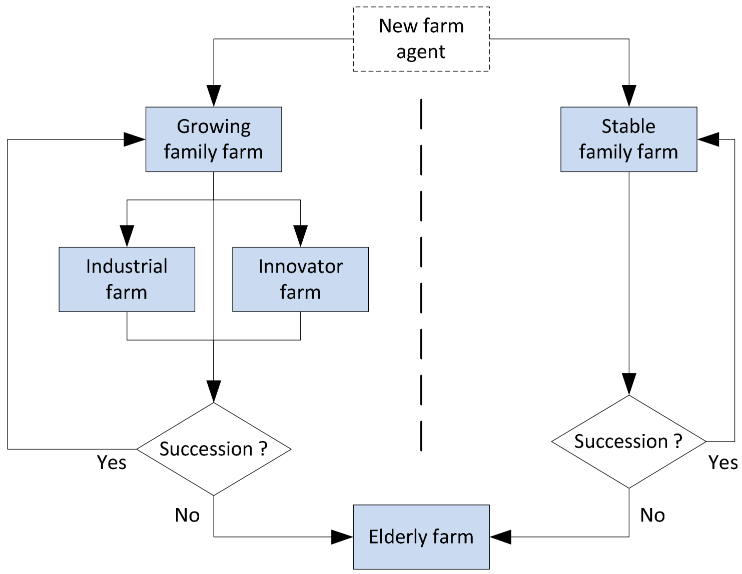
The third objective function is not based on a value, but on an ideal farm structure. Maximisation implies that the agent disposes of a range of choices. For instance, the choice of a mixed farmer to stop raising pigs and to specialise on dairy farming instead, can be part of the decision process. But this is not a valid choice for one type of farms called ‘stable family farms’. The ‘stable family farm’ is based on characteristic behaviour of Belgian small-scale farmers. This type of farmers are active in agriculture and are passionate about their specific farm type or about the animals they raise. Entirely driven by personal preferences and conviction, this type of farm can for instance prefer pigs. Despite the fact that crop farming presents larger marginal benefits, this farm will continue to raise pigs. There are no alternatives considered during a maximisation process. Their objective is the creation of an ‘ideal’ farm configuration and size, based on personal preferences of animals and crops. The ‘ideal’ farm contains a certain land surface, and a specific stock of animals. This ideal also consists of a full ownership of all the land under cultivation. Every affordable step that can bring the farm closer to the ideal, is implemented. When achieved, the farmer stops the farm growth and invests only in efficiency.

VI. BEHAVIOUR DIVERSITY

The first behaviour model uses behaviour uniformity and assumes a constrained profit maximisation for all agents.

The second behaviour model implements behavioural diversity, constructed according to the procedure of Smajgl et al. [19]. Diversity is a key feature in evolutionary analyses. Following the variety of farmers in Belgium, the implementation of technical diversity leads to a large range of technical variables, combinations and characteristics in the model. The additional implementation of behavioural diversity adds another level of differentiation between the agents, leading to a multiplication of variable combinations. This large combinatorial freedom could signify in practice that the model is very hard to build empirically. But the application of diversity in both technical and behavioural characteristics is feasible because one can rely on the coherence between the two aspects. Farm agents are classified in different groups based on their technical characteristics, including farm size, type of activity, location, profitability, or age. This defines the attribute data, and attribute-based classes. The behavioural diversity is also explicitly integrated by forming classes of farmer behaviour. When one considers certain behaviour to be continuous, it will influence the lay-out and structure of the farm over the long term. Mixed farms will not be held by farmers pursuing a maximum production efficiency, or large farms require a certain willingness to take risks from the farmer. Through recursive optimisation of the classes, groups of farmers are constructed that combine each a technical type and a behaviour class. In each case, the method integrates empirical datasets and qualitative information to build the full model [28].

Figure 3 : The links between the different farm agent behaviour types



In this case, different types of farmer behaviour have been distinguished through discussion with experts. For this application, five different types of farms have been determined: (i) growing family farms, (ii) stable family farms, (iii) innovator farms, (iv) elderly farmers and (v) industrial farms. Every behaviour type is related to technical farm characteristics, as described in Table 4.

At the start the farm agent can be defined as a growing family farm, or as a stable family farm. The two types have very different behaviours. Stable family farms are based on one family pursuing a stable surface of land and stock of animals. The main objective of these farmers is to obtain a stable farm configuration, while increasing ownership of the land under cultivation and achieving a growing income and farm value. The farmer does not optimise the value nor the income of the farm. The farmer defines an ideal farm and pursues this structure. Investments to increase efficiency are implemented when affordable. The farm size is limited, the total amount of external labour does not exceed 1 FTE. Growing family farms on the other hand, have a very different behaviour. These farms are also created from one family with a growing surface of land and stock of animals. But the main objective of these farmers is to grow steadily. Growth of production can be achieved both by acquisition of production assets as by implementing innovative technologies for increased production efficiency. Through multiple adaptations, the growing family farm can become an innovator farm or an industrial farm.
The innovator farm adopts a long-term strategy based on high specialisation and innovation. The farm aims for high specialisation and innovation. Growth is pursued, but it is not the primary objective. Investments in efficiency increase and in niche production are preferred. The farmers of innovator farms are over 45 years old, allowing them to achieve sufficient experience and background to invest in multiple innovations. These farms achieve the highest production efficiencies. The type is most commonly associated with specialised pig and dairy farms, less with cattle farmers. The industrial farms on the other hand, are less specialised, but larger than innovator farms. Industrial farms are managed as industrial plants. The farms maximises the total value of the farm in the long run. The strategy is based on economies of scale, and leads to intensive growth of the farm. These are the largest farms but do not require specialisation.

Finally, at the end of the lifetime of the farmer, the farm has to find a successor, or he is to evolve into an elderly farm. Succession is a crucial step in the history of family farms. This is increasingly the case, as farms grow larger in size, to a point where it is difficult to start a new farm without any capital or assets available from a predecessor [37]. However, the current rate of farms that find a successor on time is low. Farms without a successor can present zero growth or decrease in total farm assets [38]. On the other hand, elderly farmers stay active after their pension age, and continue farming without further adapting their farm structure.

The typology of elderly farms consists of farmers that gradually retire, and don't find a successor. The elderly farmers live up the farm's assets, maintain the land in ownership and do not invest in higher efficiency or new innovations. The activity only stops when the owner passes away. Besides the high age of the farmer, these farms also present low efficiencies and high stability of activities or even decreasing activities. Currently, a succession rate of 41% is implemented in the model. Any farm that fails to have a successor on time (growing family farm, innovator, industrial or stable family farm), becomes an elderly farm when the farmer's age reaches 65 years.

So the behaviour typology can be divided in two very different evolutions, one based on stable family farms, the other on growing family farms that can potentially evolve towards industrial or innovator farms. Both types turn to elderly farms at the end of their life. The difference between the two evolutions is especially a difference of adaptability & learning capacity. The growing family farm is responding to market prices by adapting his production assets. This is characteristic shared with the innovator and industrial farms. On the other hand, the stable family farms remain focused on their ideal farm structure. Stable family farms do not adjust their production according to market prices. At most they delay investments because of insufficient liquid assets. The stable family farms represent a very stubborn and fixed behaviour. The other farm types represent a very flexible and adaptive behaviour. The percentage stable family farms in the total farm population is therefore an important factor for the overall adaptability of the agricultural sector. This percentage also has to be determined through calibration.

VII. Calibration Method and Results

Empirical calibration of evolutionary models has been gaining attention lately [39], and several approaches are available [40]. Still, calibration has been noted as a critical problem in applications of empirical ABM's and solid calibration methods are required to guarantee the credibility of the results [41]. Standard calibration takes two steps. The first step calibrates the input data of the model on realistic data sets and benchmarks. The second step compares the output with empirical data for the output and determines the validity of the model. A specific and pragmatic calibration method, the Werker-Brenner method, adds a third step [23]. The method uses specificities of evolutionary models, exhibiting often numerous degrees of freedom. The Werker-Brenner approach labels itself as 'critical pragmatist' in the sense that the model is not required to deliver one correct solution. The more pragmatic approach is to allow for several realistic solutions that are able to explain the same phenomenon. Several acceptable sets of input data are determined that return solutions in line with the calibration constraints. The third step is thus to investigate the underlying dynamics, similarities and differences between the inputs sets. These patterns show underlying principles common to all acceptable data sets. This approach narrows the sets of possible entry data down to more realistic figures, and this improves robustness of the model [42]. This paper applies this calibration method. First the initial situation is fixed. This initial situation is calibrated to technical and production characteristics of the Belgian agricultural sector in the period 2001-2003. A limited number of immeasurable parameters, especially those related to behaviours, are selected at random. The model is executed separately with profit maximising and with the heterogeneous behaviour rules. After hundreds of model runs with random parameters, the results are chosen that correspond best with the historical evolutions in the period 2003-2013.

Table 1 : Comparison of the calibrated farm agent set with quantities in reality

General data		
# of reference farms selected		49
Total number of agents at initialisation		40583
Comparison according to farmer's age		
Age	Number of farmers in reality	Represented at initialisation
18-34	5 002	99%
35-44	12 059	97%
45-54	11 154	96%
55-64	9 989	97%
>65	9 016	96%
Comparison according to land size		
Land size	Number of farmers in reality	Represented at initialisation
<5	8 780	84%
5-10	5 180	88%
10-20	7 010	102%
20-30	5 850	102%
30-50	7 840	103%
>50	7 240	103%

Weights			
Avg	SDv	Min	Max
828	299	86	1 000
Comparison with macroeconomic benchmarks			
	2001	2002	2003
Cow production	104%	96%	103%
Pig production	104%	103%	101%
Dairy production	100%	101%	101%
Comparison according to the size of the animal stock on the farm			
	Total LSU on farm	Number of animals in reality	Represented at initialisation
Cows	< 20	109 440	100%
Cows	20-50	1 082 940	98%
Cows	>50	1 585 710	97%
	Total LSU on farm	Number of animals in reality	Represented at initialisation
Pigs	< 20	3 480	100%
Pigs	20-50	85 380	102%
Pigs	>50	1 872 723	108%

A. Calibration of the initial reference farm agents

The start of the model is calibrated on production benchmarks and on benchmarks of farmer diversity during the years 2001-2003. The model is populated with a heterogeneous group of farm agents. This group consists of reference farm agents, each attributed a specific weight that determines their multiplication at the initialisation of the model. The model selects farms from the Farm Accountancy Data Network (FADN) database to shape the reference situation of the farm agent on a realistic basis. In this case, the farm selection is not based on expert knowledge, as this would imply a manual selection. This is not feasible given the high number of agents and several simultaneous conditions. Therefore, we adopted a method, based on the solution of Happe et al. [12] and Sahrbacher et al. [14]. This enables to automate the selection as an optimisation solved with quadratic programming. There have been 26 criteria fixed for the selection of the reference farms. Nine criteria are related to the total macroeconomic production of the Belgian agriculture during the years 2001-2003.

It is the objective that the selected farms should replicate the annual national production of cows, dairy and pigs. The reason to decide on three consecutive years rather than on one single year, is to avoid selection of farms with irregular production output, or farms for which data was not available for a longer period. Seventeen additional criteria relate to the age diversity and size distribution of farms in the year 2003. The selected group of reference farms should represent the same age pyramid, and size distribution, both in land surface as in livestock size, as the Belgian agricultural sector in reality. The quadratic optimisation yielded a total of 49 different reference agents, representing 40 583 farms. The comparison of this selection for each criterion is illustrated in Table 1.

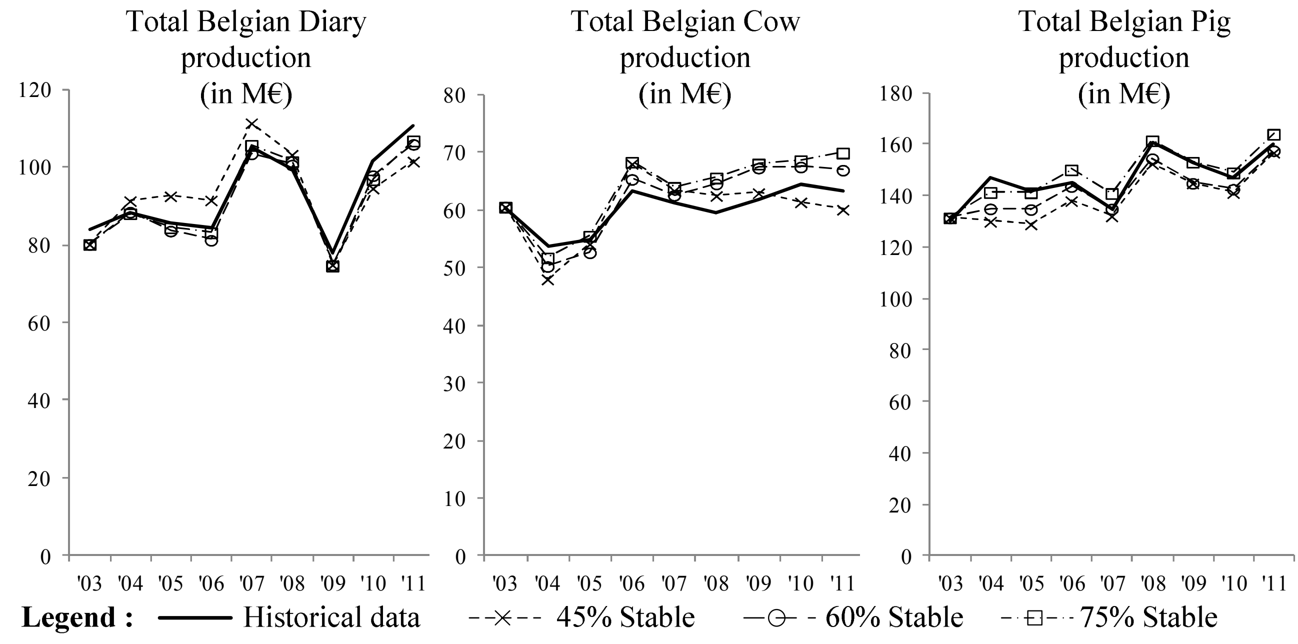
B. Calibration runs compared with historical evolutions

The simulation results are compared to the actual productions of dairy, cows and pigs during the period 2003-2011. The calibration is used to determine behavioural uncertainties.

When the first submodel is used, all agents are focused on profit maximisation. Profit-maximisation is a more determined behaviour, but it still disposes of some variables that have to be chosen randomly for the calibration runs. These are the size of transaction costs, the annual land availability for farmers and the price of efficiency investments. In this case however, no sufficient approximation has been found for the profit-maximising model. The results are illustrated in Figure 4. When the model assumes profit-maximising behaviour for all farms, the simulated productions cannot be brought closer to the quantities in reality.

In the second submodel, assuming heterogeneity, several scenarios can be determined that bring the simulated evolutions closer to the real annual productions. The variables that need to be determined through calibration are : the adaptation capacity of the farmers' community, the annual availability of land, the transaction costs, the efficiency increase/innovation cost for efficiency improving investments, the proportion of growing family farms compared to the number of stable family farms.
Not all of these variables exert a similar influence on the evolution of the model. An essential role remains for the proportion of growing family farms compared to the proportion of stable family farms. This can be clarified by highlighting the large differences between the two.

Figure 4 : The model assuming profit-maximising behaviour cannot replicate the real evolutions.



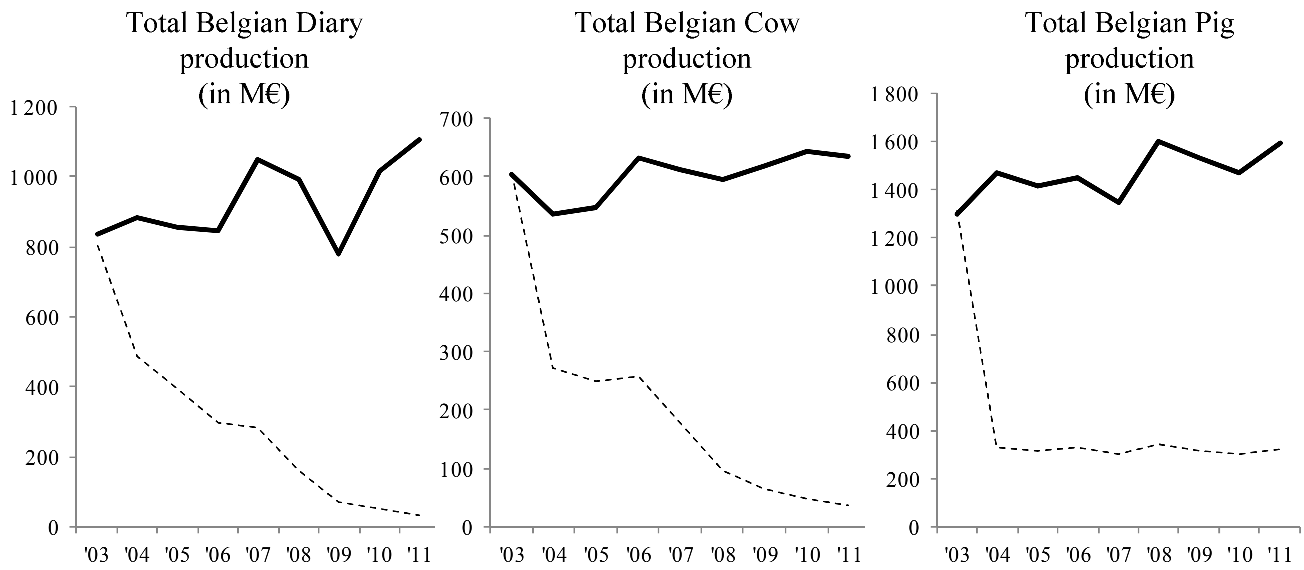


Figure 5 : Comparison of annual turnover for simulations and historical data

The growing family farms are very reactive to their environment and to the price signals they receive. They are also the basis for the emergence of larger and more innovative farms.

The stable family farms however, are mostly driven by internal motivations and constrained by personal limits on size and labour. A high proportion of growing family farms yields a model that is highly reactive to price evolutions. Consequently, a high proportion of stable family farms yields a model driven by changes in land surfaces and age pyramids of the farmers.

The calibration has been done for a varying proportion of growing versus stable family farms. The optimal values for the corresponding parameters are reported in Table 2. The three best approximations (with 45%, 60% and 75% of stable family farms) are illustrated in Figure 4.

Table 2 : Optimal parameter sets to simulate the actual production

Proportion of stable family farms	**0%**	**15%**	**30%**	**45%**	**60%**	**75%**	**90%**
Adaptation capacity[1]	1%	10%	10%	15%	20%	30%	10%
Land availability[2]	5%	10%	20%	30%	40%	40%	50%
Transaction costs[3]							
Dairy	5	-	-	-	-	-	-
Other cattle	15	10	-	-	-	-	-
Pigs	5	5	5	5	5	5	-
Efficiency / cost ratio[4]							
Dairy	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Other cattle	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pigs	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Approximation quality[5]	22.1%	11.1%	7.0%	3.8%	2.8%	4.1%	7.2%

[1] : The adaptation capacity is the proportion of farm agents that execute the strategic decision process per year.
[2] : The Land availability is the proportion of farm agents that has land available for purchase or for rent in his neighbourhood per year.
[3] : The transaction costs are defined as an additional cost when change is undertaken, of x times the price of the livestock quantity change.
[4] : The cost of an efficiency improving investment is the e/c ratio times the size of the livestock, per percentage efficiency improvement.
[5] : The average relative differences with the real macroeconomic productions is used as a measure of approximation quality for the scenario.

Table 3 : Translation of the behaviour in modelled rules

Name	Evolutionary traits	Technical characteristics	Optimisation objectives	Optimisation constraints
Industrial farms	These farms set out from the start to behave strategically as industrial firms and have a relatively high chance to find a successor.	Farm owner is older than 45 years. Farm size exceeds 350 LSU. Farm is not specialised in one animal type.	The farm maximises the profit of the firm.	Growth is constrained by a maximal financial risk of 60%.
Innovators	These farms start as family farms. When the farm achieves sufficient experience, efficiency and specialisation, it can become an innovator. These farms also have a relatively high chance to find a successor.	Farm owner is older than 45 years. Farm is specialised in one animal type. The farm production efficiency exceeds 110% for dairy farms, 135% for cattle farms, 150% for pig farms.	The farm maximises a double objective, maximum farm value and maximum production efficiency.	Growth is constrained by a maximal financial risk dependant of the owner's preference. And the total labour burden should remain smaller than 20 times the farm household size.
Growing family farms	Farms start as growing or as stable family farms. Only growing farms are interested in an evolution towards industrial or innovator configurations.	The farm owner is younger than 65 years, or has a successor. There is no other technical restriction for this type of farms. Farm types are randomly designed growing or stable family farms at the creation of the farm agent.	The farm maximises the total value of the farm, composed of liquid assets, and fixed assets including land.	Growth is constrained by a maximal financial risk dependant of the owner's preference. And the total labour burden should remain smaller than the farm household size plus one.
Stable family farms	Farms start as growing or as stable family farms. These farm remain in this category unless they fail to find a successor in time.		The farm pursues a size of land and livestock, determined on beforehand as ideal. Whenever land is available or financial reserves allow it, these farmers grow their assets until they reach their ideal size.	Purchase of new assets is constrained by a maximal financial risk dependant of the owner's preference. And the total labour burden should remain smaller than the farm household size plus one.
Elderly farmers	All farms that do not find a successor in time become elderly farms.	The farm owner is older than 65 years, and has no successor.	The farm doesn't change investments any more, nor does it invest in efficiency improvements. The same activity is maintained with slowly declining efficiency.	
Remarks: - Farms that are facing bankruptcy due to negative cash flows, revert to cash maximisation as a short term survival strategy. When the danger of bankruptcy is averted, they return to their standard optimisation procedure.				

VIII. Discussion

Profit-optimisation in this approach induces a lot of effects that do not represent realistic behaviour. A first effect is that farmers tend to sell land, and increase their rented area under cultivation. Secondly, the agents are not inclined to invest in longer-term solutions or in innovations to improve production efficiency. Finally, production forecasts are set on prices. The real prices have been relatively low in this period; so many farm agents decide to focus on crops or to leave farming altogether. A decrease in sales prices for one year has the immediate effect that the least productive farmers leave this segment of production. One year of bottom prices thus has a very strong effect on the number of active farmers. The assumption of profit-maximisation is related to several other suppositions. It implicitly assumes that farmers have multiple alternatives to choose from and that they also consider these choices annually. This is not supported by the actual evolutions of animal production. As discussed above, because of lack of skills or knowledge, several alternatives can be unattainable for the farmer. The farmers prefer a longer time-frame, and present a certain persistence. They avoid making disruptive changes to their farm. Finally it has to be stressed that the considered decade 2003-2013 has not been very profitable for Belgian farmers. The prices for their production were and are still relatively low. Several segments of the market contain active farmers that have a very hard time to cope with these negative market developments. Still bankruptcy remains very low in agriculture. This is again a sign of strong persistence, showing why classic economic behaviour models cannot replicate the actual historical evolutions adequately.

The results from the model applying diversified behaviour are more realistic. The evolutions for pigs and dairy can be approximated closely. The closest predications can be made assuming a proportion of stable family farms between 45% and 75%. Both below and above this range the simulations remain further from the real historical productions. However, there are general tendencies over the entire range. With a low proportion of stable farmers, higher transaction costs , low adaptability and rigid land markets are required to match the real evolutions. Transaction costs serve as a barrier for change. When considering a change, the farm agent calculates the benefit. Large transaction costs indicate that the additional benefit from the change has to be substantial, before the change is considered. With an increasing proportion of stable family farms, the transaction costs diminish, the adaptability has a tendency to increase, as well as the land availability. However, these increases are non-linear, indicating intricate dynamic relations between the different parameters. The best approximation, with 60% stable family farms, stays each year within a range of 5% of the historical dairy production, and within a 10% range of the cow and pig production.

The common patterns between these parameter sets are the resistance to change in the agricultural sector. With low proportions of stable farms, there is rigidity in the market and in the learning processes. With growing proportions of stable family farms, the rigidity in the market and in learning can be reduced significantly. In these last cases, the rigidity resides in the behaviour of the farm agents themselves. Stable family farms are modelled to remain on an evolutionary track that they determine themselves at the start of their activity. Adverse price conditions or market pressure do not change their strategy. This rigidity is required if one is to explain the reasons behind the evolution of Belgian agriculture during the last decade. Whenever a modelled farm agent gets a chance to review his own situation and to consider alternatives, he chooses in most cases to leave animal farming and to do something else. An extreme illustration of this rational decision making is in the profit maximising model. But these large exits from animal farming did not happen in reality. Farmers rather continue to produce and invest despite low output prices. It is mostly because of this behaviour that the Belgian agriculture is capable of presenting a stable and growing annual production.

This application of diversified behaviour modelling yields promising results, given the fact that it flows from a first tentative construction of such a model for the Belgian agriculture. The model results are capable as such to indicate the existence of important rigidities in the evolution of farms. But it cannot pinpoint the exact location of this rigidity in this first application. The current application can only present the first step in an iterative refinement of the model through questionnaires, participatory techniques or mediated modelling. The present shortcomings include the difficulty to adequately predict the production of live cows, and the simplicity of behaviour rules for certain farm agent types.

IX. Conclusions

A better understanding of the drivers and dynamics behind of the evolution of the agricultural sector is crucial to increase the effectiveness of new policies in the long run. To this effect, an agent-based model of the dairy, cow and pig production sector in Belgium is constructed, to benchmark new policy scenarios. This model is calibrated on historical data, with two different behaviour submodels, all other inputs remaining equal. A first submodel assumes constrained profit-maximisation with limited information availability. The second submodel assumes behaviour heterogeneity, linked with technical characteristics of the farm agents. The results from the profit-maximising submodel indicate that this type of optimisation behaviour is not appropriate for most farms in Belgium. We show that a combination of diverse types of behaviour should be preferred to model farm evolutions. Hence, using a more diversified range of optimisation objectives and constraints can mimic closer the past evolutions of production.

The results of the calibration show an important resistance to change. This resistance can be caused by difficulties in the learning process, by market rigidities or by farmers unwilling to give up their ideal farming configuration. The exact cause of the evolutionary rigidity can be the subject of further research. Still, these results show that farmers very often

continue producing the same animals and crops, despite adverse economic situations. And it is mostly because of this behaviour that the Belgian agriculture is capable of presenting a stable and growing annual production.
Both behaviour and technical characteristics influence heavily the evolution of the agricultural sector. Currently, there is a lot of data available to describe the technical characteristics and the micro-economic situations of farms. Unfortunately, data on behaviour and decision frameworks is less available. More research on the actual behaviour of farmers is required to produce more realistic models. Aspect such as household characteristics and risk balancing behaviour can improve actual behaviour models.

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Age-dependent Mortality, Fecundity, Mobility Effects on the Neolithic Transition

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***Abstract*—We present a model that makes it possible to analyze the effect of the age dependences of mortality, fertility and dispersal persistence on the speed of propagating fronts in two spatial dimensions. Speeds derived analytically agree very well with those obtained from numerical simulations. Infant mortality and total fecundity are the most relevant parameters affecting the front speed, whereas the adult mortality rates and dispersal persistences are less important. We apply the model to the Neolithic transition in Europe. The predictions of the model are consistent with the archaeological data for the front speed, provided that the infant mortality lies within a relatively narrow range.**

I. Introduction

Reaction-dispersal front propagation models have been recently applied to many systems, such as human invasions [1], [2]. A variety of models has been developed in recent years to analyze the speeds of human invasion fronts [3]. Recently, the following integro-differential equation has been proposed (for some derivations, see Eq. (10) in Ref. [4], Eq. (4) and Fig. 1 in Ref. [5], and Eq. (176) and Fig. 17 in [6]),

$$p(x,y,t+T) = F\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p(x+\triangle_x, y+\triangle_y, t)\,\phi(\triangle_x,\triangle_y)d\triangle_x\, d\triangle_y, \quad (1)$$

where $p(x,y,t+T)$ is the population density at the location (x,y) and time $t+T$. The time interval T is that between two subsequent dispersal events or 'jumps', i.e. one generation (defined as the mean age difference between an individual and her/his children). The parameter F appearing in Eq. (1) is the net fecundity or reproductive rate (number children per parent which survive to adulthood). The dispersal kernel $\phi(\triangle_x,\triangle_y)$ is the probability per unit area that the children of an individual located at $(x+\triangle_x, y+\triangle_y, t)$ become adults at $(x,y,t+T)$. Strictly, Eq. (1) is valid at sufficiently low values of the population density p, because there is a maximum saturation density above which net reproduction vanishes (see Eq. (9) in Ref. [4]).

Equation (1) is called the non-overlapping generation model. Note that in this model, all traits in the life history of the individuals are ignored, i.e. only the age-independent parameters T and F are used. Therefore, this model cannot analyze any effect on the front speed of the fact that the fecundity, mortality and dispersal kernel depend on the age of individuals. In this paper, we will extend this model to allow for such dependencies [7].

II. The Model

In order to take into account the dependencies of fecundity, mortality and dispersal on age, we regard the population as subdivided into several age groups. For simplicity, and also for later application to data appropriate to the Neolithic transition (Sec. IV), we consider only four groups (however, all of our results can be easily extended to an arbitrarily large number of groups). For definiteness, let the age group subindices be ordered so that $p_1(x,y,t)$ corresponds to the youngest age group and $p_4(x,y,t)$ to the oldest one. Then we generalize Eq. (1) into the set

$$\begin{cases} p_1(x,y,t+\tau) = & f_2\int\phi_2(\Delta_x,\Delta_y)p_2(x+\Delta_x,y+\Delta_y,t)\,d\Delta_x d\Delta_y \\ & +f_3\int\phi_3(\Delta_x,\Delta_y)p_3(x+\Delta_x,y+\Delta_y,t)\,d\Delta_x d\Delta_y \\ & +f_4\int\phi_4(\Delta_x,\Delta_y)p_4(x+\Delta_x,y+\Delta_y,t)\,d\Delta_x d\Delta_y \\ p_2(x,y,t+\tau) = & (1-m_1)\int\phi_1(\Delta_x,\Delta_y)p_1(x+\Delta_x,y+\Delta_y,t)\,d\Delta_x d\Delta_y \\ p_3(x,y,t+\tau) = & (1-m_2)\int\phi_2(\Delta_x,\Delta_y)p_2(x+\Delta_x,y+\Delta_y,t)\,d\Delta_x d\Delta_y \\ p_4(x,y,t+\tau) = & (1-m_3)\int\phi_3(\Delta_x,\Delta_y)p_3(x+\Delta_x,y+\Delta_y,t)\,d\Delta_x d\Delta_y \end{cases} \quad (2)$$

where $p_i(x,y,t)$ is the population density (number of individuals per unit area) of age-group i, f_i is its fecundity, m_i its mortality, and $\phi_i(\Delta_x,\Delta_y)$ its dispersal kernel. We assume that the infant population $p_1(x,y,t)$ does not reproduce, so that $f_1 = 0$ in Eqs. (2) (this is in agreement with the data we will use in Sec. IV). The time interval τ should be chosen so that the demographic data on mortality, fecundity and dispersal, which are always recorded in age intervals, can be applied to Eqs. (2) (see Sec. III). Similarly to the age groups with densities p_1, p_2 and p_3, mortality will also affect the dynamics of subpopulation p_4, but this effect is not included in Eqs. (2) for the following reason. Since by definition p_4 is the oldest age group, all individuals corresponding to p_4 will simply disappear after their reproduction and dispersal, and their death will not affect the front speed.

In order to derive the theoretical speed for our model, we look for constant-shape solutions for each subpopulation, i.e. $p_i(x,y,t) = w_i \exp[-\lambda(x-ct)]$ *(i=1,2,3)* in the limit in which the coordinate co-moving with front $z \equiv x - ct \to \infty$. Then the set of Eqs. (2) becomes

$$\begin{cases} w_1 \exp(\lambda c) = f_2 w_2 \int_0^\infty \varphi_2(\Delta) I_0(\lambda\Delta)\Delta d\Delta \\ \quad + f_3 w_3 \int_0^\infty \varphi_3(\Delta) I_0(\lambda\Delta)\Delta d\Delta \\ w_2 \exp(\lambda c) = (1-m_1) w_1 \int_0^\infty \varphi_1(\Delta) I_0(\lambda\Delta)\Delta d\Delta \\ w_3 \exp(\lambda c) = (1-m_2) w_2 \int_0^\infty \varphi_2(\Delta) I_0(\lambda\Delta)\Delta d\Delta, \end{cases} \tag{3}$$

where

$$I_0(\lambda\Delta) \equiv \frac{1}{2\pi}\int_0^{2\pi} d\theta \ \exp[\lambda\Delta\cos\theta] \tag{4}$$

is the modified Bessel function of the first kind and order zero, and we have assumed that ϕ_i depend only on distance $\Delta \equiv \sqrt{\triangle_x^2 + \triangle_y^2}$ (isotropic kernels). The dispersal probability per unit area $\phi_i(\triangle)$ is related to that per unit length $\varphi_i(\Delta)$ (i.e. into a 2D ring of area $2\pi\Delta \ d\Delta$) as $\varphi_i(\Delta) = 2\pi\Delta\phi_i(\Delta)$ [8].

For simplicity, let us assume a simple description in which

$$\phi_i(\Delta) = p_{ei}\delta^{(2)}(\Delta) + (1-p_{ei})\delta^{(2)}(\Delta - r) \tag{5}$$

where $\delta^{(2)}$ is the two-dimensional Dirac delta function, i.e., an individual of age group i either stays at rest (with probability p_{ei}, which is called the persistence of age group i) or moves distance r (with probability $1-p_{ei}$). Such a description has been useful previously in several models [4], [5], [9] that did not take the age structure of the population into account. In those papers it was also shown that a realistic value for the mobility distance of prehistoric human populations is $r = 50$ km. We use a single value for r because using a different value for each age group would substantially complicate the simulations in Sec. III. We think this is reasonable because in our model the value of the persistence p_{ei} (and, therefore, the mobility behavior of the individuals) is allowed to depend on age. Then, using matrix notation, the system (3) can be rewritten as

$$\exp(\lambda c)\vec{w} \equiv \overrightarrow{\overrightarrow{H}}(\lambda)\vec{w}, \tag{6}$$

where we have defined

$$\overrightarrow{w} \equiv \begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix}, \tag{7}$$

$$\overrightarrow{\overrightarrow{H}}(\lambda) \equiv \begin{pmatrix} 0 & f_2\Psi_2(\lambda) & f_3\Psi_3(\lambda) \\ (1-m_1)\Psi_1(\lambda) & 0 & 0 \\ 0 & (1-m_2)\Psi_2(\lambda) & 0 \end{pmatrix}, \tag{8}$$

and

$$\Psi_i(\lambda) \equiv p_{ei} + (1-p_{ei}) I_0(\lambda r). \tag{9}$$

As usual, according to marginal stability analysis [10] the front speed c for systems with the form (6) can be found from the well-known expression [11]

$$c = \min_\lambda \frac{1}{\lambda}\rho_1(\lambda), \tag{10}$$

with ρ_1 the largest of the eigenvalues of $\overrightarrow{\overrightarrow{H}}(\lambda)$.

III. Numerical Simulations

The numerical simulations of the system (2) are performed on a 2D grid with 1000 x 1000 nodes, with nearest-neighbors distance $r = 50$ km (see Sec. II). Initially $p_i(x,y,t) = 0.25$ (but the front speed does not depend on this value) for $i = 1, ..., 4$ at the central node, and 0 elsewhere. At each time interval, corresponding to $\tau = 12.5$ yr, we compute the new subpopulation number densities $p_i(x,y,t+\tau)$ at all nodes of the 2D grid in a two-step process: dispersal and growth (the latter includes reproduction and deaths). In the dispersal step, as in the analytical model in Sec. II, a fraction p_{ei} of the population in age group i stays at the original node, and the remaining fraction is distributed equally among the nearest neighbors, i.e., a fraction $(1-p_{ei})/4$ jumps a distance $\pm r$ along each horizontal or vertical direction. In the second step, the effects of reproduction and mortality are computed as follows. At each node, the new infant population density p_1 is computed as $\sum_{i=2}^4 f_i \ p_i$ (the numerical values of f_i are given below). The new population density p_i for each of the remaining three age groups ($i = 2, ..., 4$) is computed by removing a fraction $m_{i-1}p_{i-1}$ to the population density p_{i-1} (see the last three equations in the set ((2)). In order to avoid an unbounded population growth, if after any of these steps a population density in a grid node exceeds the saturation value, then it is set equal to the saturation value (we used a saturation value of unity in our simulations, but changing it does not modify the front speed). The two-step dispersal-growth cycle is then repeated many times, until a constant speed for the propagation of the population profiles is reached.

The mean observed values of the parameters, as well as the ranges used in the simulations, are reported in Table 1. They have been obtained as follows. First, as mentioned above, in order to use the histograms for the fecundities in Refs. [12], [13], the appropriate interval between age groups is $\tau = 12.5$ yr. From table 2 in Ref. [12], the characteristic value for the total fertility ratio F of preindustrial agriculturalists was estimated as $F \simeq 6.6$ children per adult woman. The characteristic value of F is given in children per adult in our Table 1, as appropriate for application in our model (this is half the value per adult woman, because the number of women and men in human populations are approximately the same). An upper bound for F was set to 7.0 children per adult woman

TABLE I
MODEL PARAMETERS AND THEIR RANGES

Parameter (units)	Value	Minim.	Max.	Refs.
F (children/adult)	3.30	3.00	3.50	[12] , [13]
m_1 (dimensionless)	0.55	0.27	0.77	[14]
m_2(dimensionless)	0.30	0.15	0.45	[14]
m_3(dimensionless)	0.40	0.20	0.60	[14]
m_4(dimensionless)	1.00	1.00	1.00	[14]
p_{e1}(dimensionless)	0.38	0.19	0.54	[15]
p_{e2}(dimensionless)	0.38	0.19	0.54	[15]
p_{e3}(dimensionless)	0.38	0.19	0.54	[15]
p_{e4}(dimensionless)	0.38	0.19	0.54	[15]

(from the estimations for Linearbandkeramic (LBK) farmers during their range expansion in Western Europe [13]). The minimum value for preindustrial agriculturalists is $F = 6.0$ children per adult woman, according to table 2 in in Ref. [12]. The age-dependent fecundities f_i used in our model were estimated by multiplying the total fertility ratio F times the age-specific relative ratios (defined as the age-specific rate f_i divided by the total rate F) in natural fertility populations, as given in Ref. [13], Fig. 2.5. This yields $f_1 = 0.0$, $f_2 = 2.3$, $f_3 = 1.0$, $f_4 = 0.0$ children per women. Therefore, note that for a given value of F, the values of f_2 and f_3 are given by the equations $f_2/f_3 = 2.3$ and $f_2 + f_3 = F$. Age-dependent mortalities were estimated from table 4 in [14], yielding the characteristic values $m_1 = 0.55$, $m_2 = 0.30$, $m_3 = 0.40$, $m_4 = 1.00$. Finally, Ref. [15] is the only source we know with quantitative dispersal data for preindustrial agriculturalist populations. Unfortunately, it does not seem possible to estimate the age-dependent persistencies p_{ei} because all mobility data give individual distances moved since birth, not since the individual had several specific ages. However, Ref. [15] makes it possible to estimate several values of the infant persistence. As noted in a previous publication [4], the mean is $p_{e1} = 0.38$ and the range is $0.19 \leq p_{e1} \leq 0.54$. Due to the lack of more refined information, and because infants necessarily move with adults, we approximated the adult persistencies (p_{e2}, p_{e3} and p_{e4}) to the same range as that of p_{e1} (Table 1). Moreover, we will find that our model is consistent with the data for any value of the adult persistencies (Fig. 1).

IV. APPLICATION TO THE NEOLITHIC TRANSITION IN EUROPE

Finally we can apply our model to the Neolithic transition in Europe. In Fig. 1, the full lines are the analytical results from Eq. (10), and the symbols have been obtained using the numerical simulations described in the previous section. In Fig. 1, the persistence of the infant population p_{e1} has its mean observed value (Table 1) and we have assumed $p_{e2} = p_{e3}$ (because, as mentioned above, only p_{e1} can be reliably estimated from the ethnographic data available, whereas p_{e2} and p_{e3} cannot). The persistence of old adults p_{e4} does not have any effect on the front speed (simply because it appears only in the term multiplying $f_4 = 0$ in Eqs. (2)). The hatched

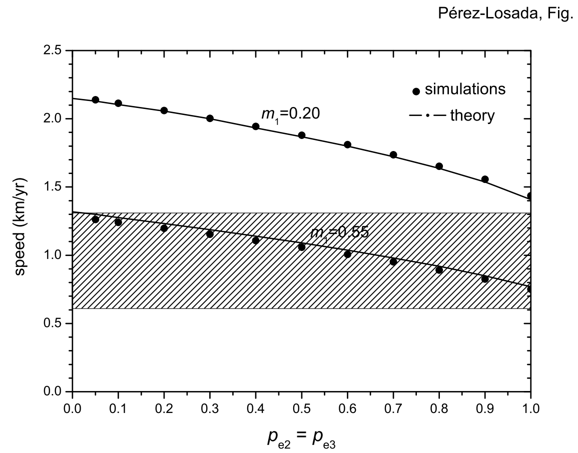

Fig. 1. Front speed in 2D versus adult dispersion persistence, for two values of the infant mortality. Adapted from [7].

rectangle corresponds to the speed range of the Neolithic transition in Europe, as determined from archaeological data (0.6 to 1.3 km/year) [16].

From Fig. 1 we see that the infant mortality m_1 has a very important effect on the front speed. Indeed, the predicted speeds are consistent with the observed range (hatched rectangle) for an infant mortality of m_1 = 0.55 (this value has been directly measured for some preindustrial populations, see table 4 in [14]). However, the predicted speeds are totally inconsistent with the observed range for other values of the infant mortality, e.g. for m_1 = 0.20. From Fig. 1 we conclude that (i) the predictions of the model are consistent with the observed speed range for realistic values of the infant mortality, and (ii) the role of the infant mortality should be taken into account in order to understand human invasion front speeds, as done here for the first time. In Fig. 1 we also note that the speed decreases with increasing values of the mortality, as was to be expected intuitively (if less people survive, less people can migrate and the front speed should be slower). Also, according to Fig. 1, the higher the value of the adult persistence ($p_{e2} = p_{e3}$), the slower the front propagates, as was again to be expected (less people migrate if the persistence is higher, see Sec. II). Finally, in Fig. 1 it is seen that the numerical simulations (circles) confirm the validity of our analytical results (curves).

It is important to estimate the importance of each parameter value on the front speed. In order to do so, in Fig. 2 we present a sensitivity analysis, performed as follows. All but one of the adjustable parameters were fixed at the characteristic value given in Table 1. The speed was then computed for the single remaining parameter set to its minimum and maximum values in Table 1. Figure 2 shows that the model is very sensitive to the infant mortality m_1 and, to less extent, to the total fecundity ratio F. The model is somewhat sensitive to the young adult mortality m_2 and to the persistencies of the

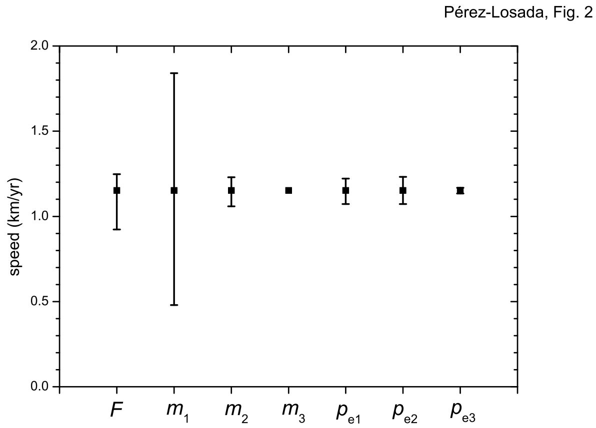

Fig. 2. Sensitivity analysis of the model as regards its parameter values. Adapted from [7].

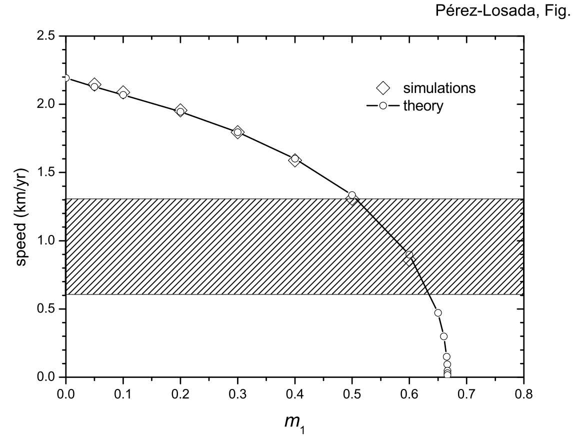

Fig. 3. The effect of infant mortality on the speed of the Neolithic transition. Adapted from [7].

infantiles (p_{e1}) and young adults (p_{e2}), albeit to a lesser extent. The persistence of the mature adults, p_{e3}, has a non-vanishing but a very small effect. Finally, the model is insensitive to the mortality of mature adults, m_3. This was expected because, according to the ethnographic data [14], the oldest individuals (with density p_4) do not reproduce ($f_4 = 0$), so the last equation in the set (2) should not affect the propagation behavior of the front, and it is only in this equation that the parameter m_3 appears. Indeed, this expectation has made it possible to reduce Eqs. (2) to the simpler system, which in turn has lead us to our analytical result for the front speed [Eqs. (6)- (10)].

Finally, let us analyze in more detail the effect of infant mortality m_1 on the invasion front speed, given its importance (Fig. 2) as well as its novelty. Figure 3 shows this effect (when keeping the other parameters fixed at their baseline or characteristic values in Table 1). As in Fig. 1, the hatched rectangle shows the observed speed range for the Neolithic transition in Europe (0.6 to 1.3 km/year). Simulated values (rhombus) are in almost perfect agreement with theoretical ones (open circles and full curve). It is important to note that, according to Fig. 3, for the predicted speed to lie within the experimental range, the infant mortality must be rather high, $m_1 > 0.5$ (as is indeed observed in preindustrial populations [14]). Moreover, and quite interestingly, beyond a threshold value ($m_1 \simeq 0.63$ in Fig. 3) infant mortality is too high and the speed too slow compared to the range implied by the archaeological data (hatched rectangle). For even larger values of infant mortality, the front speed drops until it vanishes, thereby leading to a front propagation failure induced by infant mortality.

Although we have illustrated our model for a specific application (the Neolithic transition in Europe), clearly it can be also useful to other population expansions. Moreover, the effect of the mortality shown in Fig. 3 could be related to several interesting factors. For example, a region with less natural resources (or a period of drought) could lead to higher values of the infant mortality m_1, and thus to slower speeds (Fig. 3) or even to the failure of the invasive species (vanishing speed, also seen in Fig. 3) to successfully colonize the new habitat.

V. Conclusions

In this paper we have analyzed the effect of age-dependent mortality, fecundity and persistence on the invasion speed for populations that spread across a two-dimensional space. Our simulated and analytical front speeds are consistent with each other and, for realistic parameter ranges, with the observed speed of the Neolithic transition in Europe. Predicted speeds fall within the experimental range for realistic values of the infant mortality (e.g., $m_1 = 0.55$), and this conclusion is independent of the adult dispersal persistence (Fig. 1). The sensitivity of the results has been analyzed, with reference to a baseline case for the parameter values obtained from the ethnographic literature (Fig. 2). Infant mortality m_1 and total fecundity ratio F have the most important effects. This is the first model that relates the Neolithic front speed to the age-dependent demographic and dispersal parameters of the population. We have found that there is a relatively narrow range for the value of the infant mortality ($0.5 < m_1 < 0.63$) consistent with the observed range of the Neolithic front speed (Fig. 3). Of course, more complicated models can be considered, but for the application considered here it is very difficult to find more detailed ethnographic data, and our simple model takes into account the age dependency of the major demographic parameters.

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Social Scientists, Qualitative Data, and Agent-Based Modeling

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***Abstract*— Empirical data obtained with social science methods can be useful for informing agent-based models, for instance, to fix the profile of heterogeneous agents or to specify behavioral rules. For the latter in particular, qualitative methods that investigate the details of individual decision processes are an option. In this paper, I highlight the challenges for social scientists who investigate social/psychological phenomena but at the same time have to consider the properties of agent-based simulation. To illustrate these challenges and potential solutions, I present four examples in which qualitative data is acquired for subsequent use in agent-based simulations and discuss the examples in terms of the challenges.**

I. Introduction

THE functions of qualitative data for modeling and simulations vary [1]. [2] evaluated different empirical methods and distinguished among sample surveys, participant observation, experiments (field and laboratory), companion modeling, and GIS and remotely sensed spatial data. Thus, various methods are available, each more or less suitable for different functions. In this presentation, I ask what functions of (qualitative) empirical data can be identified in modeling projects and give examples from my research. I draw on my experience and other literature and propose four different functions of qualitative data in modeling and simulation. There may be other functions, such as extraction of causalities between environmental triggers and actor behavior, which are not discussed here.

For instance, with *explorative* investigations we want to identify where to look deeper with other qualitative or more quantitative measures (e.g., surveys, databases, and statistics). Another function is to distill details of the rules of agent interaction or decision making [3, 4]. A third function is validation, for instance, of a model's plausibility or its simulation results [5]. Fourth, for simulations of future system behavior, one often has to rely on scenario data [6]. This can be more quantitative but often is qualitative, denoting a relative increase or decrease in exogenous variables.

Acquiring the necessary data looks different in different cases [7], and challenges await the social scientist who usually is trained not in "feeding" agent-based models (ABM) but in conducting disciplinary state-of-the-art research. This issue is important if one considers the increasing interdisciplinarity of many research projects, where researchers from different disciplines often follow different rationales and apply different methods. In the remainder of this extended abstract, I present challenges for social science research in dealing with agent-based models and simulation, followed by examples of specific functions of qualitative methods and data for agent-based models, and last, discuss the relation between the challenges and these functions.

II. Challenges for the Social Researcher

In this section, I briefly discuss challenges for the social researcher; other disciplines may face different challenges.

One problem with including stakeholders for data acquisition is the potential for "stakeholder bias." The question regarding qualitative data obtained from a low number of participants is, how representative is the data informed by individuals or small groups? This means that models and thus the simulation results may be valid only for the specific case and not easily generalizable. This may not be perceived as a problem if the model is meant as a means for social learning [8]. If the model developed is meant to be a more generic type, then the available empirical data may have to be generalized [9].

A second challenge is translating empirical data into agent profiles or rules[1]. Some authors share procedures for this implementation step [10]. For instance, [3] reports on semi-structured personal interviews with several stakeholders from business (e-commerce), which were recorded and transcribed. The most important quotes were then related to agent properties, such as "technical competence" with a range of integers from 1 to 3. Other statements were interpreted as an exponential function (for the variable demand).

Third, another issue is translating social science models or concepts into ABM rationales. Social science models usually—if at all—are tested or corroborated with

[1] Moreover, a potential challenging issue is if not all data is available and model implementation has to be based on assumptions – an unusual situation for social scientists.

quantitative studies or experiments but seldom in a *dynamic* way. Social scientists often do not think in "simulation dynamics." From this tradition, it is not self-evident how to implement variables and temporal dynamics into ABM. For instance, the theory of planned behavior, including the conceptual model proposed by [11], has been applied in different multi-agent systems, for example, by [12]. However, the challenge is to consider the temporal aspects not explicit in this static (or at least short-term) concept. Here, methods have to be applied that investigate the underlying processes (e.g., longitudinal survey or experiments).

Fourth, regarding the dynamics of real-world phenomena, qualitative data may provide insights into single actors' intentions, rationales, and behaviors. However, to capture the underlying processes of behavior variability under different environmental conditions, the question is how to access often *implicit knowledge and information processes* that are not consciously available to the individual? Selected methods may help elicit such knowledge, such as participatory interviews [13, 14].

In more general terms, these challenges force social scientists to adapt their methods to comply with the needs for agent-based systems and simulation. In the following, I illustrate four issues by referring to the use of qualitative methods in past and current modeling projects. I then relate these issues to the challenges I discussed in the introduction.

III. DIFFERENT FUNCTIONS ILLUSTRATED BY FOUR CASES

A. Explorative function

The first example illustrates the explorative function, where to look more thoroughly with quantitative measures (survey or statistical data). In a large-scale interdisciplinary project on global change and the water cycle, a risk perception module was to be implemented in an agent-based system so that agents could respond to water-related risks [16, 17]. The first qualitative investigation used a visualization of the participants' mental models during semi-structured interviews. Results showed that participants were in principle aware of slowly evolving future risks regarding drinking water availability and quality on the one hand and sudden risks from flooding due to climate change on the other. However, participants did not relate these processes to their daily routines, their near future, or their own (spatial) situation.

Thus, the main message of these qualitative interviews was to focus on two risks: high water and drought (because water quality, although a concern of the participants, was not covered by the models in the project). Another outcome was that we assumed personal avoidance techniques, because participants admitted that currently they do not think about these risks and only after incidents may the relevance may increase. We thus assumed that a decay function of agents' alertness is appropriate. In a subsequent quantitative survey, we focused on basic awareness of water-related climate risks and avoidance. Both issues were then implemented in the agents' profiles. The explorative interviews were not perfectly planned to inform agent rules but inspired further social science methods.

B. Details of rules (agent interaction, decision making)

A single cross-section survey is not appropriate for informing individuals about a dynamic phenomenon such as changes in public opinion. A longitudinal survey is better, but cannot help in terms of the micro-processes of opinion formation and change. In this case, socio-psychological experiments are more suitable. However, experiments can be conducted more or less artificially and controlled. For instance, we currently face the trade-off of a more restricted but controlled experiment (interaction of a participant with computer-aided portrayals of arguments on a topic for which the valence and importance are varied) versus a more natural interaction between participants and an instructed person. To distill the rules of changes of argument (and thus opinion) for the agent-based simulation, a careful analysis of the real interaction would be sufficient, since we seek prototypical behavior instead of specific cases. However, for the social-psychological researcher, an experiment based on computer interaction is more convenient, controlled, and precise, and thus more easily published in high-ranking socio-psychological journals. Therefore: *How much emphasis should be placed on model development and simulation at the expense of the experimental setting*?

C. Validation function

As [1] observed, validation and model construction should be seen as a joint process rather than different stages or processes. However, expert judgments and stakeholder interviews regarding model results and project outcomes are seen as potential means for validation. Often, the emerging macro-patterns are considered more or less reasonable [18].

In a current transdisciplinary case study (http://www.tdlab.usys.ethz.ch/casestudy/cs_actual), we evaluate a major interdisciplinary project on land-use that also implemented stakeholder knowledge in a set of coupled models [19]. We investigate what impact the project had and has among local stakeholders in one of the study regions (some participated in the project; others did not).

Aggregated results from agent-based models may be discussed as well as if the implemented rules are valid. Preliminary results indicate that it strongly depends on the applied perspective: Simulated land-use by farmer agents can make sense from a farmer's perspective, but forestry stakeholders have a different perception of land-use. This illustrates that rules implemented in a data-driven model are case specific and may be constrained and prototypical, particularly when the data has been obtained from stakeholder input. Validation of the model results and project outcomes again depends on the background of the stakeholders asked.

D. Scenarios function

The project mentioned in section *C* includes scenario workshops with stakeholders in the study region. We developed multi-scale scenarios (from the local to the global scale) [20] that provide the frame for the land-use change agent-based model (thus far the implementation of the ABM uses broad global scenarios only; see http://www.openabm.org/model/2870/version/2/view).

We applied formative scenario analysis, a structured technique that integrates knowledge from a wide range of sources such as literature, statistics, and stakeholder workshops, to arrive at a coherent and robust set of scenarios. This technique combines qualitative and quantitative approaches (using specific software: http://www.systaim.ch/). We realized that if we relied on stakeholders' knowledge and judgments alone we would obtain a biased picture, depending on the specific group of stakeholders and the most important impact factors uttered. It is all the more important to complement this type of data with scientific literature and other informants for a more generic picture that is not limited to the details of the case.

A critical issue, though, remains, regarding scenarios of long-term developments of social and environmental conditions. They cannot be forecast exactly, and future individuals' behavior and decisions are not fully predictable based on current individuals' interview data. For instance, qualitative stakeholder judgments in workshops on future landscapes and land-use to inform a land-use ABM remain limited because it is based on current preferences and people are blind to changing norms as the cognitive shifting baselines show [15]. This problem is difficult to overcome even with methodological insight.

IV. Discussion

In this section I, will discuss the previous examples and relate them to the challenges I mentioned in the introduction (see Table I).

TABLE I.
FUNCTIONS OF EMPIRICAL QUALITATIVE DATA AND RELATED CHALLENGES

Functions	Challenges
Explorative	Translation into ABM rationale; usability (type of data)
Details of agent rules	Translation of socio-psychological models of behavior (and considering the temporal dynamics); translating implicit knowledge.
Validation	Stakeholder-bias
Scenarios	Stakeholder-bias vs. detailed anthropological; constraints on complexity

Exploring potential key variables for subsequent investigations and agent-based models is a valuable function, especially for qualitative methods. However, the challenge is translating these variables appropriately into agent properties. The explorative function may or may not yield relevant results for the model. Moreover, the results may be preliminary, sufficient for adjusting the social scientists' focus to specific phenomena but not readily usable for the agent-based approach. In addition, the data may hint at issues that cannot be covered by the models applied. For instance, even if water quality is emphasized as an important issue during interviews (and in the literature), if the models' aim is different or implementation is just too complex, one cannot pursue this issue within this project.

To investigate the micro-processes that inform *agents' rules*, an experimental setting may be appropriate, because one can focus on specific processes in controlled settings. However, due to these controlled situations, the experiments are artificial and constrained to narrowly defined phenomena. Thus, the precision is higher than necessary for many multi-agent simulations. Therefore, as in our example, the trade-off is between socio-psychological excellence (artificial situation and control) and application relevance (e.g., focus group discussion or interacting dyad).

Validating the model concept and/or simulation results is part of the modeler's responsibility during the modeling process. However, as illustrated by the case of evaluating stakeholders' judgments, this evaluation has to be critically reflected. Stakeholder bias is a challenge here, too. Another challenge is that evaluation usually targets the macro or aggregate level of agent simulations (whether expected patterns emerge). Social scientists such as psychologists, instead, tend to be interested in phenomena and processes on the micro level, and address questions of representativeness of the results for individuals.

Developing scenarios with stakeholders or based on the literature forces the analyst to identify the most important impact factors and their future states. The question arising is what is the limiting factor: the complexity of the topic, and thus the number of impact factors and future states, or the number of parameters in the model? To arrive at a coherent set of scenarios, the interaction between the impact factors must be considered, whether they are conflicting, neutral, or enhancing. However, the degree of detail is usually limited by practical constraints. Here, a trade-off similar to the one identified in case *B* (details of rules) may appear. A scenario analysis focusing only on the properties of the model may fall short in relevance as a standalone contribution. An idiosyncratic, anthropological perspective on the case study area at hand and its specific conditions may be extremely interesting for social researchers and an idiographic approach recommended from a qualitative social-science perspective. However, from a modeling perspective, one cannot implement every detail, and each model will be limited in terms of the phenomena it can address.

The problem of potential stakeholder bias is obvious in the *scenario* function described for the formative scenario analysis but also affects the *validation* function. A counter-measure is a thorough stakeholder analysis and a representative group of participants (actors) from different sectors to cover different factors [21]. However, in reality, a "convenience sample" is often used, because of the time constraints of researchers and stakeholders alike. In our case, for instance, we missed representatives of the tourism business (e.g., hotel owners), because they were not interested in and were unavailable for our workshops.

The type of data needed for agent-based models typically differs from data gathered in social-science research; thus, sometimes the methods differ or are applied differently. Researchers using modeling are more interested in process data (e.g., behavioral rules) or time-series data (of long-term environmental and social variables). In this presentation, I highlighted examples social scientists (primarily social psychologists) may use to serve functions in agent-based modeling and simulation. As shown, there are challenges ahead, and compromises have to be made and trade-offs solved. A deeper discussion of these issues may yield interesting insights and reveal additional challenges, relevant for researchers of other disciplines. Moreover, reflections by researchers from other disciplines should complement the perspective given in this presentation.

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Social Contagion and Homophily within Romantic Network

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***Abstract*—This paper presents an agent based simulation model which attempts to show how the diffusion of a cultural-trait can be affected by an uneven distribution of influence-capacity among individuals. For the sake of concretion the model represents a population of teenagers who attempt to find a romantic relationship looking for a partner within their friendship ties. Partner choice is ruled by a homophilic principle (agents look for someone who is similar to them in a given socio-cultural trait, given a certain range of tolerance to difference). It is shown how the assignment of an especial weight on partner's influence can affect the contagion process, even if the number of romantic relationships represents a small fraction of the total number of links.**

I. Introduction

THE aim of this paper is to present an agent based simulation model, which attempts to show how the diffusion of a cultural-trait can be affected by an uneven distribution of influence-capacity among individuals. In addressing this problem two theoretical concepts are central: contagion and homophily.

"Contagion" is a fairly well known social phenomenon. Since Coleman, Menzel and Katz celebrated study on the diffusion of the use of "gammanym" among doctors [1], it is widely accepted that the influence of peers on individuals' decision to accept or refuse a given socio-cultural trait produces a kind of "snow-ball process" that usually can be represented with a typical S-shaped diffusion curve, being the speed of the process dependent on certain characteristics such as the characteristic of the "critical mass" or the network topology. This process usually ends with a fairly large proportion of the population adopting the new trait [2].

Homophily is a basic principle of structuration of social relations which means that similar individuals are connected among themselves more often than dissimilar ones, a well documented pattern in many realms of social life [3, 4]. This tendency may be the product of the distribution of population over relevant social attributes [5], the structuring impact of social foci of interaction on individuals' networks [6], or the preferences of individuals for similar others [7]. Whatever its cause, homophilic patterns have the implication of larger homogeneity in social relations than would otherwise be expected.

For the sake of concretion the model presented in this paper represents a population of teenagers who attempt to find a romantic relationship looking for a partner within their friendship ties. Partner choice is ruled by a homophilic principle which is, in the case of this artificial society, assumed to operate in a very simple way: agents look for someone who is similar to them in a given socio-cultural trait, given a certain range of tolerance to difference. At the same time, the value of this trait (which is assumed to be measured in a quantitative scale) for every agent is influenced by the values of other agents' traits in its immediate environment but –and this is the central issue of the paper- if the agent is engaged the influence of its partner is assumed to have an especial weight (which is also assumed to be measured in a quantitative scale). The statistical analysis of the model's outputs show that this uneven influence indeed has an effect on the contagious effect. What makes this result noteworthy is the fact that, because the network structure is assumed to be fixed and the rules of making romantic relationship are so restrictive (see the description of the model below), it emerges as the product of the behavior of a very small fraction of the population.

The paper will proceed as follows: First, the computational model is briefly described. Second, main results of the analysis of the model are presented. Then a discussion of the results follows. Finally, the paper ends with a short section of conclusions.

II. A Social Contagion and Partner Choice Model

In order to analyze how the dynamics of homophily and contagion interact, I have built an agent based simulation model (which I call SCPCM) where diffusion of a trait and

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partner choice evolve at the same time within a population of 200 agents embedded in a network of 20 links per node on average. The structure of the network is kept constant (that its, there is no network evolution) in order to not to confound the effects of variation of agent's behavior and the possible effect induced by the variation of network topology. The model is fully described in the appendix, following the ODD protocol designed by Railsback and Grimm [8]. A brief description of SCPCM is provided in this section. Afterwards some hypothesis are suggested.

A. Brief description of SCPCM.

The program was implemented in the platform Netlogo [9], and reproduces the following steps (see Diagram 1 below):

1. The social network is seeded
2. One of the agents is randomly chosen.
3. If the agent has not a partner, it is asked to look for someone according to the following rules:
   - The partner must be found among link neighbors
   - The partner must be of a different sex.
   - If the agent' sex is male the partner must be younger; and the other way round if it is female.
   - The difference between the values of the trait must be within a range of tolerance which is set by a tolerance-parameter (τ).
4. If a partner is found, both agents engage. This relationship may be broken with a probability which is set by a breaking-probability-parameter (β).
5. Whether a partner is found or not, the agent is influenced by their link neighbors according to the following rules:
   - If the agent is not engaged, the value of its trait becomes the median of its link neighbors.
   - If he agent is engaged, the value of its trait is determined by both the value of the trait of its partner, weighted by a weight-parameter (ω), and the median of its link neighbors, weighted by 1 - ω .
6. Return to 2 until the process is reiterated 1,100 times.

In summary, the model contains two different mechanisms of social interaction: On the one hand, agents select their partners following a homophilic rule. The homophilic strength of the choice is determined by the parameter τ, which ranges from 0 to 1. On the second hand, agents are influenced by other agents they are tied to, so the values of their traits converge to a central value of the local environment. This contagious process is, nevertheless, affected by previous partner selection, since the value of trait of partner has a special weight. The strength of partner's influence, relative to other agents' influence, is determined by parameter ω, which also ranges from 0 to 1.

In the end there is a feed-back process between partner choice and trait contagion: the distribution of trait values influences agent's partners' pool; and, at the same time, agents' choices of partner influence the distribution of trait values. The model attempts to show the outcomes of these reinforcing flows, paying special attention to the fact that the variation among agents' values of trait within the network is determined by parameters τ, β and ω.

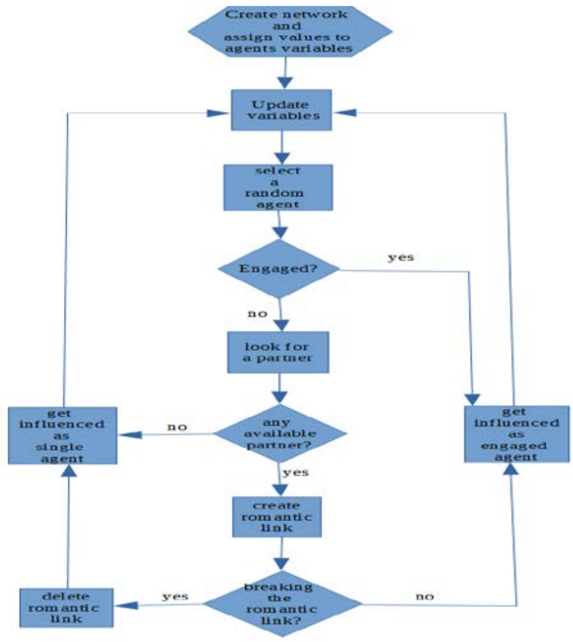


Diagram 1

B. Hypothesis.

Concerning the contagious process, variation in the distribution of trait should be positively associated with tolerance, since tolerant individuals will be "comfortable" in a world with high diversity. It should also be negatively associated with weight of partners influence, since if may partner has a strong influence on my, overall diversity is reduced. Nevertheless, there is not an obvious way to relate it to the probability of breaking a relationship. Therefore it can be expected that:

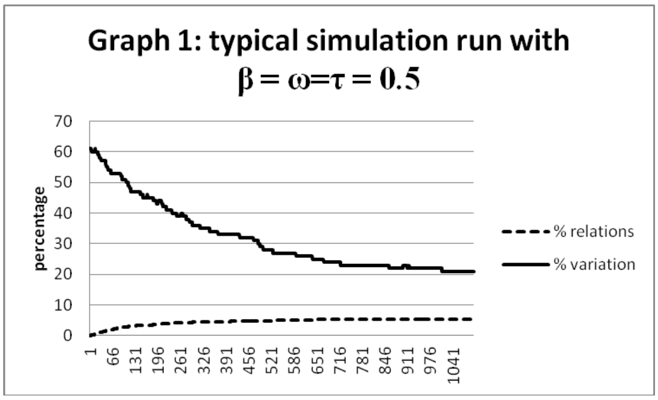
- The higher τ, the higher coefficient of variation of the trait (H1).
- The coefficient of variation of the trait will not be sensitive to β (H2).
- The higher ω, the lower the coefficient of variation of the trait (H3).

On the other hand, concerning the partner choice process, it is straight forward that as the probability of breaking romantic relationships increases, the final number of relationships must also increase. It would also seem quite obvious that the higher the tolerance to trait's difference the number of relationships should also increase. Therefore it can be expected that:

- The higher τ, the higher the number of relations (H4).
- The higher β, the higher the number of relations (H5).
- The number of relations will not be sensitive to ω (H6).

III. RESULTS

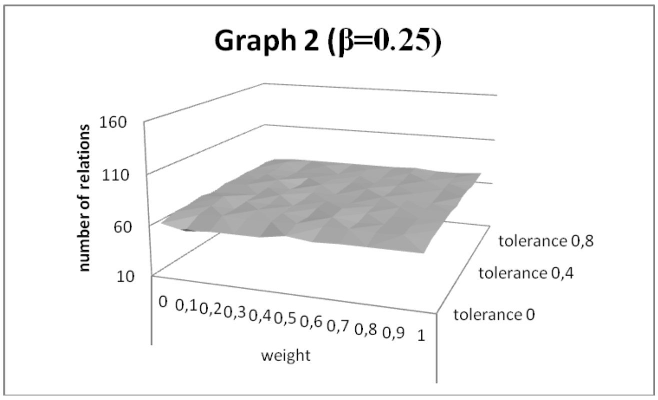
A series of simulation experiments exploring the parameter space of τ, ω and β were conducted; reiterating the simulation 50 times for every experimental condition, which amounts to 66,500 simulation runs. Results of these experiments show the emergence of patterns which are quite different from the simpler models, where every dynamic operates independently. Graph 1 displays the evolution of coefficient of variation of trait (%) and of number of relations (as a percentage of total friendship links) in a typical simulation run. The trends are quite clear: the variation of trait continuously decreases from roughly 60% to roughly 20% as the simulation progresses; meanwhile a number of romantic relationships emerge on the early stages of the simulation, and although some of them will disappear and new ones will appear the rate to total friendship relations will be kept mainly constant throughout the simulation run at a value of roughly 5%.

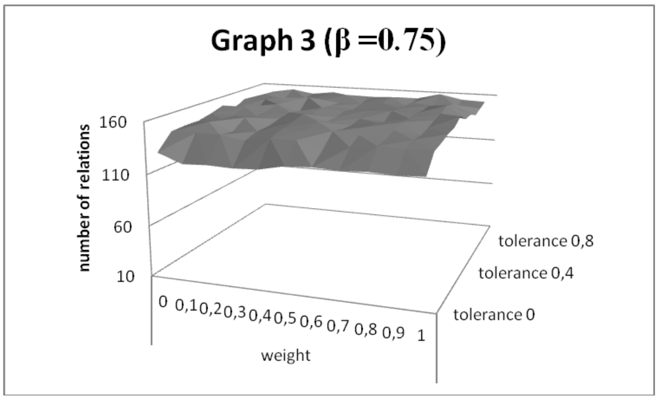


A. Number or romantic relationships.

Concerning the number of romantic relationships, the simulation provides clear support for hypothesis H5 and H6, as can be easily shown in graphs 2 and 3, which represent the number of final relationships for every combination of the spectrum parameter of τ and ω, when β equals 0.25 and 0.75 respectively[1]. It is quite obvious that variation in parameter β has the expected effect: the higher the probability of breaking a relationship, the higher the number of final relationships. It is not only the expected effect but also the greatest effect, since parameters ω and τ do not seem to have any influence. This result is clearly counter-intuitive, since one would expect the number of relations to increase with tolerance to trait of partner, as suggested by H4.

[1] Results shown in graphs are the mean values of 50 repetitions for every combination of parameters.





The linear multivariable regression model estimated for this dependent variable clearly confirms the impression produced by the graphs. "Probability of breaking a relationship" has the strongest significant effect on the dependent variable, while "weight" has no significant effect at all and "tolerance" has a very weak (although significant) effect, as shown in Table 5.1, which displays the results of the model. The value of R square for the model 0.547.

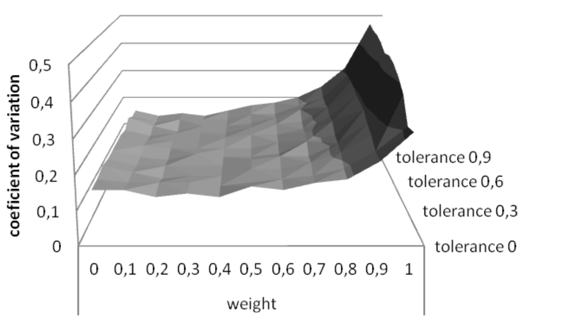
TABLE 1. DEPENDENT VARIABLE: NUMBER OF ROMANTIC RELATIONS

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	30.075	.171		176.289	.000		
probability-of-breaking-up	109.753	.203	.738	540.454	.000	1.000	1.000
tolerance	8.801	.185	.065	47.606	.000	1.000	1.000
weight	-.248	.185	-.002	-1.338	.181	1.000	1.000

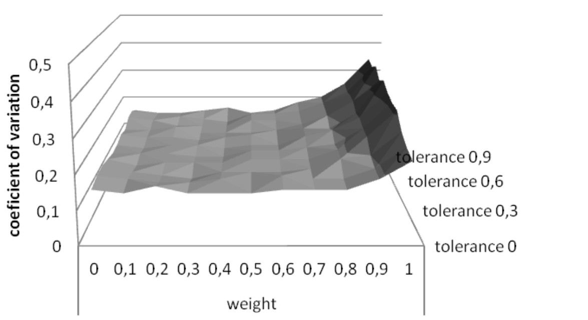
B. Coefficient of variation of trait.

The results concerning the coefficient of variation of trait are more counter-intuitive. The variation of trait among agents increases as β decreases, but only with high values of both ω and τ. If weight of partner's trait is high, but tolerance to partner's difference is low or, the other way round, tolerance is high but weight is low, the probability of breaking a relationship does not seem to have an effect on the coefficient of variation.

Tolerance to partner's trait and weight of partner's influence have very different effects. On the one hand the coefficient of variation does not seem to be very sensitivity to the values of parameter τ. On the other hand, parameter ω seems to have the strongest influence, as coefficient of variation of trait clearly increases the higher the values of ω.



Graph 4 (β=0.25)



Graph 5 (β=0.75)

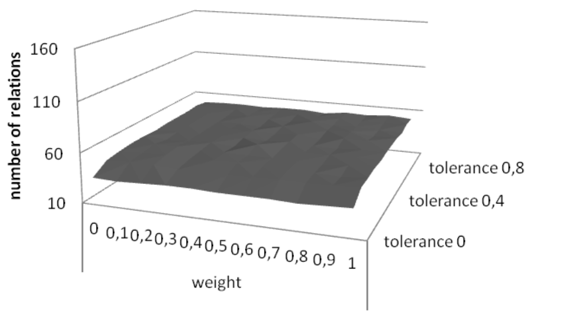
The linear multivariable regression model estimated for this dependent variable shows (see Table 2) that "weight" has the strongest significant effect on the dependent variable, but it is negative rather than positive. The effect of "tolerance" has the expected direction, although it is a rather small. Contrary to our expectations "probability of breaking a relationship" has a significant, even if small, negative effect. The value of R square for the model is just 0.192, implying that the model poorly captures the logic behind the variation of the dependent variable.

TABLE 2. DEPENDENT VARIABLE: COEFICIENT OF VARIATION OF TRAIT

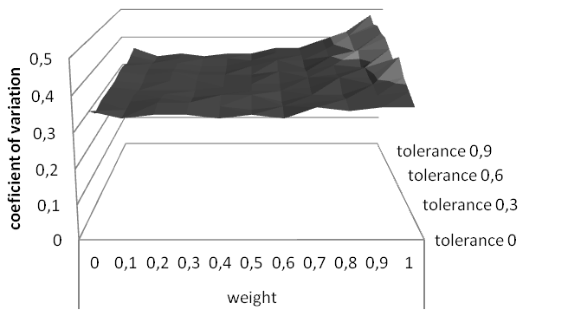
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	.181	.001		353.862	.000		
probability-of-breaking-up	-.030	.001	-.090	-49.124	.000	1.000	1.000
tolerance	.018	.001	.059	32.170	.000	1.000	1.000
weight	.129	.001	.424	232.622	.000	1.000	1.000

C. Sensitivity to average number of ties.

A straightforward question over these results is whether they are dependent (and if so, to what extent) on the topology of the network. (As explained in the appendix, the network is created by means of an algorithm which randomly assigns links to agents until the number of links per agent fits a certain average node degree parameter, which throughout the whole range of simulations has been set to 20).



Graph 6 (average node degree = 4)



Graph 7 (average node degree = 4)

In order to answer this question, new simulations were conducted varying the average node degree. Graphs 6 and 7 show the number of relations and coefficient of variation when the average node degree equals 4 (i.e. agents have 4 links on average) and the probability of breaking a relationship equals 0.5. The influence of average node degree on the number of relation is obviously a deterministic outcome of the model: since agents choose their partners among their linked neighbors, the less the number of ties the less the number of romantic relationships. The estimated regression model (see Table 3) shows a strong significant effect of this variable. R square for this model raises up to 0.743 .

TABLE 3. DEPENDENT VARIABLE: NUMBER OF ROMANTIC RELATIONS

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1 (Constant)	-12.346	.162		-76.092	.000		
probability-of-breaking-up	109.790	.153	.738	716.837	.000	1.000	1.000
tolerance	8.773	.139	.065	62.921	.000	1.000	1.000
weight	-.253	.140	-.002	-1.811	.070	1.000	1.000
average-node-degree	3.394	.008	.442	429.131	.000	1.000	1.000

On the other hand, the influence of average node degree on the coefficient of variation is less straightforward. The linear multivariable regression model estimated for the coefficient of variation (see Table 4) shows that "average node degree" has the strongest significant effect, which is negative. The effects of "weight", "probability of breaking a relationship" and "tolerance" are similar to the model shown in Table 5.2 above. The value of R square raises in this model up to 0.507.

TABLE 4. DEPENDENT VARIABLE: COEFICIENT OF VARIATION OF TRAIT

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1 (Constant)	.302	.001		599.056	.000		
probability-of-breaking-up	-.030	.000	-.090	-63.098	.000	1.000	1.000
tolerance	.018	.000	.059	41.360	.000	1.000	1.000
weight	.129	.000	.424	297.775	.000	1.000	1.000
average-node-degree	-.010	.000	-.561	-393.762	.000	1.000	1.000

IV. DISCUSSION

Summarizing, in SCPCM the probability of breaking a relationship has a very strong positive effect on the number of relations, and a weak (but still significant effect) negative effect on the variation of trait. Tolerance to others has a positive significant effect on both variables, but in every case this effect is rather small. The strongest effect on variation of trait comes from the average node degree and the weight of partner influence (which has no effect at all on the number of relations).

There are a number of counter-intuitive results that should be stressed. One would expect higher levels of trait variation the higher the tolerance; however tolerance to others has no strong effect on trait variation. In the model the coefficient of variation invariably falls, mainly driven by the number of available ties per agent and the weight of partners' influence. These effects are also counter-intuitive, insofar as one would expect the influence of these variables to operate on the opposite direction than they actually do. It should be expected the variation of trait to increase as the number of different neighbors also increases, and to decrease as the weight of partner's influence increases. But the statistical tests show that it actually happens the other way round. Why is this so?

The dynamic of the simulation model allows us to understand this puzzle. Because the process of contagion is necessarily stronger the denser the network of ties, the diversity among agents is reduced (and, at a network level, the emergence of a number of trait-clusters is fostered). A result which has already been observed in previous models [10, 11]. Furthermore, when the influence of the (similar) partner has a higher weight than the influence of other linked neighbors, homophilic choices of partners seem to reinforce the homogenization effect of social contagion. I do not know of previous research accounting for this effect.

Finally, an important result of the analysis is, since the effect of "weight" on the variation of trait necessarily depends on the number of romantic relationships created through the simulations, and because this number is only a small proportion of the total amount of relations (unlikely to be higher than 5%), it follows that the behavior of a small number of agents have a strong impact on the evolution of the whole system, what is an usual feature of complex adaptive systems.

V. CONCLUSION

Contagion models usually relay on the assumption that an agent is "infected" if the rate of infected neighbors is above a certain individual threshold. The model presented in this paper departs from this basic scenario in two ways: Firstly, agents do not show a dichotomic trait (so they cannot be classified just as "infected" or "not infected", but they differ on a continuous scale measuring a certain trait (e.g. a given musical taste), and secondly they are not equally sensitive to all its neighbors (i.e. one of its neighbors has an especial "weight" on agent's decision to change its trait). Our analysis suggest that attention should be paid to "power" differences (especial weights) on the influence process driving social contagion, since it may have a significant impact on it.

APPENDIX: ODD PROTOCOL

A. Overview

1. *Purpose*: the model has the purpose of exploring how two different social dynamics, diffusion of a cultural trait and romantic matching, influence one each other. The specific problem the model addresses is: how these processes are both dependent on interaction based on three individual characteristics: sensitivity to others' similarity, influence of partner on owns decisions, and likelihood of breaking a romantic relationship. The model explores this dynamics in a fixed network of 200 agents which are intended to represent teenagers who hold friendship relationships which may evolve, if the right partner is found, to romantic relationship.

2. *Entities, state variables, and scales*: the model has three kinds of entities: boys, girls and links. The environment consists of a torus of 81x81 patches which have no state variable. All agents, whether boys or girls, have the following state variables: sex (boolean), age (numerical), engaged? (boolean), partners-memory (list), trait (numerical), and influence-threshold (numerical). Links represent the type of relationship between two agents by means of a color code (see below).

   Global variables are: number-of-romantic-relationships (numerical) and trait-variability (numerical), which are the main outputs of the model. Other global variables are set as parameters: likelihood-of breaking-a-relationship (numerical) tolerance-to-cultural-difference (numerical) and weight-of-partner-influence (numerical). All three of them are key parameters to explore in the model. Besides them, average-node-degree (numerical) and mean-influence-threshold (numerical) are parameters who control the average number of ties per agent, and the average sensitivity of agents to social influence.

   There are no temporal or spatial scales, since real time and/or real environment are not simulated.
3. *Process overview and scheduling*: The model includes the following actions executed every time-step in the same order:
   1. One agent is randomly chosen.
   2. If the agent is not engaged he is asked to look for a partner.
   3. If a partner is found the agent is asked to engage.
   4. Whether the agent is engaged or not it is always asked to be culturally influenced (i.e. change the value of its cultural trait).
   5. Variables are updated.

   The simulation stops after 1100 time steps, which is enough for the model to reach an equilibrium point.

B. Design Concepts

4. *Design Cocepts:*

- *Basic Principles*: The model attempts to capture the interaction of two different mechanisms: homophily and contagion. Homophily is the principle by which people tend to make relations with other people similar to them in certain traits. For the sake of simplification only one trait is represented. Contagious is a process which produce the spread of a certain trait among a population by means of social influence. In the model agents look for a romantic partner similar to them in a certain cultural trait, which is measured in a quantitative scale. At the same time agents are also influenced by their relationships, whether romantic or friendship, although these two different sources of influence do not have the same weight.
- *Emergence*: The model shows how the dynamics of romantic-matching and social influence are interdependent so the rate of variation of the cultral trait among the population and the number of romantic relationships both differ from the scenario where these two processes are independent.
- *Adaptation*: Agents perform two kinds of adaptive behavior. They become engaged if there is an agent in their local environments who meet the conditions to be chosen as a partner (details below). Second, agents change the value of their trait by means of a social influence process (details below).
- *Objectives*: There is not a fitness or utility measure in the model to be optimized. However agents behave as if they had the goal of finding a romantic partner.
- *Learning*: Agents do no learn from past experience.
- *Prediction*: Agents do not predict future conditions.
- *Sensing*: All agents occupy a position in a network, which is assumed no to evolve as time progresses. The network represents the web of friendship relationships among teenagers. When searching for a partner and when updating the value of its cultural trait, every agent has access to states variables of its local environment (i.e. other agents it has a direct tie with).
- *Interaction*: Boys and girls in the same local environment interact making (and breaking) romantic relationships (see details below). All agents in the same local environment interact influencing one another on the value of their cultural traits (see details below).
- *Stochasticity*: Stochastic processes are used in the initialization in different ways. The social network is seeded with random number 1111, in order not to confound the effect of variation on the network's topology with the effect of agents' behavior. State variables of agents are randomly initialized in every simulation run. The agent behaving in every simulation run is also randomly chosen. Since there are 200 agents and the simulation lasts for 1200 ticks, every agent has on average 6 chances of making a relationship and being influenced. Random numbers are also used in some submodels (see details).
- *Collectives*: There are two agent sets: boys who may engage with girls younger than them; and girls who may engage boys older than them. Both, boys and girls, are subject of social influence in the same way.
- *Observation*: At the end of every simulation run required outputs are: a) number of social relationships made up through the simulation; b) actual coefficient of variation of the cultural trait. Plots show the evolution of these indicators through time steps. Besides that, it is also shown in the interface whether a certain link represent

friendship (black links), a current romantic relationship (green links) or a past relationship (grey links). Agents are represented by means of circles whose color shows the value of the cultural trait (from light gray for low values to dark gray for high values).

C. Details

5. *Initialization*: The simulation is initialized with 200 agents, whose state variables are randomly assigned. Sex is assigned with 50% chance. Age of agents is picked up from a uniform distribution within the range 14 to 17. Trait of agents is picked up from a uniform distribution within the range 0 to 9. Influence-threshold is set by a parameter between 0 and 1 (currently set to 1, i.e maximum sensitivity to influence). The variable engaged? is set false for all agents. Memory of past partners is initially empty.
   Then, links are then created with a random seed; the random assignment of links to agents ends when the condition of 20 links per agents on average is met. This produces a small-world type of network. The procedure is copied from Stonedhal and Wilensky (2008).
6. *Input data*: no input data are required.
7. *Submodels*:

- *Look for a partner:*

If an agent is selected to look for a partner it will randomly pick, if any, one of his link neighbors which meet tall three conditions:

a) opposite sex

b) if agents is a man, partner must be younger. If it is a woman, partner must be older.

c) the absolute difference between the two values of trait divided by ten must be less than the value set by the parameter tolerance. This grants that agents will engage with agents with very similar value in trait when tolerance is low; but pool of possible partners will be larger when tolerance is high.

- *Get engaged:*

If a partner has been selected, the agent checks that it is not a member of the list of previous partners. Then it includes partner in this list, change the state of engaged? to true, and asks partner to do both actions. However if a random number extracted from a uniform distribution between 0 and 1 is below the value set for the parameter probability of breaking the relationship, the variable engaged? is set again false for both agents.

- *Get influenced:*

Whether the agent is engaged or not it will be subject of social influence. If it is engaged its trait will become equal to the value of the trait of its partner, weighted by the value of parameter weight, plus the median of the values of their local relationships, weighted by one minus weight. When it is not engaged, the value of its trait just becomes the median of the value of their local relationships.

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Triadic Balance and Closure as Drivers of the Evolution of Cooperation

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ABSTRACT

The prevalence of human cooperation continues to be one of the biggest puzzles for scientists. Structured interactions and clustering of cooperators are recognized mechanisms that help the dissemination of cooperative behavior. We analyze two dynamic micro structural mechanisms that may contribute to the evolution of cooperation. We concentrate on two mechanisms that have empirical justification: triadic closure and triadic balance. We study their relative efficiency under different parametric conditions, assuming that the structure of interactions itself might change endogenously as a result of previous encounters.

Keywords: evolution of cooperation; signed graphs; network dynamics; negative ties; triadic closure, triadic balance.

I. INTRODUCTION AND RELATED LITERATURE

It is difficult to justify the wide spread and extent of human cooperation. Cooperation is not the option that a calculative (rational) individual should choose in a social dilemma situation, such as the Prisoner's Dilemma (Axelrod 1984; Axelrod and Hamilton 1981). Structured interactions and the consequent clustering of cooperators, have been suggested as major mechanisms that support the emergence and dissemination of cooperative behavior (Hauert and Doebeli 2004; Lieberman et al. 2005; Nowak 2006; Ohtsuki et al. 2006; Santos et al. 2006). In fact, human interactions are seldom truly random: they are frequently repeated and they include partners in close spatial proximity or who are linked by a social network. The structure of social interactions also changes over time, sometimes endogenously, as a result of cooperation (Santos et al. 2006; Wang et al. 2013; Yamagishi and Hayashi 1996; Yamagishi et al. 1994). In this study, we consider a non-random structural dynamics and we use agent based modeling to explain the emergence and spread of cooperation in such context.

Social networks change in many different ways. The underlying mechanisms that govern their dynamics have just started to be characterized systematically (e.g., Ahuja et al. 2012). *Exogenous random changes* tend to diminish chances of cooperation diffusion as they introduce frictions to the establishment of clusters of cooperation (Durrett 2007). It is more realistic to consider *exogenous non-random changes*, such as preferential attachment and small world rewiring that describe observed patterns of dynamics and drive networks towards clustered topologies. These dynamics tend to result in more success for cooperative strategies (Wang et al. 2008). Finally, *endogenous topological changes* that reflect on previous play, are the most realistic as they highlight the interdependence between structure and behavior. Moreover, they are the most likely to speed up the evolution of cooperation.

In the current study, we concentrate on two endogenous mechanisms that have empirical justification in many social contexts: triadic closure and triadic balance. Both mechanisms are related to the concept of cognitive balance (Heider 1946), i.e, to the propensity of couples of individuals to align the way they feel about an object (or, in our case, a third person). *Triadic closure* is the tendency of "friends of friends" to become friend themselves or, from a network topology perspective, of triads to close (Fararo and Skvoretz 1987; Granovetter 1973; Rapoport 1953). *Triadic balance* is the tendency of people to maintain cognitive consistency in their relationships by changing the valence of their relationships in established triads so that the multiplication of signs turn positive and the relationships are structurally balanced (Cartwright and Harary 1956). In the context of our model, these mechanisms are chosen as they allow to endogenize both the relational sign evolution and the topological network update in an empirically justified manner.

Our aim is to study the efficiency of these dynamic network mechanisms for cooperation under different parameter conditions. We analyze their effect alone, but we also test if they have a synergic impact on cooperation, in addition.

II. THE MODEL

The agent-based model presented in this paper builds on our previous models (Righi and Takács 2013, 2014a,b,c). Our setup allows the coevolution of network structure, relational signs and agents strategies in the context of *signed networks*. In the current study, we introduce two empirically based mechanisms (triadic closure and triadic balance) that guide the evolution of cooperation.

We consider a population of size N, connected by a non-weighted, undirected network. The ties are assumed to be signed and are either positive or negative. Each agent i can play the Prisoner's Dilemma (PD) with peers in his current first order social neighborhood, and only with them. The social neighborhood of i is the subset of the population he shares network ties with, formally $\mathcal{F}_i^t \subset N$. The cardinality $|\mathcal{F}_i^t|$ (i.e., the degree of agents at time t) is assumed to be distributed according to some arbitrary probability mass function $f(k)$. For the sake of the preliminary simulations discussed in this manuscript, we considered an Erdős-Rényi *random network* with each link existing with an independent probability 0.10 at the setup. This type of network provides a useful benchmark against which to study results for other topologies.

Considering the existence of a signed link between two agents i and j, the strategy played by i in the PD can be of three types. (1) *Unconditional Cooperation* (hereby named UC): a strategy that always cooperates, regardless of the sign of the relationship between i and j. (2) *Unconditional Defection* (hereby named UD): a strategy that, symmetrically, always defects. (3) *Conditional Play* (hereby named COND): a strategy that prescribes cooperation for i if the link between i and j is positive, and prescribes defection if the link between i and j is negative.

Each dyadic game yields a payoff for the players, defined according to the classical PD in Table 1. When two agents cooperate with each other, each gets a reward (R). When they both defect, they are both punished (P). Finally, when one agent defects and the other cooperates, the first gets a temptation payoff (T) while his partner obtains the sucker payoff (S). The game is defined with payoffs $T > R > P > S$. In line with Axelrod (1984), we further assume that $T + S > R + P$. The dynamics of our model is summarized

TABLE 1: The Prisoner's Dilemma payoff matrix. The numerical payoffs used here are the same as those of Axelrod (1984).

	C	D
C	$(R = 3, R = 3)$	$(S = 0, T = 5)$
D	$(T = 5, S = 0)$	$(P = 1, P = 1)$

in Algorithm 1. At each time step, every pair of currently connected agents play the PD, and individual payoffs are calculated. As a consequence of the strategies played, tension emerges in a relationship, if a cooperator faces defection from the opponent. Tension can result (with probability P_{bal}) in an update of the status of the relationship which is hereby modeled through the empirically grounded mechanisms of balance. Moreover, in the absence of tension among agents, the mechanism of triadic closure mechanism is activated with probability P_{clo}; implying the closure of one triad involving the partners. Tension in social relationships in intended to model in a very simple way, the emotional consequences of partners behavior. In addition, in order to make meaningful comparisons, we will also study the effect of exogenous triadic closure and balance mechanisms on cooperation, in which the structural change is independent of previous play, but depends on previous structure.

for *each pair of individuals* i *and* j *connected at time* $t-1$ **do**
  Compute the social neighborhood $\mathcal{F}_i^{t-1}$ and $\mathcal{F}_j^{t-1}$;
  Play the PD with i and j and compute payoffs;
  if *the link between i and j is tense* **then**
    Update relational signs between i and j so to maximize triadic balance (with probability P_{bal});
  else
    Select an acquaintance k of either i or j who is not connected to the other and close the triad (with probability P_{clo});
    Assign a relational sign randomly to the new relationship;
    Delete one relation who does not include i or j that has the relational sign of the new relationship randomly;
  end
end
for *each agent* i **do**
  Compute average payoff of agent i;
  Observe the average payoffs of each agent $j \in F_i^{t-1}$;
  Adopt a random (strictly) better strategy (with probability P_{adopt});
end

Algorithm 1: Pseudo-code of dynamics of our model, repeated at each time step t. The relational update performed at time t, take effect only at time $t+1$. The PD is therefore played in parallel by all agents. The implementation details about the closure and balance mechanisms are discussed below.

Let's define more precisely the procedure through which closure and balance are introduced in our model.

Triadic Closure. Two agents, sharing a stable positive relationship (i.e. in the absence of tensions due to past behavior) tend to increase the number of common friends. This triadic closure mechanism is adopted with probability P_{clo}. When this is the case, agents (say i and j) select one of the acquaintances of either i or j, who is not an acquaintance of the other (denoted here with k). Agent k is then connected with the other agents so to obtain a complete triad. The new link is assigned a random sign. [1] Finally, to keep the overall density constant, one old link, not involved in any triad between i and j is selected randomly and eliminated. As we want to keep triadic closure neutral with respect to the evolution of relational signs, we further assume that if a new negative relationship is created, then an old negative one is deleted, and a new

[1]One could assume instead that the new link takes a sign such that the triad that results is in balance. However, we choose to use the random sign allocation rule in order to separate more effectively the role of triadic closure from that of triadic balance.

positive sign implies the deletion of an old positive sign. This mechanisms allows network topology and agent's strategies to co-evolve endogenously. Indeed, structural changes are induced by the absence of tension, which results from previous positive interactions. The probability P_{clo}, is assumed to be equal for the whole population and non-strategic.

Triadic Balance. When tension emerges in a dyad, due to the divergence of agents' behavior in the PD, it can be resolved through a balance mechanism. This is assumed to occur with probability P_{bal}. In this case, we consider the signs involved in all triads where both i and j are members. The relational sign between i and j is then changed so to maximize the number of balanced triads that involve them.

As discussed, each individual can only play the PD with other agents in his own local neighborhood. Following most of the literature on evolutionary games played on networks, we assume the *average* of the payoffs obtained in dyadic interactions as the measure of individual fitness. Due to this assumption, it is important that the order in which dyads are selected for interaction, does not matter for the outcome. For this reason, each dyad interacts and updates strategies and link signs observing only the previous step status quo. Moreover, changes in network topology, relational signs and strategy updates take effect from the following time step. We thus assume that updates are made in parallel.

Finally, the **evolutionary mechanism** that we adopt in this paper is relatively simple. After all agents performed their round of social interactions, each observes his average payoff as well as the ones of the agents he played with in his social neighborhood. Thus each agent is able to measure the relative local efficiency of his strategy. If a subset of agents in $\mathcal{F}_i^t$ has a payoff higher than his own, then agent i adopts the strategy played by one of them, selected uniformly at random. Evolutionary update happens, for each agent, with probability P_{adopt} which is assumed equal for all agents.

III. Preliminary Results and Discussion

In this section, we introduce some preliminary results on this model. In particular, we study the effect on cooperation of one of the mechanisms discussed: triadic closure. In the simulations reported, we fixed P_{bal} to 0.15. This is a first step in the direction of a more comprehensive analysis that we are in the process of developing. What is the impact of triadic closure on the level of cooperation observed in the model? In Figure 1 and 2 we show that, at any level of P_{adopt}, in the absence of a closure mechanism, no cooperation survives. Increasing the probability of closure to occur progressively, our setup suddenly enters a short but intense phase of instability, where simulation results differ widely (hence the high standard deviations). Subsequently, the proportion of negative ties, surviving at the end of the simulation, suddenly drops and the proportion of conditional and unconditional cooperators jumps to values significantly larger than zero.

Moreover, the level of closure required for the emergence of cooperation increases with the probability of adoption of a better strategy. Indeed, increasing the evolutionary pressure tends to favor the evolutionary stable strategy: defection.

IV. Final Remarks and Further Work

In this extended abstract we introduced a model aimed at studying the emergence of cooperation in a system where network topology coevolves with agents strategies and with relational signs. Building on our previous work, we introduced two mechanisms (and we began to study the impact of one of them) with the objective of understanding their impact on cooperation on signed networks.

In this paper we only provide some exploratory results showing the role of triadic closure on the outcome of the simulations. Our results show that, at any level of evolutionary pressure the introduction of enough triadic closure leads to the possibility of emergence of cooperation. The emergence of cooperation is not gradual but happens right after a sharp *phase transition*. On this regard our result is similar to the one proposed by Santos et al. (2006), which shows how rewiring can provide a mechanism for the emergence of cooperation. However we provide the sociological micro-foundation that justify the rewiring (and its effect on cooperation) and we extend the study to signed networks.

We are currently designing the simulations to study the impact of the triadic balance mechanisms on cooperation. Furthermore we are exploring the emerging meso-level mechanisms that produce the results discussed. Our further analysis will focus in particular on two aspects of our model: (1) the effects on cooperation of the interaction between triadic balance and triadic closure for different levels of probability of these two mechanisms and (2) the implications, for the emergence of cooperation, of the existence (or the absence) of an explicit causal link between the strategy played by agents and network/relational signs updates (endogenous vs exogenous dynamics).

One potential limitation of our approach is that both the social interactions and the social mechanisms are fully local. A further direction of research that we intend to explore will address this limitation studying the impact of closure and balance in a context where the PD can also be played among non connected agents.

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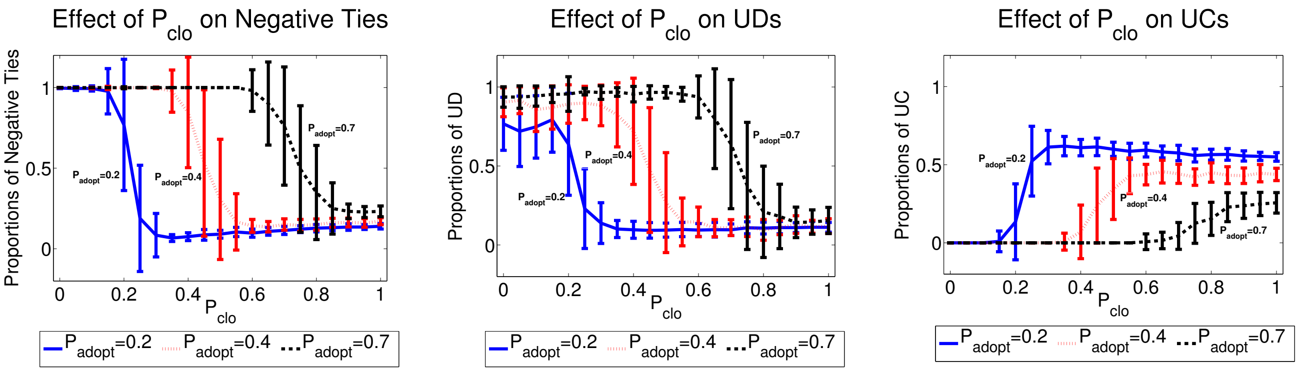

Fig. 1: Effect of the *Triadic Closure* probability at different levels of probability of adoption of a better strategy (P_{adopt}). Results provided for $P_{adopt} = 0.2$ (solid blue line) for $P_{adopt} = 0.4$ (dotted red line) and for $P_{adopt} = 0.7$ (dashed black line). Data for the final proportion of negative ties in the network (Left Panel), of UDs (Central Panel) and of UCs (Right Panel) are displayed. Each data-point represents the average of 50 simulations. For each simulations $N = 200$ and network signs are randomly initialized with equal probability. All populations are initialized as equally divided among the three agent types. The social networks are initialized as *random network* with each link existing with the independent probability 0.10.

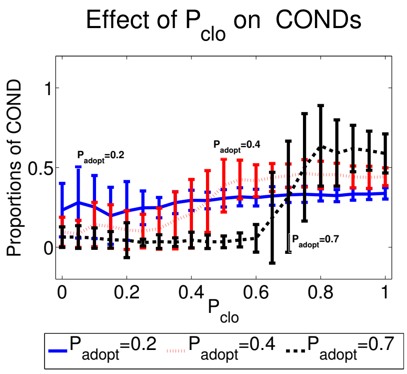

Fig. 2: Effect of the Triadic Closure probability on the proportion of CONDs, at different levels of probability of adoption of a better strategy (P_{adopt}). Results provided for $P_{adopt} = 0.2$ (solid blue line) for $P_{adopt} = 0.4$ (dotted red line) and for for $P_{adopt} = 0.7$ (dashed black line). Parameter values are the same as those in Figure 1.

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Rise, Fall and Abandonment in the Zambezi Plateau: An Agent-Based Model using the Canonical Theory

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***Abstract*—The Zambezi plateau region in Southern Africa has seen the rise and fall other several polities of different levels of complexity for many centuries before the arrival of Europeans and the beginning of the region's written history. One of the enduring questions this work raises is to explain the rise, fall and abandonment of large polities centered around large edifices with massive stone walls called "zimbabwes." The agent-based model presented here provides support for an explanation based on the Canonical Theory. In this theory, a succession of opportunities to engage in collective action by a polity strengthens or weakens the complexity of the polity. The main finding presented in the agent-based model is that group dynamics, centered on the collective feelings of loyalty to the group, can generate the macro level behavior that we see in the archeological record of Southern Africa.**

I. Introduction

THE MOTIVATION for this model is to explore how the Canonical "Fast Process" [1] can lead to polities dissolving with people moving to join larger, more advanced groupings.This process of abandonment exists in the archeological record of the Zambezi Plateau in present-day Zimbabwe.The process of abandonment is significant, especially in the case of the Zambezi Plateau, for two reasons: 1) it is important to establish how the first state-level polity in Africa came to be and why it disappeared, and 2) the abandonment and subsequent condition of Great Zimbabwe carries great weight in historical and modern Southern Africa [2, p. 771].

The walled enclosure of Great Zimbabwe supported a capital city for roughly 200 years, from 1275 CE to 1450 CE, based on the presence and absence of imported Chinese ceramics in the archeological record [3, p. 68]. After this date, Chinese blue-on-white porcelain is not found at Great Zimbabwe, but it is found at other important centers in Zimbabwe before and after this date. It is important to note that Collett, et al. disagree with Huffman on this point due to the presence of a large blue-on-white porcelain piece from the Ming Dynasty, 1488-1505 CE that is possibly related to Great Zimbabwe [4, p. 157]. However, Collett, et al. still use the term "abandoned" to describe Great Zimbabwe [4, p. 140].

Great Zimbabwe was not the first or only significant polity in the Zambezi Plateau. Pikirayi notes that prior to Great Zimbabwe, Mapungubwe "attained regional prominence during the thirteenth century, managing the resources of a territory that was equivalent to a state in both political and economic terms" [5, p. 3]. After the fall of Great Zimbabwe, the so-called "Zimbabwe Culture", "…marked by the presence of massive stone walls built in a variety of architectural styles," split into the northern and southwestern regions [5, p. 2-3].

Kim and Kusimba note that the first agrarian communities of the Zambezi plateau date to the first millenium CE and that "[t]he landscape …was dotted with temporary rockshelter settlements, semi-sedentary camps villages, and permanent settlements" [6, p. 137].

As can be seen, the sites of the Zambezi plateau have been the subject of significant archeological research; however, it has still been difficult to provide a theory of why this pattern of rise, fall and abandonment has occurred within the area. For example, Great Zimbabwe existed as a capital for a relatively short period of time, and when that period was over, it was seemingly cut off from receiving imports that had been coming to it from China. And rather than becoming a regional capital, or a noncapital, but still significant city, the site is treated as abandoned. This view of Great Zimbabwe helps explain how from the Portuguese arrival, which begins the written historical record, until the beginning of the twentieth century, there is a question of whether the site was even created by Africans [4, p. 140]. Even in the current day the site of Great Zimbabwe is treated with a distant reverence reserved for a hallowed, but forgotten place [2].

This paper examines how the Canonical Theory can provide an overarching theory to explain the process of rise and abandonment within the Zambezi plateau. This process can be explained by examining the interplay between group leadership and group loyalty during times of stress within the group. In this paper, I will present an agent-based model based on the Canonical Process that demonstrates how a social environment can evolve from something like what existed in the Zambezi plateau in the first millenium CE through the progression of larger and larger groupings. These larger groupings come about through a process of group dispersal by the individual agents, which serves as the significant collective action by the group.

II. Methodology

A. *Agent-Based Model of Canonical Process*

The methodology of this paper is based on the building and analysis of an agent-based model. In particular, the model was developed to implement a process for explaining the rise of social complexity called the Canonical Theory [1]. This theory describes a branching process that polities go through, where the polity follows particular branches when it experiences opportunities for collective action. As these opportunities come up again and again, the choices made by the polity can lead to greater, or lesser social complexity when examined on a longer time scale [1, p.138]. This "recursive" process [1, p.138] can happen relatively quickly, but the results and effects of it accumulate over time. This is key to the Canonical Theory which terms these the "fast" and "slow" processes [1, p.138].

The Canonical Theory provides a framework that ties together the micro-level activity by people in a society and the macro-level changes that a society goes through over long periods of time. This fits well with the goal of this paper, the examination of how individual-level choices can cause the startling effects that are seen in the archeological record around the rise and abandonment of sites in the Zambezi plateau. An agent-based model was chosen because one of the hallmarks of these types of models is that macro-level behavior in the model comes from the micro-level decisions of individual agents. In the current model, the agents represent individual people. Each individual can join a group of people, and each has a level or amount of two attributes: fealty and leadership. Fealty in this model is a measure of how attached or loyal one feels towards one's group in general and its leadership in particular. Fealty is a measure of attachement in that if it drops too low for the members of the group, they will seek to move onto another group with stronger leadership. All members in a group have a leadership score; however, when group decisions or measurements need to be made, only the individual with the highest leadership score counts as the group leader.

B. *Model Details*

The model is initialized with 100 groups, each with 50 members. This was chosen to represent a flat, undifferentiated setting as would exist prior to the origin of social complexity in the region. At the start, each agent is given a starting value for fealty and leadership. Both are taken from triangular distributions. Fealty randomly is assigned a value between 0 and 100, with a mode of 50. Leadership is assigned a value between 0 and 50 with a mode of 10. This is done to create an initial setting where high leadership is relatively rarer. Model input parameters set the payoff for an increase or decrease in fealty, which occurs as a result of collective action taken by the group. Runs of the agent-based model were made on a Macbook Pro with 4 processor cores. The model was created with Python 2.7.1 and the model allows for setting the fealty and leadership adjustments as input parameters; however, to clarify analysis, all runs are reported here with the same leadership adjustment parameter.

C. *Model Action*

The agent-based model runs as event loop where at each clock tick, each group of agents gets a chance to act on one or more of its behaviors. In this model, the event loop starts with the groups each deciding if some collective action should be undertaken. This is left as abstract within the current model. Collective action is "[w]hen a society correctly perceives and understands a given situational change, it may or may not be willing and able to undertake collective action ... in response to such a change" [1, p.144]. Specifically, the group will undertake collective action if the average fealty score for the group is below 50. If the average fealty score is below 10, the group will disband and abandon their site, dispersing to other groups. Collective action is successful with differing probabilities depending on the quality of the group's leadership (25% with good leadership, 10% with poor leadership). If collective action is successful, each member's fealty is increased by some (differing) amount If collective action is unsuccessful, fealty for each member is decreased. Furthermore, leadership scores are adjusted as a result of some (but not all) of the collective action attempts.

III. Results

The most significant result of the model is that the flat, homogenous set of groups quickly coalesce into a small number of much larger groupings, as seen in Fig. 1 and Fig. 2. This happens within the first 18 to 35 steps of the model. The model is set to begin with 100 groups, each with 50 members. Rapidly, this becomes between 1 and 13 groups with an average of between 384 and 5,000 members. No agents are born or die in this model, so the overall population remains the same. The speed with which the change in the model's society happens varies with different input parameters. It is interesting to note that the leadership scores have a positive linear relationship with the size of the group, even though it is only the score of the leader that is counted; that is, leadership scores are not additive among the group. Also, as the average number of groups increases, average fealty increases until between 5 and 6 groups, when average fealty decreases as number of groups get larger.

Additionally, the model shows a particular qualitative behavior in the movement of the average fealty levels during model runs. A fealty value is given to each agent at the start of the model in a triangular distribution between 0 and 100 with a mode of 50. The results from the model show that fealty quickly drops to relatively low values, becomes unstable, then recovers to a high value that stays stable for the rest of the model run. An example of this behavior is seen in Fig. 4. This happens at various beginning parameters and it happens at different speeds. One case behaves differently. Here (see Fig. 3), average fealty falls as before, rises to the starting level, then collapses to a very low value.

As the number of groups declines, the leadership score of the remaining group leaders rise. A leadership value is given to each agent at the start of the model in a triangular distribution between 0 and 100 with a mode of 10. Few agents begin with high leadership scores. However, the successful leaders end model runs with leadership scores orders of magnitude higher than what they started with as in Fig. 5 and Fig. 6. This point can be shown with representative graphs of the evolution of leadership in two groups, a successful one (Fig. 8) and one that disbanded quickly (Fig. 7). These two groups also present representative examples of the change in membership (Fig. 9 and Fig. 10) and the group fealty level (Fig. 11 and Fig. 12).

IV. Discussion

This model demonstrates how a society of disparate, small groups might evolve into one with a few large groups in response to changes in how group member

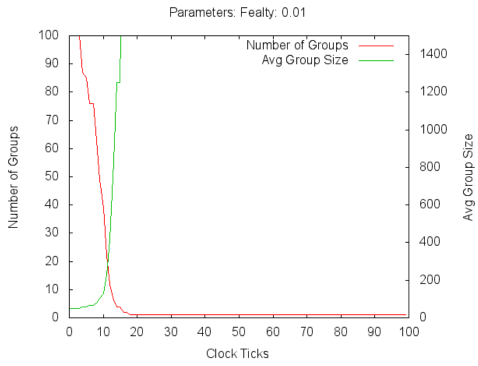

Fig. 1: Input parameters: Fealty, 0.01

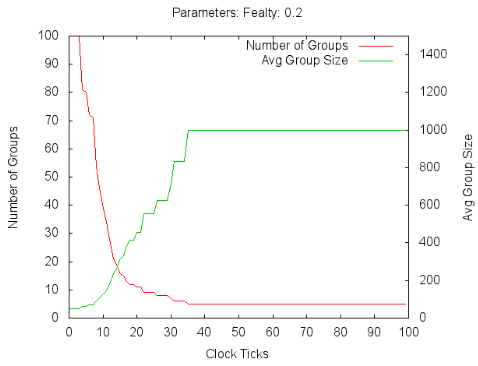

Fig. 2: Input parameters: Fealty, 0.2

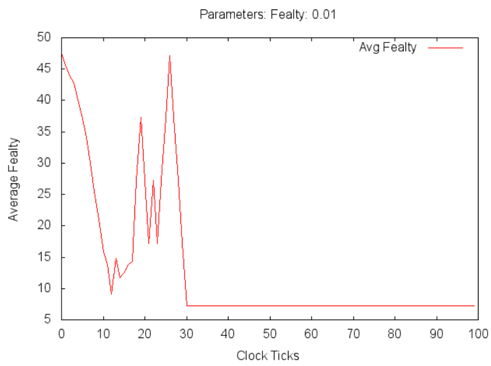

Fig. 3: Input parameters: Fealty, 0.01

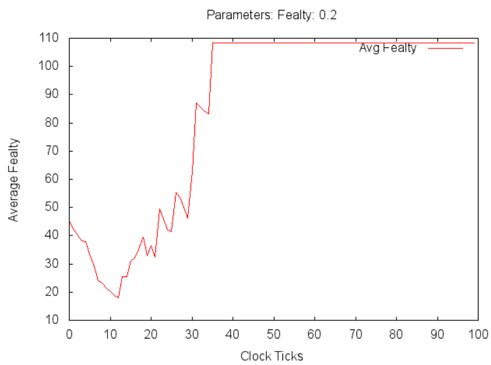

Fig. 4: Input parameters: Fealty, 0.2

TABLE I: Table of Model Results for Representative Fealty Adjustment Amounts

Fealty	Tick	Numb of Groups	Avg Size	Avg Fealty	Leadership Score
0.01	18	1	5000	27.285	5079.352
0.1	31	4	1250	77.730	1281.403
0.2	35	5	1000	108.317	1011.797
0.25	33	13	384	64.488	396.870
0.3	32	12	416	78.023	426.149

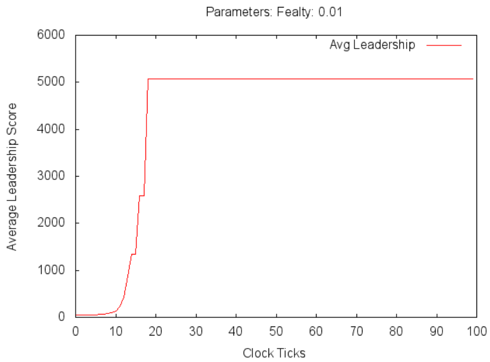

Fig. 5: Input parameters: Fealty, 0.01

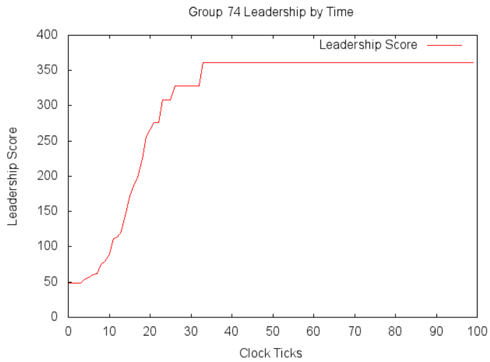

Fig. 8: Input parameters: Fealty, 0.25

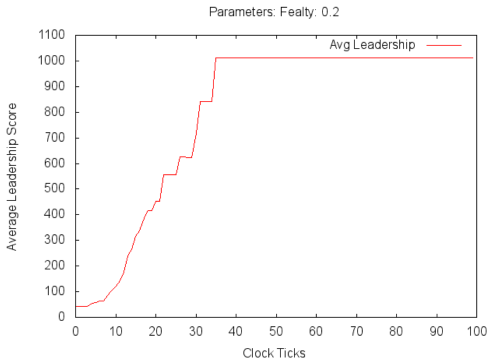

Fig. 6: Input parameters: Fealty, 0.2

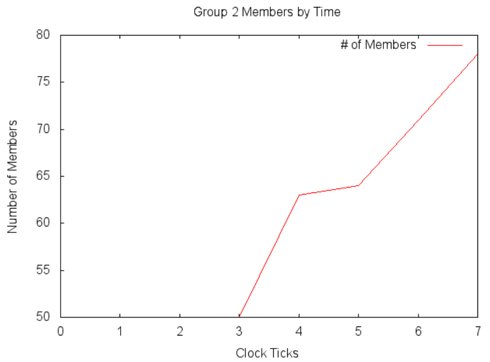

Fig. 9: Input parameters: Fealty, 0.25

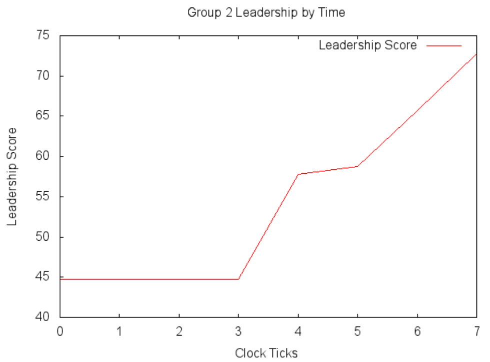

Fig. 7: Input parameters: Fealty, 0.25

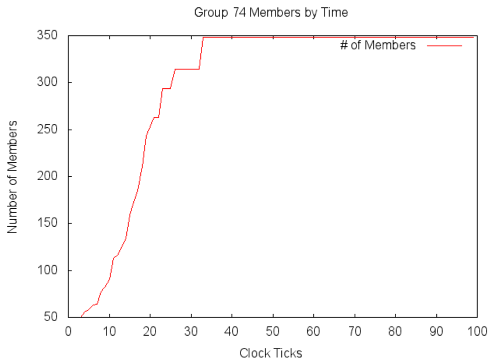

Fig. 10: Input parameters: Fealty, 0.25

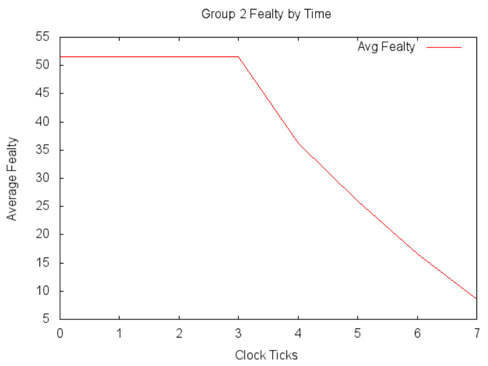

Fig. 11: Input parameters: Fealty, 0.25

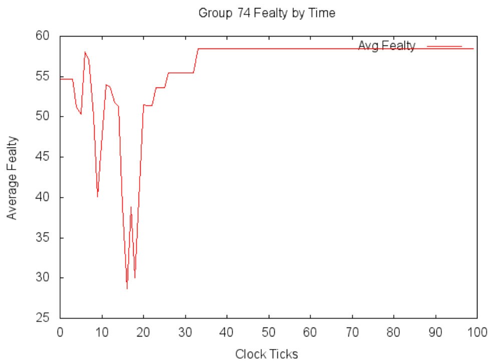

Fig. 12: Input parameters: Fealty, 0.25

perceive their group and its leadership. The key in the model, and in societies such as existed in the Zambezi plateau is the taking of a particular kind of collective action, that is, to abandon a group that is perceived to be unsuccessful and join another, more successful group.

Model runs result in a few large groups even though groups and group leadership get more than one chance to improve the overall feeling of loyalty to the leadership. Groups must, at each clock tick, reexamine the need for collective action, and this examination is largely independent of that history of the group. Though this is more forgiving than the real world, it is still enough to cause the failure of some groups and the rise of large groups. Comparing Fig. 11 with Fig. 12 we see that one group suffered a significant fall in the average feelings of loyalty, but then saw that it recovered, due to successful collective actions and the addition of members from failed groups.

Results were largely expected given the importance of membership in groups with strong leaders. However, it is surprising how few groups remain in the stable system, and it is surprising the speed at which the system coalesces. This needs further investigation; however, it may be due to the fact that the model does not take into account any dampening effects in regards to communications among group members and between groups. In the archeological and historical record, long distance communications are known to, of course, take time. Furthermore, the model could be extended to add activation and decay effects to the behavior of the agents. This would make the slow process more realistically "slow".

Leadership is strongly, positively related to group size, but not to average fealty within the group. The preferred group size, by average fealty is around 1000, while the average fealty is quite low when everyone is in one large group. However, leadership scores continue to rise as groups get larger. This is counterintuitive. Leadership is expected to vary in the same way as average fealty, assuming a direct link between leadership and positive group feelings. This is an area that would need to be explored as the model is extended; however, it may also bring to light the problem of when group dynamics fail even in the presence of adequate leadership.

It is interesting that in most runs of the model, average fealty declines at the beginning of the model run, only to (sometimes) recover and rise. This is due to the fact that collective action succeeds only 25% of the time with good leadership, and only 10% of the time with poor leadership. This means that most agents will experience failed collective action more often that successful collective action. However, as groups begin to disband to join stronger groups, group leader scores go up, which increases the overall chance of experiencing successful collective actions.

A. *Further Model Development*

This model could be developed further in a number of ways. As constructed, the role of environment factors are not taken into account. These could be global factors that are beyond group control or they could play more of a role in instigating collective action. Furthermore, environment may affect different groups in different ways. The model could be extended to place the relatively homogenous in size groupings in locally distinct environments. This is supported by work done in analyzing the clustering of farming community archeological sites in the Zimbabwean plateau by Sinclair and Lundmark, as described by Sinclair et al., who note "[t]here remains a strong impression that environmental factors of topography, soils and rainfall play an important role in the localization of southern clusters as a whole, but it seems clear that cluster spacing and internal organization within clusters is much more the result of social and political factors" [7, p. 709]. This model is currently constructed without geographic detail; however, we know that geography plays a very important part in the prehistory of the Zambezi plateau.

V. Summary

The Zambezi plateau region in Southern Africa has seen the rise and fall other several polities of different levels of complexity for many centuries before the arrival of Europeans and the beginning of the region's written history. Much archeological work has been done to recover this past. One of the enduring questions this work raises is to explain the rise, fall and abandonment of large polities centered around large edifices with massive stone walls called "zimbabwes". Several of these survive to the present day, the largest of which is called Great Zimbabwe near present-day Masvingo, Zimbabwe. The Great ZImbabwe period, lasting only 200 years was proceeded by Mapungubwe and succeeded by zimbabwes built to the north and southwest of the Great ZImbabwe site. Given the success of these states, what causes them to fail is such a way that the sites can be considered not just in decline but abandoned?

The agent-based model presented here provides support for an explanation based on the Canonical Theory. In this theory, a succession of opportunities to engage in collective action by a polity strengthens or weakens the complexity of the polity. This so-called "fast process" over time creates larger structural changes in which the effects of collective action within the fast process accumulate into a polity at a different level of complexity.

This model demonstrates that how a society can change its complexity over time through the individual fast-process type decisions made by group members. In the model, groups rose, declined and disbanded as the feelings of loyalty and attachment to the group rose and fell. These feelings were effected by the success or failure of collective action, and the probability of success was dependent in part on the strength of the group leader.

The main finding presented here is that group dynamics, centered on the collective feelings of loyalty to the group, can generate the macro level behavior that we see in the archeological record of Southern Africa. This has implications on the benefits of further investigation into the ideologies and imagery around views of group leadership and loyalty of the people of the zimbabwes of Southern Africa.

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The Linkage between Financial Market and Real Economy: The Analysis with An Agent Based simulation

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Abstract— Financial markets are driven by the real economy and in turn also has a profound effect on the financial economy. Understanding the feedback between these two sectors leads to a deeper understanding of the stability, robustness and efficiency of the economic system. In this paper, we investigate the effect of credit linkages on the macroeconomic activity by developing an agent-based model, which allows us to explain some key elements occurred during the recent economic and financial crisis. In particular, we study the linkage dependence among agents (firms and banks) at the micro-level and to estimate their impact on the macro activities such as the GDP growth rate, the size and growth rate distributions of agents.

I. INTRODUCTION

In recent decades, a massive transfer of resources from the productive sector to the financial sector has been one of the characteristics of global economic systems. This process is mainly responsible for the growing financial instability characterized by the current global crisis. In production sectors, there has been dramatic increase in the output volatility and uncertainty. Macro economy has created well defined approaches and several tools that seemed to serve us for the past decades. However, recent economic fluctuations and financial crises emphasize the need of alternative frameworks and methodologies to be able to replicate such phenomena for a deeper understanding of the mechanism economic crisis and fluctuation.

To jointly account for an ensemble of these facts regarding both micro-macro properties together with macro aggregates including GDP growth rates, output volatility, business cycle phases, financial fragility, and bankruptcy cascades, agent-based approaches are getting more and more attention recently. We need to analyze explicitly how agents interact with each other.

From this perspective, the network theory is a natural candidate for the analysis of interacting social systems. The financial sector can be regarded as a set of agents (banks and firms) who interact with each other through financial transactions. These interactions are governed by a set of rules and regulations, and take place on an interaction graph of all connections between agents. The network of mutual credit relations between financial institutions and firms plays a key role in the risk for contagious defaults.

This work was not supported by any organization

II. BACKGROUND

Research on this line has been initiated by the work Delli Gatti, et al. (2005) which, simulating the behavior of interacting heterogeneous firms and one bank, is able to generate a large number of stylized facts. Grilli, et al, (2012) extend their model by incorporating a system of multiple interactive banks. They introduce multiple banks which can operate not only in the credit market but also in the inter-bank system. They model credit and inter-bank systems as random graphs and study the network resilience by changing the degree of connectivity among the banks' agents.

In their model, firms may ask for loans from banks to increase their production rate and profit. If contacted banks face liquidity shortage when trying to cover the firms' requirements, they may borrow from a surplus bank in the inter-bank system. In this market, therefore, lender banks share with borrower banks the risk for the loan to the firm. Bankruptcies are determined as financially fragile firms fail, that is their net worth becomes negative. If one or more firms are not able to pay back their debts to the bank, the bank's balance sheet decreases and, consequently, the firms' bad debt, affecting the equity of banks, can also lead to bank failures. As banks, in case of shortage of liquidity, may enter the interbank market, the failure of borrower banks could lead to failures of lender banks. Agents' bad debt, thus, can bring about a cascade of bankruptcies among banks.

The source of the domino effect may be due to indirect interaction between bankrupt firms and their lending banks through the credit market, on one side, and to direct interaction between lender and borrower banks through the inter-bank system, on the other side. Their findings suggest that there are issues with the role that the bank system plays in the real economy and in pursuing economic growth. Indeed, their model shows that a heavily-interconnected inter-bank system increases financial fragility, leading to economic crises and distress contagion.

However, from the point of view of the average macroeconomist, agent based modeling has the drawback: It makes impossible to think in aggregate terms. The modeler, in fact, can reconstruct aggregate variables only from the bottom up by summing the individual quantities. As a consequence the interpretation of the mechanism of shocks is somewhat arbitrary. If we also consider simulations as experiments, reproducibility is a crucial question. In the context of models created to describe real-world phenomena, emphasis must be put on the reproducibility of experiments to validate the results as a scientific result. If a model cannot generate the same output for the exactly same conditions, its scientific value is questioned.

III. Study Policy

In the first part of our work, we replicate and extend the model of Delli Gatti et al.(2005) and that of Grilli et al. (2012). We then address the questions of validating and verifying simulations. We propose the model refinement strategy which validate through some universal laws and properties based on empirical studies revealing statistical properties of macro-economic time series. We begin the presentation with the widely acknowledged “stylized facts” which describe the firm (and bank) growth rates of fat tails, tent distribution, volatility, etc., and recall that some of these properties are directly linked to the way time is taken into account (Stanley, et al.(1996)).

It is well known that the growth of firm size, the distribution of firm sizes, the distribution of sizes of the new firms in each year are be well approximated by a log-normal. We investigate whether the simulation results shown in Fig.1, the logarithmic distribution of the growth rates with a fixed growth period of one year as Y, and companies with approximately the same size S as X, obeys an exponential form.

Fig. 1 shows our simulation result for the growth rate of firms. It allow us to be able to attest because it is very sufficiently similar in “stylized facts”.

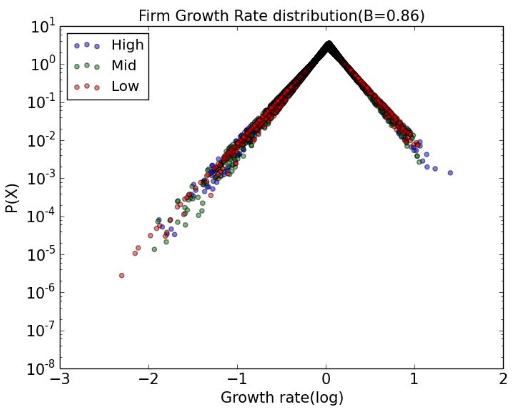

Fig. 1 Growth rate of firm as the simulation result

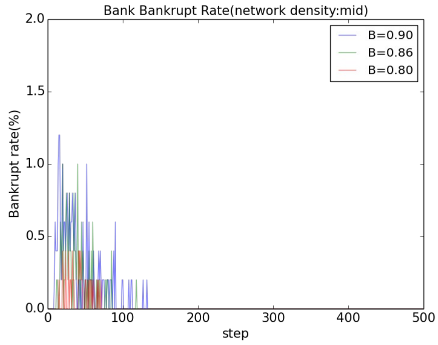

Fig. 2 rata of banks’ bankruptcies

We validate our simulation results in this way and analysis them. In the second part of our work, we investigate the linkage between financial markets and the real economy using the validated agent-based modeling. We especially investigate the effect of credit linkages on the firms’ activities to explain some key elements that occurred during the recent economic and financial crisis. In particular, we study the repercussions of inter bank connectivity on agents' performances, bankruptcy waves and business cycle fluctuations. The purpose of the model is to build up the dependence among agents (firms and banks) at the micro-level and to estimate their impact on the macro stability. Fig. 2 shows an example of our simulation result for the rate of banks’ bankruptcies by time steps, where β is output elasticity of capital of firms’ production function. When β increases, the rate of banks’ bankruptcies also increases. By this result, it is evident that the change of firms has an effect on banks through the linkage between firms and banks.

IV. OVERVIEW OF AGNET MODEL

Our model is based on Grilli, et al (2012). We consider two types of agents, ,firm agent and bank agent.

A. Firm agent

The firm agent i has net worth $A_{i,t}$ and loan $L_{i,t}$ at time step t and produce an output $Y_{i,t}$. At Grilli‘s model, production function is defined as

$$Y_{i,t} = \phi(A_{i,t} + L_{i,t})$$

However, it is well known that production function is not a liner function and the liner product function affects the growth rate of firms than actuals value. Therefore, we define production function as

$$Y_{i,t} = \phi(A_{i,t} + L_{i,t})^{\beta}$$

where ϕ is the capital productivity and $\beta \in [0,1]$ is output elasticity of capital. If β = 1.0, our model equals Grilli‘s model.The firm product’s price is the selling price $P_{i,t}$, which is assumed to be a random value with the average price P_t. Wedefine the relative price ui,t as the ratio of Pi,t to Pt, which has the normal distribution with a certain mean and finite variance. Firms pay back their debt commitment according to

$$\overline{L}_{i,t} = \frac{1}{\tau} \quad {}_{t-\tau}^{\;t} (1+r_t^{i,j})L_{i,t}$$

where $r_t^{i,j}$ is the interest rate of the loan from bank j. The net worth is updated with firms' profit $\pi_{i,t}$, given $u_{i,t}$, $Y_{i,t}$ and $\overline{L}_{i,t}$, as

$$\pi_{i,t} = u_{i,t}Y_{i,t} - \overline{L}_{i,t}$$

At each step, firm maintain their capital stock $K_{i,t} = A_{i,t} + L_{i,t}$ in the optimal stock

$$K_{i,t}^{*} = \frac{\phi}{2c\phi(\lambda r_t^{i,j} + (1-\lambda)l_{i,t})} + \frac{c\phi A_{i,t}}{2c(\lambda r_t^{i,j} + (1-\lambda)l_{i,t})}$$

If $A_{i,t}$ is under $K_{i,t}^{*}$, the firm asks banks for the loan

$$L_{i,t}^{d} = K_{i,t}^{*} - A_{i,t}$$

B. *Bank agent*

Bank agents have the equity $E_{j,t}$, and deposits $D_{j,t}$. Then, Banks' have the credit supply $S_{j,t}$ limited by their equity $E_{j,t}$ and uniform value α

$$S_{j,t} = \frac{E_{j,t-1}}{\alpha}$$

When banks are asked a loan by firms, banks check firm's demand of loan $L_{i,t}^{d}$ and investment risk $p_t^{j,i}$ according to

$$p_t^{j,i} = 1 - \chi\left(\frac{\overline{G}_{i,t}}{S_{j,t}}\right)^{\psi}$$

where $\overline{G}_{i,t}$ is the amount of firm's debt. When $p_t^{j,i}$ is 0.1 $p_t^{j,i}$, this means that one out of ten banks lend money to a firm. If the bank j credit supply is $S_{j,t} < L_{i,t}^{d}$, bank j asks other banks through the inter-bank market. The lender bank k checks the demand of credit supply $S_{k,j}$ and borrower bank's investment risk $p_t^{k,j}$. The lender bank k makes a loan to firm i or bank j with interest rate based on the leverage of borrower firm or bank. Then, the bank's profit is defined as

$$\pi_{j,t} = \frac{1}{\tau}\Big[\sum_{z,\,t-\tau \le t' < t} L_{z,t'} r_{t'}^{j}\Big] - \overline{r}_{j,t}(D_{j,t-1} + E_{j,t-1})$$

where z is index of borrower firm or bank.

C. *Network Structure*

Our model makes two networks. One of the networks is the linkage between firms and banks. If the firm i has a chance to offer a loan to bank j, it is regard credit linkage from firm i to bank j (it means that it is not necessarily required to borrow a loan). And if the firm's net worth becomes negative, the firm i undergoes bankruptcy and imposes a loss based on their loan at a rate from ten to ninety percent on the lender bank j through the credit linkage. Another network is the linkage called interbank network and is formed between banks to be able to borrow from or lend to a loan. It is to transfer the damage from the bank going bankruptcy to lending bank through interbank network. The two networks have different network topologies. The firm-bank network topology is random graph. At each step, a firm can randomly choose three or less banks. For example, firm i chooses three banks at step t, then step, firm i chooses one bank that is not the same bank at step t. On the other hand, interbank network is a two-type network topology. One of them is also a random graph. The banks choose partner banks less than a number limited by the network density at random and, after several steps, change a partner bank chosen randomly into other bank which is not linked. Other network topology is similar in the real network. A bank cut off a partner bank which has the lowest number of partner banks and cooperate with a new partner bank which has a larger number of partner banks than the cut off bank and has an equity which is greater than itself.

V. Simulation Setting

The model is done for the combination of the output elasticity of capital β and the interbank network connectivity. From the result of preliminary experiment, "Big firm", which is 1010 times larger than other firms, appear if β is 0.86 on more. Therefore, we simulate in the environments where there are no "Big firm" ($\beta=0.8$), a few "Big firm" ($\beta=0.86$) and almost half of firms that are "Big firm" ($\beta=0.9$).

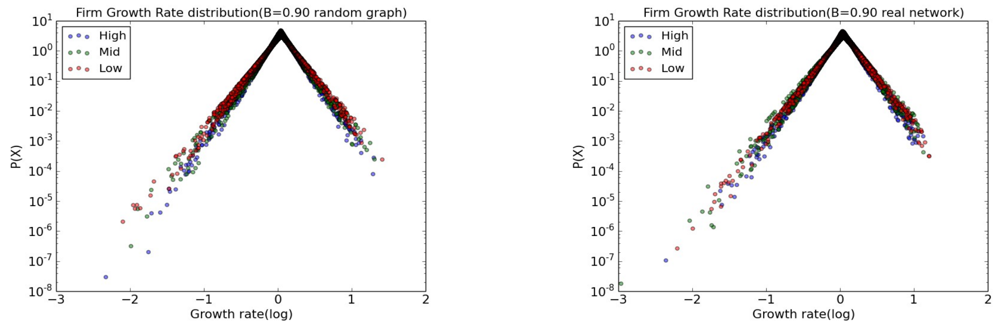

Fig. 3 Firm growth rate distribution β=0.9
(left side: random network, right side: real network)

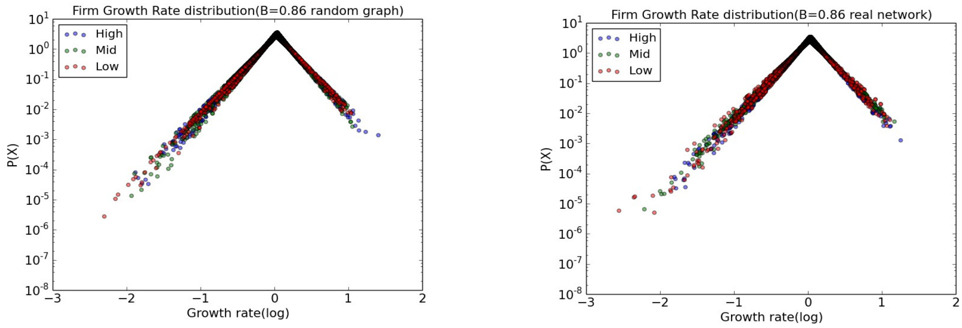

Fig. 4 Firm growth rate distribution β=0.86
(left side: random graph, right side: real network)

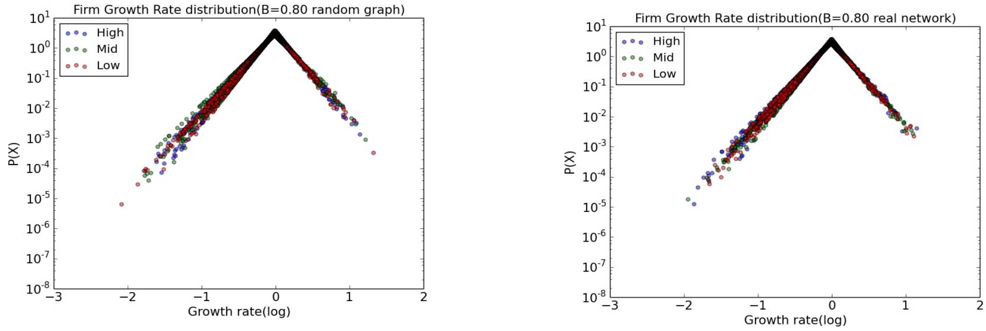

Fig. 5 Firm growth rate distribution β=0.80
(left side: random graph, right side: real network)

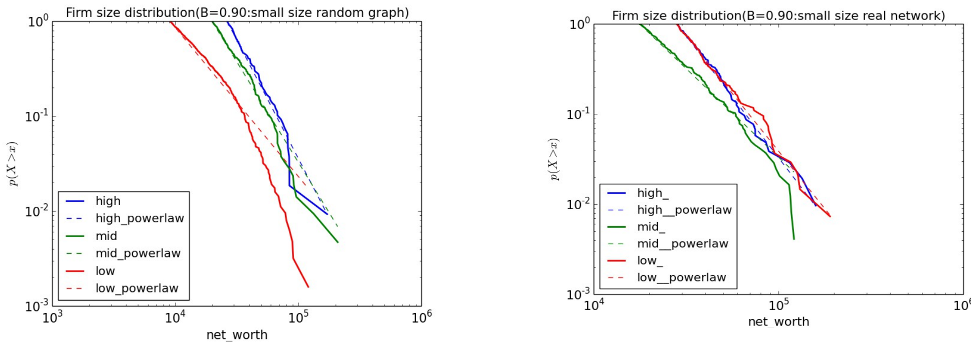

Fig. 6 Small firm size distribution β=0.9
(left side: random graph, right side: real network)

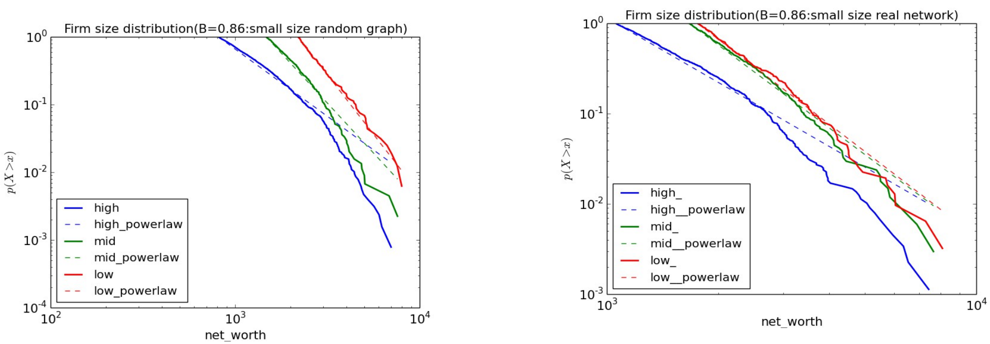

Fig. 7 Small firm size distribution β=0.86
(left side: random graph, right side: real network)

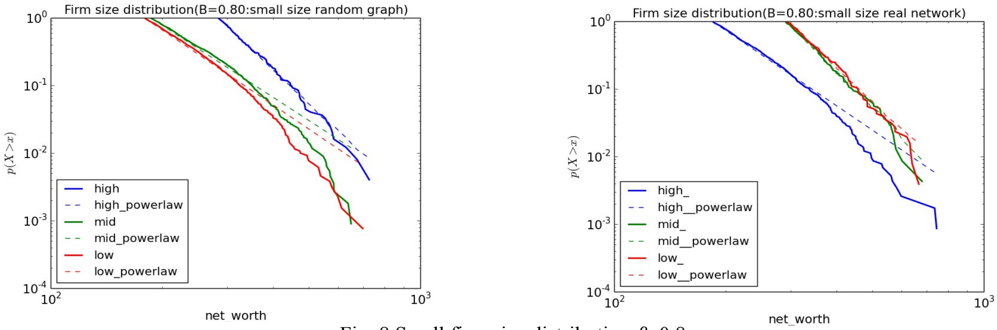

Fig. 8 Small firm size distribution β=0.8
(left side: random graph, right side: real network)

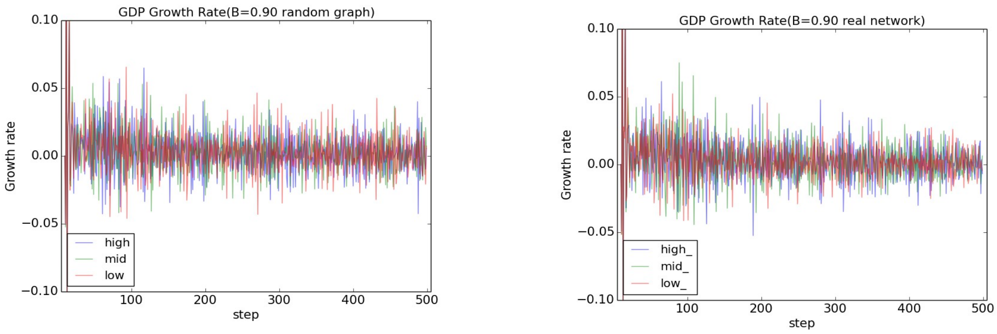

Fig. 9 GDP growth rate β=0.9
(left side: random graph, right side: real network)

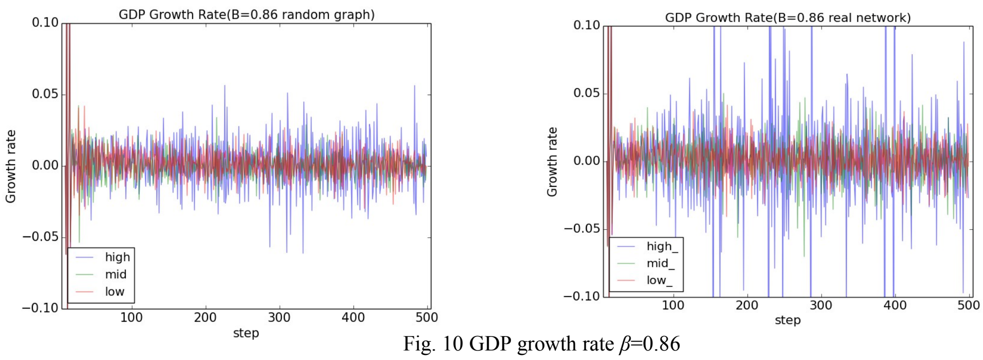

Fig. 10 GDP growth rate β=0.86
(left side: random graph, right side: real network)

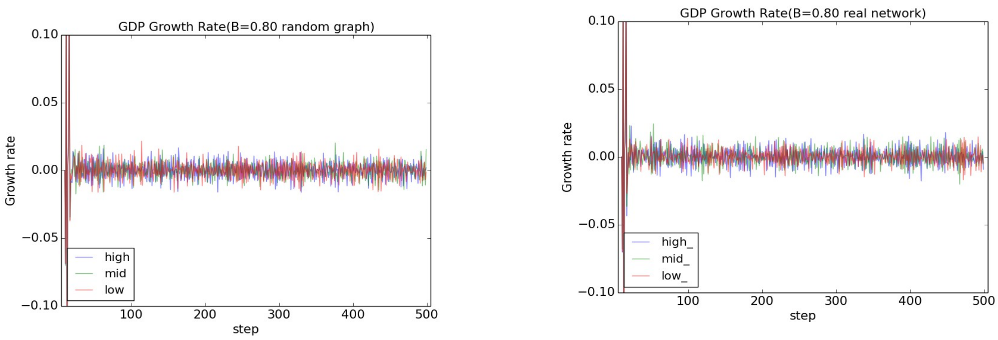

Fig. 11 GDP growth rate β=0.8
(left side: random network, right side: real network)

We investigate that the alteration of firms' production function influences bank's growth and GDP through firm-bank linkage. There is an upper limit with interbank network topology. A maximum number of links are defined by network density. The network density is divided into three levels: low connectivity, middle connectivity and high connectivity. The maximum possible number of links are six, twelve, twenty five. In random graph topology, the maximum link limit is maintained until final step. However, in similar real network topology, the limit is applied only in the first step. By this way, we observe what kind of effect the difference of interbank network topology has on macro economy.

VI. DISCUSSION

Fig. 3, 4 and 5 show firm growth rate distribution at each environment. The distributions are similar in "stylized facts" except for the shift at the top of their distribution. By this result, our model has enough reasonability. Fig. 6, 7 and 8 show firm size distributions which are $\beta = 0.90$ except for "Big firm". Big firms almost behave in a power low fashion and, in fact, it is well known that firms' size distribution is a power law distribution. This simulation result also provides the validity of our model.

We compare the firms' size distribution with different combination of the output elasticity of capital β and the interbank network connectivity to estimate the effect of the network topology. In the case that the network topology is a random graph, firms' size probability increases if the network density increases. However, in the real network topology, firms' size probability does not necessarily increase when the network density increases. There is empirical evidence that as the connectivity of an interbank network increases, there is an increase in the network performance, but at the same time, there is an increase in the chance of risk contagion which is extremely large. Allen and Gale (2000) introduced the use of network theories to enrich our understanding of financial systems and studied how the financial system responds to contagion when financial institutions are connected with different network topologies. Furthermore, we observe that the change of network topology has an effect on the economy. We also compare the GDP growth rate. Fig.9, 10 and 11 show that the range of change of GDP growth rate depend on β. Basically, when β increases, the range spreads out. However, in the real network topology, the maximum range is produced when $\beta = 0.86$ and the network density is high. By this result, the network topology not only amplifies economic trend simply, in this particular case, but also takes on complexity to economic activity.

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The Individual Agent Makes a Difference in Segregation Simulation

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Abstract–**Urban social segregation modeling from the bottom up attempts at understanding the processes which take place when residents look for a new home. This micro-scale perspective thus requires implementing actual individual agents instead of socially unified communities with similar or identical behavior. Complementary, meso- and macro-scale determinants such as housing markets, estate agencies, urban planning institutions, and societal life-style preferences must be incorporated in order to comprehensively and adequately simulate residential mobility. The paper presents an attempt to simulate urban socio-spatial segregation for the city of Salzburg, Austria, by consistently taking the individual household scale into account. We first apply the beneficial features of a Schelling-style simulation model by also taking macro-social regularities into account. This is followed by a description of an adapted segregation model that includes the mentioned requirements. The paper concludes with an extensive presentation and discussion of the model results achieved so far.**

I. Introduction

The distribution of households in urban space, its underlying mechanisms, processes and spatiotemporal structures, is a complex phenomenon (see, for instance, [1], [2] as references for complexity science). The social and spatial patterns which arise and – subtly and dynamically – change over time, such as segregation, residential up- and down-grading, gentrification, places of inclusion and exclusion, are significantly influenced and determined by numerous rules, markets, political attitudes, and behaviors of different stakeholders. Attempts to model issues of households' location-allocation patterns and of simulating their processes have to take the three crucial domains of 'scales', 'entities', and 'interactions' explicitly into consideration to adequately analyze and evaluate how social and spatial forces are mutually linked.

The following paper presents an attempt at modeling and simulating processes of urban socio-spatial segregation by primarily focusing on the local scale of households, their interactions and decision-making when reflecting on the socio-spatial neighborhood setting compared with preferences and/or dissatisfactions. In so doing, the theoretical domain of the model's purpose is to highlight the individual acting conditions embedded into the context of intra-urban moves. An actor-centered modeling perspective appears to be important, because it makes the scope and constraints from the bottom up explicit and visible. This perspective, however, ought to be complemented by macro determinants, such as housing markets, the capitalization of these markets, Estate Agencies, urban planning strategies, as well as social norms and cultural attitudes towards life-style and neighborhood building, which affect individual decisions in a top-down manner. Putting emphasis on intra-urban moves is justified since they make up the majority of all residential mobility; for European cities, for instance, they vary between approx. 20 movers per 1,000 inhabitants in Irish cities and up to 121 in Finnish cities, per year [3, p. 252] (comparative data is from 1980). This remarkable range can be used as one indicator for the mutual relationship between the local-individual and global-social scale.

The methodological domain of the model's purpose is to comprehensively model residential agents as individual units. The Schelling-style segregation model serves thereby as a starting point and benchmark. One of the great benefits of this model type lies in its emphasis on emerging spatial patterns at the macro level which cannot be thoroughly explained by investigating the motives and interaction patterns at the micro level. The aim of this paper is to alter some of the agents' premises and neighborhood rules of evaluation and movement in order to strictly individualize the defined entity of households. The problem of many Schelling-style models is that they do not consistently account for the individual but refer only to collective acting. From the initialization of the model up to the agents' evaluation and decision to move, a homogenized rule setting procedure has been implemented.

In the remainder we first take a brief look at some of the macro-social regularities which determine the agents' power to act, followed by a discussion about the need to modify Schelling-style segregation models. An individualized model approach is then presented, describing first the agents' characteristics and then illustrating the effects by presenting some of the relevant model's results.

This work was not supported by any organization

II. The Macro Scale Of Segregation

The "Nature of Cities", published by Harris and Ullman in 1945, has changed economically, socially, politically, culturally, and geographically in structure, shape, meaning and function. With respect to the function of housing in general and the different socio-spatial patterns of segregation in particular several theoretical approaches have been developed putting the macro scale forces to the fore. One early but, to date, influential approach to investigate gentrification as a specific kind of segregation (which we are interested in here) is the rent gap theory [4], [5]. The core concern of this theory is a profit-driven economic explanation of the processes of social, cultural, and architectural upgrading accompanied by social homogenization of gentrified neighborhoods and the displacement of less affluent households. The emergence of a rent gap in city areas has been linked with suburbanization of urban agglomerations. "Inner-city decline and suburban expansion has therefore led to a **rent gap** – a disparity between the potential rents that could be commanded by inner-city properties and the actual rents they are commanding". [3, p. 145] Rent-gap-driven socio-spatial revaluation remains an important aspect in urban redevelopment, mainly as a consequence of the contemporary financial and economic crises. This in turn means that classical models, such as the Chicago model of urban structure are "[…] now largely redundant". [6, p. 128] On the other hand, an exclusive rent-gap perspective "[…] leaves little room for human agency or consumer preferences. Thus, by itself, the rent-gap theory cannot explain which cities, and which areas within cities, are most likely to be regenerated". [3, p. 146]

A different but closely related macro-scale approach, highlighting the processes of residential mobility and neighborhood change, is the concept of invasion-succession-cycles [7]. It describes the invasion of low-income households, referred to as pioneers (e.g. students, artists, alternative life-style people), into obsolescent city areas. During this phase a cultural revaluation, by establishing new and alternative stores (e.g., ethnic food restaurants) and services (e.g., galleries), and a modest architectural revaluation, the so called incumbent upgrading, takes place. A second cycle is being initiated by the invasion of gentrifiers who prefer the cultural atmosphere but dislike the built environment. Due to large-scale and costly architectural revaluation, often realized by large property development companies, housing becomes significantly more expensive, resulting in extensive displacement of less affluent households, including the pioneers of the first phase. Although this theory represents a socio-spatial generalization of city development which is often triggered by urban planning strategies and political desires of urban uniqueness under conditions of global competitiveness, it is simultaneously understood as a bottom-up approach to explaining individual preferences. It is, however, not a strict and pervasive individual perspective, but one that takes into account communities (milieus, life-styles) as more or less homogenous entities into [8, p. 66].

A further determinant influencing individual decision-making and agency is given with institutional stakeholders. [9]-[10], among others, claims an integrative approach for a theory of segregation by including a theory of social inequality, a theory of spatial inequality, and a theory of allocation of living space and city districts to households and social aggregates. Apart from builders, developers, mortgage lenders, and government agencies it is the Estate Agents who do play a crucial role within the network of mediators between sellers and buyers or landlords and tenants. Residential property management, insurance, data collection and analysis, and financing are only a few of the tasks they undertake and contribute to housing market mechanisms. "They are not simply passive brokers in these transactions, however; they influence the social production of the built environment in several ways. In addition to the bias introduced in their role as mediators of information, some estate agents introduce a *deliberate* bias by *steering* households into, or away from, a specific neighborhood in order to maintain what they regard as optimal market conditions. […] Thus the safest response for realtors is to keep like with like and to deter persons from moving to areas occupied by persons 'unlike' themselves". [3, p. 143] Though real estate agents complexify segregation processes one should keep in mind that simplified decentralized bilateral trading mechanisms, too, can exhibit remarkable complexity at the individual level, as is shown by [11].

There are undoubtedly several more approaches which deal with macro implications of segregation. One may think of the theory of fragmenting development which links global trends of economic and political developments to locally fragmented but homogenous processes of residential structuring [12]; other determinants are social housing policies, the public housing sector, or the creation of large housing complexes that give rise to influences on the individual scale of households. Though all these criteria are relevant to understanding segregation in a comprehensive way, it is usually difficult to represent them adequately. Apart from data availability at fine resolution and the necessity to suitably translate them into procedural code, it is sometimes hard to connect the (potential) knowledge to a valid synoptic unity (e.g., how do you weigh all the information properly?). The following model incorporates the above mentioned determinants in a fuzzy and approximate way by using rent price as a cumulative indicator which has been disaggregated by statistical techniques. This appears to be justified by the model's purpose, because it has its thematic priority in a comprehensive individualization of agents' agency.

III. With Schelling Beyond Schelling: Individualization of Agents

Urban segregation appears to be an amalgamation of smaller-scale intra-urban moves and larger-scale in- and out-migration. [3] refers to empirical results of intra-urban mobility which allow for some generalization in the search for regularities of social homogenization at the neighborhood scale. We refer to these regularities as a coarse framing of agents' social and spatial evaluation and decision-making behavior, in addition to the macro-social influential forces mentioned above. "The most significant regularities in intra-urban movement patterns […] relate to the relative *socioeconomic status* of origin and destination areas. The vast majority of moves […] take place within census tracts of similar socioeconomic characteristics". [3, p. 254] This result correlates closely with the distance of moves which have been found to be comparatively short, however, varying by income, tenure, ethnic belonging and suchlike. Another determinant is the distinction between voluntary and involuntary moves, which are not recognized as a sharp dichotomy in the following model (and voluntary moves are in themselves different, which causes ongoing discourses on the evaluation of 'voluntary' moves; see, e.g., [13, p. 36].

The search for a new home is commonly biased, too. Criteria such as living-space, tenure, dwelling preferences, built environment, and social neighborhood all need to be considered. In addition, the search space is strongly correlated with local knowledge about urban districts, influenced by spatial activity patterns and information sources (e.g., media, friends). "It follows that different subgroups of households, with distinctive activity spaces and mental maps, will tend to exhibit an equally distinctive spatial bias in their search behaviour". (ibid., p. 262) For the following model it is assumed that agents are flexible in their search space, being able to get information about living costs (the spatial rent domain) and the social status of neighbors (the social attitude domain) [14, p. 101].

Against this background the benefit of Schelling-style segregation models lies in its explicit focus on local circumstances as reasons for processes of socio-spatial homogenization. The model's purpose is directed towards the micro-macro link of individual agency [15], [16, p. 83]. The phenomenon that, if agents act according to their subjective aspirations of residing in close proximity to other agents with equal social characteristics, a global pattern arises which cannot be derived from these aspirations straightforwardly, is one of the most important results of Schelling's model approach. The detection of emerging segregation to a much stronger extent than individually anticipated and intended is, on the other hand, a result of a standardization of the individual agent.

For the development of a conceptual segregation model the difficulty is to combine methodologically true individual entities with socially similar characteristics and behavior. This challenge is framed by complex empirical knowledge. Just to give an example about the intentionality of contributing to socially homogenous neighborhoods: [17, p. 89], by highlighting a continuum of nearness and distance as a determinant for social relations, argues: "Therefore, for extensive co-residing as in modern cities, individuals have also developed subtle, complex and sometimes partially unconscious and unintended ways of dissociating from and discriminating against others". Contrary to this 'unconscious' and 'unintended' behavior effect, [18, p. 48] stresses an explicit desire "[…] for coherence, for structured exclusion and internal sameness […]", which in turn seems to be in contradiction with contemporary aims of living in vivid mutual supportive communities: "Innate to the process of forming a coherent image of community is the desire to avoid actual participation. Feeling common bonds without common experience occurs in the first place because men are afraid of participation, afraid of the dangers and the challenges of it, afraid of its pain". [18, p. 42] Both facets can be observed empirically, the latter, for instance, in gated communities and (partly) gentrified neighborhoods, while the former is more common in organically grown, multi-cultural urban neighborhoods.

A reliable conflation of individual agency (subjective opportunities for freedom with respect to aspirations, preferences, but also constraints) and social influences (power relations, cultural bias, or recognition of capabilities) in segregation modeling is justified by empirical experience and progressive debates on modifications and alterations of Schelling-like models [19]-[23]; for a review of these studies see [16, p. 83-87], [17, p. 88-97]. [17, p. 96] draws the conclusion "[…] that if individual preferences and perceived differences between groups refer just to one characteristic, such as ethnicity, religion or political position, and decision is binary, segregation is unavoidable and social integration is impossible". From a modeling perspective the unrealistic determination is due to the univariate reference and the binary decision scheme. Moreover, relaxing the causal link between the decision-threshold of (dis-)satisfaction and corresponding action should surmount the seeming inevitability of segregation.

Furthermore, the individual-community link complexifies the discussion about segregation when taking majority-minority relationships into consideration. In this case processes of inclusion and social cohesion can conflate with displacement, and political claims of integration and neighborhood diversity converge or diverge scale-dependently by quite similar transformations. From a model perspective it is very hard (or even impossible) to reasonably disentangle the bundle of interwoven processes and relations. "The language of 'preference' and 'tolerance' surrounding the Schelling model can give the appearance that such claims are being made. It is important to keep in mind that we could just as easily interpret the movement of minority households into friendly neighborhoods as arising from an inability to access neighborhoods with a high presence of the majority, a reading that would make the driving mechanism not preference but discrimination. Such debates are not about the model's outcomes but about its interpretation and what can be inferred from it". [16, p. 85]

To sum up: the consequent disaggregation of agents' characteristics and behavior towards the individual level is an attempt to avoid homogenous community building that derives deterministically from an *a priori* standardized setting of attributes which leaves agents indistinguishable. The inherent sameness of agents at the group level in the original model contains segregation within itself as a predictable outcome to some degree. Truly distinguishable agents do recognize social conditions, nonetheless, but they do it differently. We put the emphasis on similar agents acting similarly with regard to similar decision-making.

IV. The Segregation Model

The current version of the segregation model is a conceptual simulation model which serves predominantly as an instance to verify the model's purpose. It has been built to simulate intra-urban residential mobility in the city of Salzburg, Austria, by highlighting emerging patterns of socio-spatial cohesion. A quantity of census data from 2001 has been used to carry out a factor analysis followed by a cluster analysis. The data is applied to initialize spatial raster cell characteristics on an approximate empirical basis. The model will be further developed as soon as census data from 2011 are available (which is expected in July 2014). It is intended then to transform raster cell resolution to a 250 by 250 meter scale in accordance with the officially available data provided by the Austrian Statistics Authority [24]. A validation of segregation processes over the period of one decade will then be possible.

A. *Agents' Properties*

The entire agent population is subdivided into four different subgroups, representing cluster characteristics which have been derived from a factor analysis with 14 socio-demographic variables (e.g., education, age cohorts, religion, household size, nationality). Clusters represent demographic characteristics of the city of Salzburg at district level and have been disaggregated randomly at cell level.

The realization of creating individual agents refers to agents' characteristics and decisions as well as executed actions. With respect to characteristics, 'income' is used as a prototypical randomized variable using a normal distribution function with a small standard deviation to individualize an agent's economic situation. In addition to the variation of income within the four subgroups a variation between them has been applied. This is to vary the economic wealth of agents at the collective scale, representing social status.

Due to the normal distribution of income values there is no sharp distinction between agents as economically defined entities. In so doing, we included a second variable, 'attitude', which represents agents' social preferences (or disaffirmations) in a qualitatively generalized way; an agent's 'attitude' is represented by color. This is according to the idea mentioned above. The fluent transition of economic property (income) correlates with a clear distinction of the social characteristic (attitude) and allows for a reasonable diversity of agents; for instance, two red agents share the same attitude but differ in income, and a red and blue agent may have similar income, but differ in their attitudes.

The reference variable for every agent to derive its initial income is given with the 'rent' value of the cell (patch) in which an agent is situated initially. Thus, a valid relationship of agent-location interaction is achieved.

The evaluation procedure of an agent's neighborhood embraces the affordability of the current location and the (dis-)satisfaction with its neighborhood. Whilst in the first case agents must move if their income is less than the costs for housing, in the latter they are equipped with some flexibility when gauging neighbors' characteristics of income and attitude. The common approach in agent-based segregation modeling is a single unified threshold value which will be applied to all agents. In contrast to this approach we, first, use two thresholds (for income and attitude, separately) and, secondly, vary the values of income by applying a range of values around the mean income (the qualitative indicator of 'attitude' remains as a binary variable). The income threshold which, as mentioned earlier, represents the socio-economic status of an agent approximately, is then transformed by a normal distribution function in order to individualize the decision-making process for residential moves.

In addition, and different from traditional segregation modeling, we have inserted two more modifications. First, not all agents move even if they fulfill the condition of being dissatisfied. The reason for this can be justified with empirical observations: residential relocation is a complex fact involving lots of criteria which must be pondered deliberately and diligently (which is represented here quite inaccurate by just two dimensions). The desire of retaining social ties developed over a long period or the established familiarity of every-day activities may represent reasons which imply some inertial behavior though dissatisfaction is a significant counter force [3, p. 253]. Furthermore, even if one feels dissatisfied with one's current social and spatial neighborhood situation, relocation is not the one and only obligatory response to it. One may think of political activism or community engagement in order to improve local social well-being.

Secondly, and contrary to the first modification, agents may wish to move even though they might be satisfied with their current neighborhood. Reasons for such a decision might be the inheritance of a house or apartment, change of work place, family situation, life-style changes, or simply the search for the perfect home.

Agents who are economically not able to find an affordable dwelling in the city of Salzburg within a certain period of time are forced to move to the suburban region. In turn, agents with sufficient income can either return to the city or immigrate for the first time. With this procedure we have included migration in addition to intra-urban mobility.

B. *Spatial Entities' Properties*

Spatial entities (patches) represent housing costs as scaled values derived from cluster data. The scaling of values is based initially on a normal distribution and then adapted to the cluster characteristics. The data used represent a coarse approximation of the socio-demographic situation at census district level and is disaggregated statistically, but verified as a proven approximation by experts from city authorities.

C. *General Model Issues*

The model has been implemented in NetLogo 5.0.4 [25] and will be made public at the author's homepage (http://www.socialgeography.at) and OpenABM (http://www.openabm.org). The parameters 'income' of agents and 'housing costs' of spatial entities increase marginally per time step, i.e. there is an interaction pattern not only among agents, but also between them (the social domain) and the cells (the spatial domain). The latter type of interaction is currently implemented in an abstract way, because only a global trend of housing costs is included due to data availability restrictions. There is, however, no local modification of this global trend at the moment. One may think, for instance, of a higher/lower dynamic in areas of high/low status neighborhoods. What has been implemented, however, is an accidental above-average increase and decrease, respectively, of housing costs, whereby 5% of all patches are then affected by an increase and 3% by a decrease. The extent can be altered interactively, for the subsequent model results the increase is set to 20% and the decrease to 10%.

V. Selected Model Results

The resolution of the city is set to approx. 15,000 spatial entities inhabited by 150,000 citizens. A number of 6,000 agents is selected as potential intra-urban movers which is a conservative estimation of 4% of the total population. Initially, agents of all four subgroups are randomly distributed over the urban space, according to the price per patch, i.e., initially, every agent can afford the dwelling she/he is living in. Census districts are colored according to the cluster they belong to, representing housing costs which vary from cheap to expensive in the following sequence: brown-orange-blue-pink-green-yellow.

The standard model has the following settings: the proportion of each subgroup is the same (25%), the preferences of similarity for each group is 25% for 'income similarity' and 20% for 'attitude similarity'. Income and housing price growth rates are set equal to 0.5% per time step. 70% of actually dissatisfied agents actually move, but also 5% of actually satisfied agents do so. Two remarkable results are noteworthy: (1) Compared with a Schelling-type model, segregation is no longer a common phenomenon, being distributed evenly over the urban space (see Fig. 1).

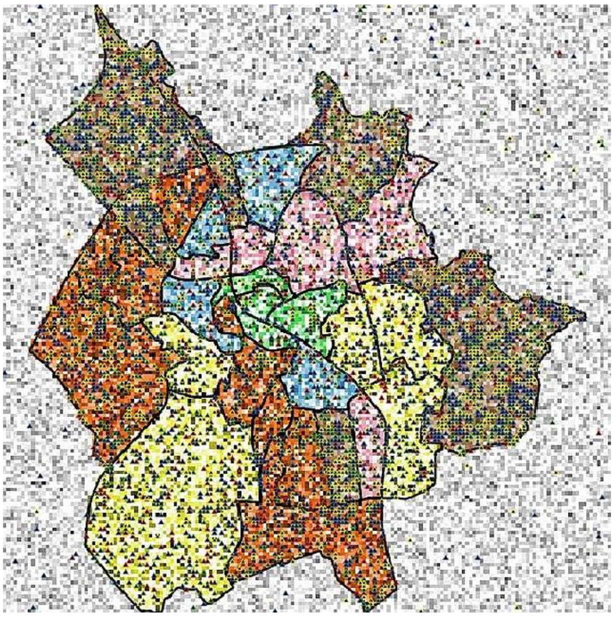

Fig. 1 spatial representation of segregation with the standard simulation model

Instead, segregation is concentrated in affordable districts (colored brown and orange), and its spatial manifestation is given at a small-scale level. In high-price districts (green and yellow) socio-spatial community building of similar agents is much harder to achieve, even for the most affluent (red agents). (2) Segregation takes place, notwithstanding. Ultimately different degrees of neighborhood evaluation, of decision-making processes and agents' as well as patches' characteristics do not avoid clustering of similar agents. The exceptional fact is the declining degree of segregation, most obvious for the least affluent (blue agents) and only very limited for the most affluent. As an attempt to interpret one might be tempted here to draw a distinction between involuntary moves, caused by displacement, and higher opportunities for freedom with respect to affordability, income and attitude preferences. For the current model there is only a qualitative statement of experts' empirical experiences, verifying the segregation clusters in the north of Salzburg, but of less scope in the eastern district. Other interesting results refer to the extent of outmigration to the suburban region, which significantly depends on the agent's income and the city's housing cost situation, and which is most problematic for the least affluent subgroup (see Fig. 2). Sudden dramatic rises of rents do affect all tenants in more or less the same way (Fig. 3).

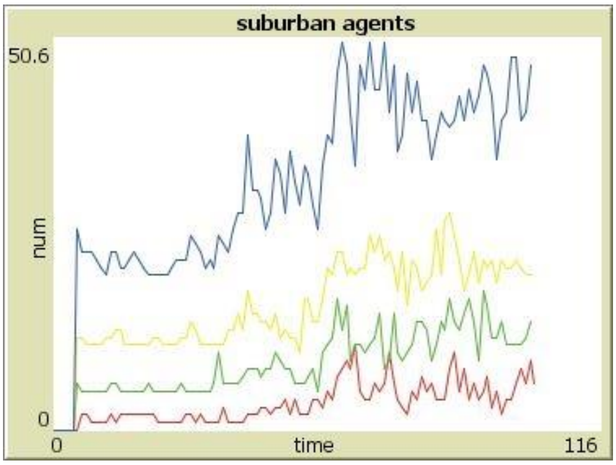

Fig. 2 number of agents expelled from the city (standard model)

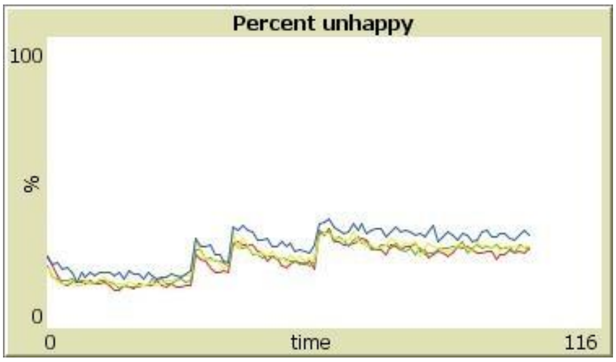

Fig. 3 proportions of agents dissatisfied and sudden increases of rent prices (standard model)

The standard segregation simulation model is provided with eleven parameters to modify and alter the behavior space of agents according to the theoretical requirements mentioned above. The behavior space, therefore, offers a wide range of opportunities for if-then-analyses and scenario building. In what follows four model variations which appear to be relevant for the (potential) emergence of segregation will be discussed briefly.

The first modification refers to the variation of the (individualized) thresholds of 'income' and 'attitude'. One hypothesis here is that the more affluent subgroups (red and green agents) appreciate higher degrees of income-similarity while the less affluent prefer higher degrees of attitude-similarity. Thus, income-similarity of red and green agents is set to 40%, and attitude-similarity to 15%. Yellow and blue agents' preferences are set to 25% for income-similarity and 45% for attitude-similarity. As Fig. 4 illustrates (with four sudden significant leaps of housing costs), a differentiation in the quality of preferences leads to two different levels of realized homogenous neighborhoods of similar agents. The trajectories of either two subgroups remain, however, relatively similar. It turns out that the emergence of neighborhoods with higher aspirations of income-similarity is less difficult to achieve than is the case for attitude-similarity. This can be explained with the continuous variance of the income variable which makes the arrangements of local co-residing much easier than for the dichotomous attitude variable, even in the case of individualized agents.

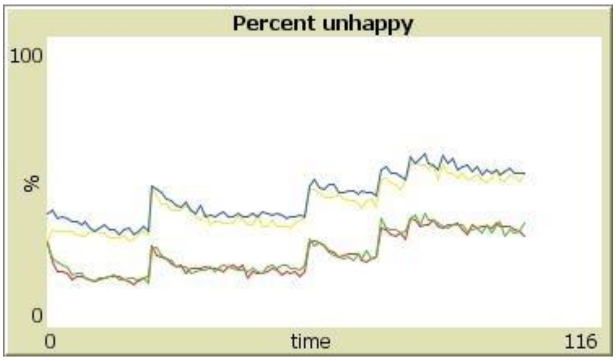

Fig. 4 proportions of agents dissatisfied and sudden increase of rent prices (change-of-preference model)

Segregation patterns are in part similar to the standard model – higher proportions of small-scale segregation have been evolved in the cheaper districts –, but are also different from that model, because red and green agents have now been more successful in the creation of homogenous neighborhoods. Finally, the effect of the cost jumps is different for the four subgroups (see Fig. 5); while for the least affluent agent population (blue) displacement is a cumulative force from the very beginning of the simulation, it is of only marginal relevance for the more and most affluent during the first half of simulation time and remains less influential in the second half.

The parameters that determine the proportion of unhappy agents who actually move and happy agents who move notwithstanding, are relatively insensitive. For the first case we varied the proportion between 60% and 90% without significant changes in the model output. The latter has been varied between 3% and 10%, again without significant changes. These results hold true if the preferences for income-similarity and/or attitude-similarity are being varied (between 20% and 40% for both kinds across agents' subgroups).

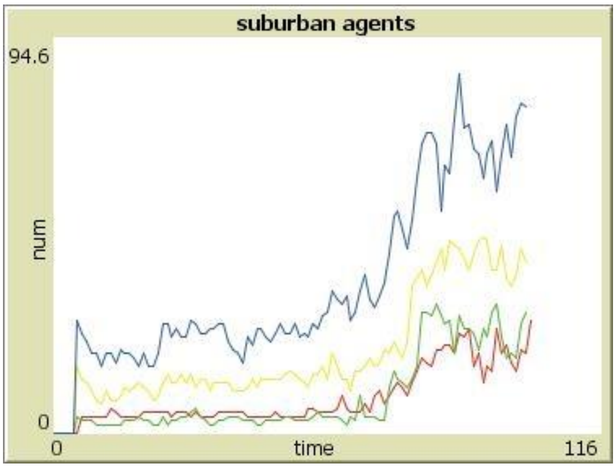

Fig. 5 number of agents expelled from the city (change-of-preference model)

A third variation of the standard simulation model considers the independent variables of 'increase of income' and 'increase of housing costs' as influential for neighborhood composition. Income-similarity and attitude-similarity is set to 35% for every subgroup. If income development is substantially higher than the development of housing costs (the subsequent model used an earnings growth of 0.7% per time step and a growth of housing costs of 0.3% per time step) then the more or less expected result is that all subgroups are able to live in the city. The differences between groups are marginal and even sudden leaps of rising prices do not affect agents' residential behavior significantly (Fig. 6).

In fact, the percentage of dissatisfied agents is decreasing slightly. Furthermore, even small clusters of homogenous neighborhoods of medium- and high-income households in more expensive districts have evolved. The situation changes with a reverse relationship, but less significant than expected. Remarkably, the four subgroups do not differ in their capability to create homogenous neighborhoods (Fig. 7). Sudden changes of housing costs do, however, influence this capability explicitly; in the simulation illustrated in Fig. 7 the percentage of unhappy agents increases from approx. 37% before up to 63% after the price jump.

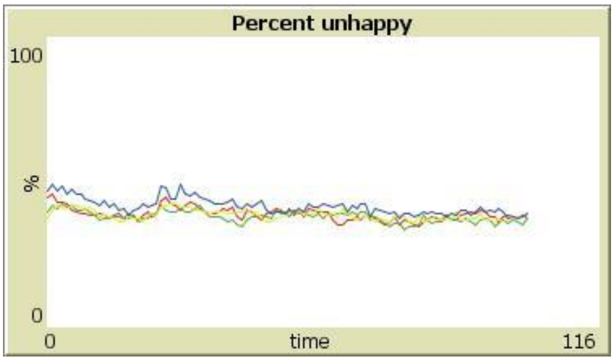

Fig. 6 proportions of agents dissatisfied and sudden increase of rent prices (change-of-income-cost relationship model), with 0.3% / 0.7% cost-income-rise relationship

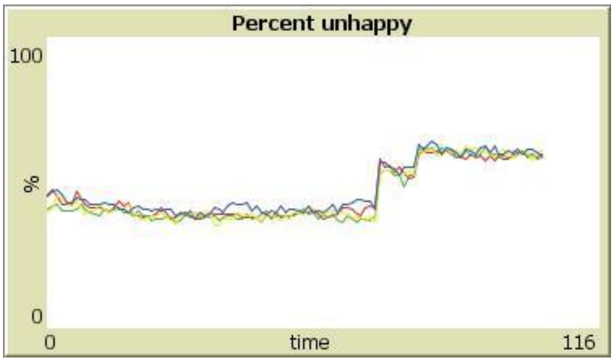

Fig. 7 proportions of agents dissatisfied and sudden increase of rent prices (change-of-income-cost relationship model), with 0.7% / 0.3% cost-income-rise relationship

The last variation takes the range of action of minorities into account. A first modification refers to the situation of having one minority in the city, starting with the least affluent subgroup (blue agents). They represent 10% of the urban population while the other three subgroups make 30% each. The poor minority wishes to live in a neighborhood of at least 50% of agents sharing a similar attitude; its aspiration towards income-similarity is comparatively low (20%). The remaining subgroups all have a relationship of 35% income-similarity and attitude-similarity, respectively.

Surprisingly, the poor minority does not have completely different troubles in dealing with its preferences of co-residing (Fig. 8) though there are fewer opportunities because of the small size of this group. The size of the group might be a suitable explanation for this result since majorities – primarily the socially adjacent group of yellow agents with slightly higher income and less restrictive preferences – are more powerful competitors in the housing market. Rent gaps and public housing allocation policy, as mentioned above, may contribute to amplify or mitigate this competitive change in socio-spatial distribution. Fig. 9

confirms this thesis in part: the competition among the three relative majorities outperforms the competition between them with the minority.

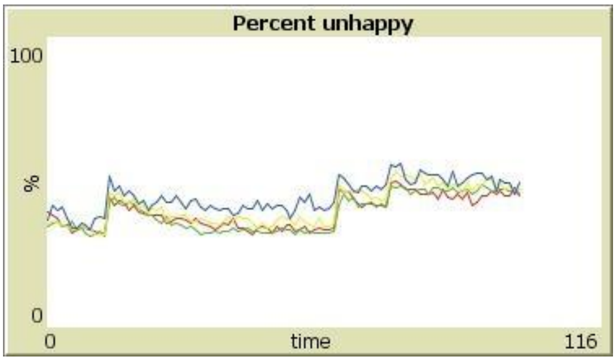

Fig. 8 proportions of agents dissatisfied (poor-minority model)

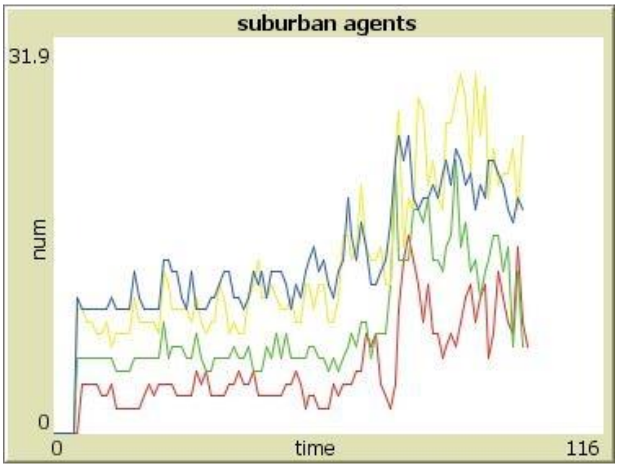

Fig. 9 number of agents expelled from the city (poor-minority model)

If the most affluent subgroup in the city is in a minority situation – and their aspirations are more directed towards income-similarity (50%) and less towards attitude-similarity (20%) – then the underlying principle does change visibly: the affluent agents do much more to achieve their preferences, and the percentage of unhappy fellows is significantly larger than it was for the poor agents (Fig. 10). Simultaneously, the least affluent agent group exhibits a contradictory fact: on the one hand it is much easier for them to segregate themselves in the affordable districts; on the other hand the number of expelled agents is much higher than it is for the other three groups (Fig. 11). One explanation might again lie in greater competition between socially and economically similar communities of the same population size.

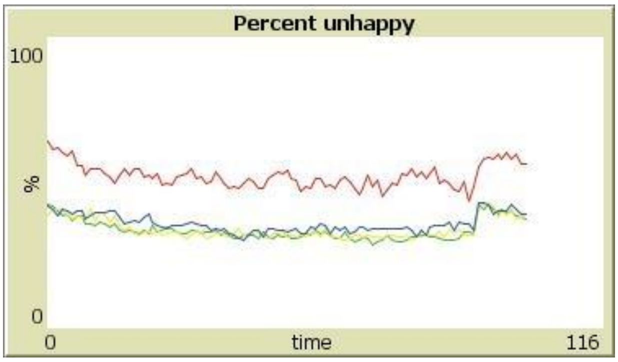

Fig. 10 proportions of agents dissatisfied (rich-minority model)

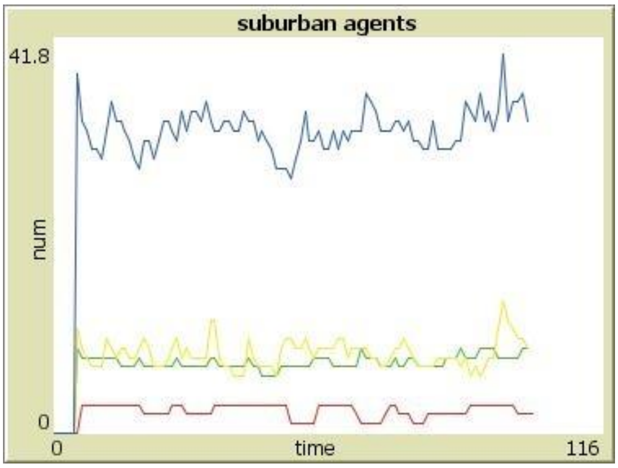

Fig. 11 number of agents expelled from the city (rich-minority model)

The second modification of majority-minority relationship investigates the constellation of two minorities. In the first scenario the most and least affluent agent groups find themselves in a minority position. While the richest agents prefer income-similarity (50% compared with 20% attitude-similarity) the poorest like it the other way round. In addition, housing costs growth is higher than income growth. Now, both minorities have significantly greater difficulties in segregating themselves (Fig. 12). They live in some kind of diaspora while the two middle-class majority populations are able to create small-scale but widespread homogenous neighborhoods. They, however, struggle most against displacement.

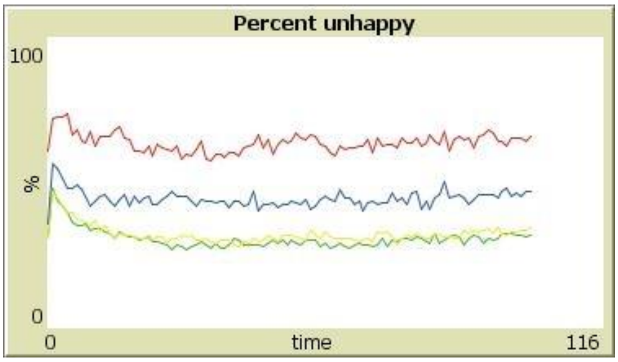

Fig. 12 proportions of agents dissatisfied (two-minorities' model)

On the assumption that social polarization took place in the city, with high proportions of most and least affluent agent groups (80%), and a strong minority of middle-classes (20%) which prefer attitude-similarity to a higher degree (50% compared with 20% of income-similarity) then, again, it becomes obvious that displacement of the poor to the affordable districts (and to the suburban region) does play a crucial role in intra-urban residential mobility (Fig. 13). On the other hand, no large-scale gentrification of the richest agents in the most expensive districts takes place. This modeling outcome is contrary to the empirical reality and thus confirms the necessity to take macro social conditions more seriously into account (thus, the failure of the model here is coherent and logical).

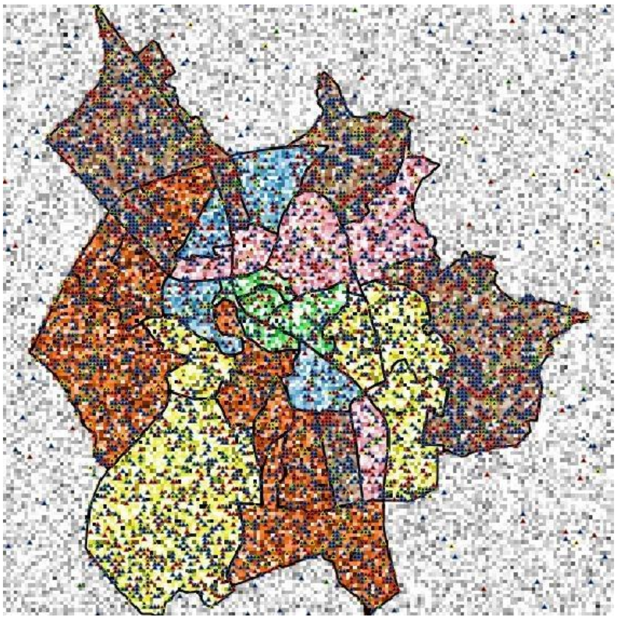

Fig. 13 spatial representation of segregation with the two minorities' simulation model

VI. Conclusion

The theoretical aim of the paper was to develop a segregation simulation model which implements a coherent individualization of agents' characteristics and behavioral settings. The model's purpose is to highlight the bottom-up processes which may help to understand better the emerging patterns of urban socio-spatial homogenization. In so doing, the social macro determinants are included as complementary, but implicit, forces of this complex phenomenon. They should be implemented in a more explicit manner in a forthcoming version of this model. The methodological aim, thus, was to verify the current conceptual simulation model. With the availability of the latest data around July 2014 this next step will be executed.

The observation of [14, p. 123], "despite the elegance of Schelling's model, empirics show neighborhoods are overall quite mixed", inspired us to use the basic ideas of this model-type in order to create true individual agents consistently. The benefit of Schelling's model approach, apart from it being the most influential approach in computational segregation research, is that it integrates a locational model and a "bounded-neighborhood model" [14]. From this starting point the results of the extended and modified simulation model presented here have demonstrated that segregation is a strong though small-scaled process when viewed from the bottom up. Even though: (1) agents individually vary in attitudes, decision-making, actions, and characteristics; (2) a universal threshold has been avoided; (3) macro social determinants have been included (with housing costs in at least an abstract manner), segregation took place.

Some empirical validation is given: while affluent households tend to exclude themselves from the rest of the society, poor households are mostly forced to segregate, although they would prefer to live in a socially mixed environment. Segregation is a controversial topic – in science, spatial planning, and politics. Among many others, one aspect has become increasingly crucial in debates on segregation: the knowledge transfer between people of different social statuses has been more and more interrupted, because of the creation of tangible and intangible borders. These borders tend to be used to make exclusion, injustice, and poverty invisible. A computational approach thus remains an important technique and provides a scientific contribution to detect the hidden mechanisms of these processes.

Acknowledgment

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Beyond Hypothesis-Testing: using Approximate Bayesian Computation for comparing multiple models of cultural transmission in Neolithic Europe.

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The current renaissance of computer simulation in archaeology is showcasing a wide array of successful applications where archaeological theory-building is formalised, and existing methods are evaluated and refined through "tactical" simulations (Lake 2010). However, hypothesis-testing continues to suffer the difficult task of comparing simulation outputs against empirically observed archaeological data. The mathematical rigour used in statistical science is hardly applied in many cases, and simulation models are often evaluated exclusively in visual and qualitative terms. Moreover, the ultimate objective is often not the rejection of a null model, but to evaluate the goodness-of-fit of a purposely designed archaeological model. Whilst this approach has undoubtedly yielded a useful basis for further theory-building through the assessment of mismatches between the artificial and archaeological data, it does not question whether alternative models that can equally, or even better, explain the observed pattern that exists. Such a multi-model approach is beginning to be used in the evaluation of competing statistical models in anthropology and archaeology through the epistemological framework of information-criteria (e.g. Beheim and Bell 2011, Eve and Crema 2014). Similar approaches in agent-based simulation are however still uncommon (but see Piou et al 2009).

Here we illustrate an alternative way to incorporate a multi-model approach based on Approximate Bayesian Computation (ABC, Csilléry et al 2010), a simulation-based methodological framework that was originally developed in population genetics (Beaumont et al 2002). Given one or more simulation models capable of generating summary statistics *S*, a prior estimate of the model parameters, and an observed target data described by the same summary statistic *S*, ABC can provide: 1) posterior estimates of the parameters of each model; and 2) numerical indices (e.g. Bayes factors, Deviance Information Criteria) indicating which model has the best fit to the data with the smallest number of assumptions.

We illustrate the application of ABC in archaeology by examining two case studies in Neolithic Europe: armature assemblages from the Clairvaux and Chalain sites in southeast France and pottery decorative styles from the Merzbach valley in western Germany. In both cases our primary objective is to assess different modes of cultural transmission by examining temporal changes in the frequency of cultural variants. This follows a long-lasting research agenda spanning almost two decades and showcasing a wide variety of case studies and methods (Neiman 1995, Shennan and Wilkinson 2001, Kohler et al 2004, Mesoudi et al 2008, Kandler and Shennan 2013) as well as critiques and limitations (e.g. Steele et al 2010, Premo 2014).

For the purpose of this paper we formalized three models of cultural transmission: 1) an unbiased transmission model; 2) a frequency-bias model which includes both anti-conformist and conformist transmission biases; 3) and a retention- bias model, where agents have a higher chance of retaining traits that they already possess. By translating the mathematical models into agent-based simulation we were also able to integrate archaeological biases such as the effect of time-averaging and differential sample size, overcoming some of the most recent critiques (e.g. Premo 2014).

Our results highlight both the limits and the potential of this approach in archaeological contexts. On the one hand, ABC successfully indicated that retention bias and anti-conformist bias are respectively the best models for the armature and pottery data. The posterior distribution returned probabilistic estimates of the model parameters, providing a better picture on the possible processes behind the observed archaeological pattern. On the other hand ABC highlighted known limits of a simulation-based analysis of archaeological data: the choice of suitable and sufficient summary statistics to describe the observed data, and the limits imposed by the problem of equifinality. ABC, however, offers the possibility of quantifying these shortcomingss, and hence we believe this is a promising venue for a more empirically grounded model-based archaeology.

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Communication apprehension, self-esteem and the Leviathan model

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Abstract— **Mc Corskey and al, 1977 have shown there is a link between a high aversion to oral communication and a lower self-esteem. We investigate if the Leviathan model which considers agents gossiping and having an opinion of each other (Deffuant et al 2013) is able to reproduce such a correlation. Our virtual agents form their opinions in face-to-face meetings. During these meetings, they act in self-defence applying vanity, and influence each other. They also gossip about their peers. In direct meeting and gossiping, a highly valued speaker compared to listener's self-opinion is more influential. The vanity impact depends on the distance between one's opinion of one self and the opinion conveyed by the speaker. Listeners felt held in low esteem sanction their speakers by decreasing their opinion of them. Those felt held in high esteem reward them by increasing their opinion of them. We modified the probability to talk of agents to consider a heterogeneous one: static depending on the agent itself, or dynamic depending on her self-esteem. The simplest law to obtain a heterogeneous probability to talk is sufficient to reproduce our search correlation. However, we also discover that the model argue it is possible to have a higher self-esteem for someone talking less than the others in some circumstances.**

I. Introduction

MC CROSKEY, DALY al. (1977) have shown there is a link between a high aversion to oral communication and a lower self-esteem whatever the age. However, they can't conclude about an explanation telling someone has a low self-esteem due to a communication apprehension or vice-versa. Moreover, these authors tell about some experiments showing these people also tends to have a less positive reputation than people talking more**.** This seminal work has been confirmed by more recent studies (see Wood and Forest 2011, p. 273 for a short review).

The Leviathan model simulates the dynamics of esteem of everyone for everyone comprised themselves. It allows the observation of the self-esteem dynamics as well as the reputation dynamics. Indeed for some parameters, agents reach consensuses on everyone's value that can be defined as reputations (Emler 1990). The basic version proposed by (Deffuant, Carletti and Huet 2013) considers everyone talks to others with the same probability. Then it is impossible in this model observing the correlations pointed out by (McCroskey, Daly, Richmond and Falcione 1977). We aim to study the minimum change to operate in the Leviathan model to obtain such a correlation: is it sufficient for people talking with a different probability or is it necessary to take into account the level of self-esteem to define the probability to talk? To answer, we studied some variants of the Leviathan model in which agents have their own probability to talk, different from the others' probability.

The Leviathan model has been recently proposed. It brings a new and unique insight into the relation between agent respective evaluations and group structure. What is the essence of this model? It is a theory explaining how people structure themselves from the agent need to form an opinion of the others, including themselves. It considers agent interaction through meeting in pairs. Motivated by the need to be held in high esteem (Hobbes 1651), agents act in self-defence, applying a process called vanity. They protect themselves from being despised by sanctioning the despiser, or favour a compliment by rewarding the compliment giver. They also gossip about their peers influencing each other with regard to what they think of them. Gossip varies in intensity, from its absence to a high number of discussed peers: the more people a speaker talks about, the more intense is the gossiping during a meeting. The impact of gossiping is considered according to various levels of openness of people. This openness corresponds to a parameter controlling how high a speaker should be held in esteem to influence the listener. Very open-minded agents are influenced whatever their level of esteem for their speaker. Very narrow-minded agents are only influenced by the speakers held in high esteem. The strength of gossip is also ruled by a propagation coefficient. This coefficient and the openness are also used to control how strongly two talkers influence each other.

Various structure forms called dynamic behavioural patterns emerge from the meeting dynamics of the Leviathan model. The result could be an absolute dominance, a very hierarchical society, or a crisis in which everyone hates each other, including themselves. In these three patterns, each agent has a reputation. Egality and elite are also power

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structure forms emerging from the Leviathan model. However, agents of these forms have no reputation. The equilibrium of the structure is based on privileged relationships between subgroups of agents, and/or positive self-opinions.

Overall it is possible to study self-esteems and reputations in this model with regard to a heterogeneous tendency to talk of the agents. We particularly focus on people talking less than the others. In the model, but also for "real", these people are less submitted than others to sanctions and rewards since they less frequently say the others what they think of them. At the same time they are less susceptible to convince the others while the others, especially those talking a lot, have many occasions to influence them. Thus this is very difficult to anticipate if someone talking less in the model is more likely to have a lower self-esteem, as it is the case in the study of (McCroskey, Daly, Richmond and Falcione 1977).

Our study shows the model is able to reproduce the results of the (McCroskey, Daly, Richmond and Falcione 1977)'s study supporting a relation between a high aversion to oral communication and a low self-esteem. The simplest law to obtain a heterogeneous probability to talk is sufficient to reproduce our searched correlation. However, we also discover that the model argues it is sometimes possible to have a higher self-esteem for someone talking less if the aversion to oral communication is an agent's personal trait. The results regarding the reputations are close to those regarding the self-esteems.

While the next section is dedicated to a short review of the body of literature regarded the Leviathan model, the following one presents the model as well as our experimental design. A section presenting the results of our analysis comes next. A final section is entirely focused onto synthesizing and discussing our conclusions.

II. Literature review of the model

In the following we sum-up what we already know about the Leviathan model which is susceptible to help our study.

The model is called Leviathan in reference to (Hobbes 1651) who pointed out that the feeling to be undervalued is a major source of violence. In practice, the basic Leviathan model (Deffuant, Carletti and Huet 2013) assumes that each agent can have a continuous opinion about every other agent, truncated if necessary to remain between -1 and +1. In the initial state, the agents don't have an opinion about the others. The agents interact in randomly chosen pairs to which two different processes are applied. The first one supposes that during any interaction, each agent propagates her opinions about herself, about her interlocutor and about several randomly chosen other known agents. In this propagation, highly valued agents are more influential, with a strength due to an agents' parameter called the openness. The second process represents a vanity effect: an agent likes to be highly valued by the others, thus she increases her opinion on those who value her well. On the contrary, she decreases her opinion of those who undervalue on her. These assumptions are not only inspired by Hobbes, but also by more recent experiments and observations from social-psychologists (Fein and Spencer 1997; Buckley, Winkel and Leary 2004; Srivastava and Beer 2005; Leary, Twenge and Quinlivan 2006; Stephan and Maiano 2007; Wood and Forest 2011). Moreover, we suppose that the access to the opinion of the others is not perfect: people may not express exactly what they think and the listener may misinterpret these expressions. To take this into account in the model, the propagated opinions are distorted by noise.

From its first study, two types of states emerge from this model. They differ from each other through the notion of reputation. They are:

- Hierarchized states where direct influence between talkers, and influence via gossiping are stronger than vanity and lead to a consensus on everyone's value, that we call reputation. These reputations are hierarchized and each agent can be seen as occupying her own rank in the hierarchy. Agents with a positive reputation are identified as leaders. These consensual leaders characterise two power structure forms emerging from the dynamics: the absolute dominance or a multiple-leaders hierarchy. There is one structure form without leaders: the dynamic behavioural pattern "crisis" in which each agent has a very negative opinion of all the others and of herself.
- Non-hierarchized states where vanity has a stronger impact on the dynamics and leads to population states in which there is no consensus about opinions. However, some structure forms are grounded in some positive relationships between agents: the dynamic behavioural patterns "egality" and "elite". In egality, each agent has a positive opinion about herself; she is connected by strong positive mutual opinions with a small set of agents and has very negative opinions about all the others. All agents have a similar number of positive (and negative) links. For some parameters, the network of positive links shows the characteristics of small world networks. The elite pattern shows two categories of agents: the elite and second category agents. The elite agents have a positive self-opinion and are strongly supported by a friend, but they have a very negative opinion of all the other elite agents and of all the second category agents. The second category agents have a very negative self-opinion, they have a very negative opinion of all the other second category agents and their opinion about the elite agents is moderate.

The first study (Deffuant, Carletti and Huet 2013) has pointed out the relative importance of the propagation coefficient of the influence compared to the vanity. This explains how people reach a dynamic pattern based on consensuses or another dynamic behavioural pattern.

In (Huet 2014), we focussed on the understanding of the effect of gossip in the Leviathan. Firstly we showed the intensity of gossip favours the consensus. Then, telling how important gossip is for the emergence and the maintenance of consensuses taking the form of reputations, the Leviathan is in accordance with the social psychology literature (Emler 1990; Foster 2004; Wert and Salovey 2004; Beersma and Van Kleef 2012). Similarly to what is outlined by these authors, gossip is a source of reputation, giving each agent a status structuring the population. It maintains the agent status and thus the group structure. It guarantees the connection between people and a sufficient level of agreement regarding the structure.

Secondly, gossip helps the emergence of leaders. Indeed, from Deffuant et al (2013), we know leaders only appear when reputations are consensual and the propagation coefficient sufficiently large compared to the vanity. It gives agents held in high esteem the opportunity to impose her standpoint about everyone's value since everyone agrees on her higher status. In the social literature, if gossip has been often cited in terms of status maintenance, it has rarely cited for high status emergence (to our knowledge, except (Emler 1990)), even if the danger of gossip for the reputation have been often discussed (Foster 2004). (Huet 2013a) has shown in the Leviathan that, since the gossip is introduced in the dynamics for a sufficient level of openness, a leader is susceptible to appear in the population. Also, the number of leaders only depends on the level of openness since agents practice gossiping. The question about the characteristics of the leaders and the various associated leadership styles is a matter of debate in social psychology (Hogg 2001; van Knippenberg, van Knippenberg, De Cremer and Hogg 2004; Uhl-Bien 2006; Martin 2009; Huet 2013a).

Thirdly, we stressed out how the openness ruling the influence strength of a given level of esteem is important, especially for the positivity bias. The positivity bias is always present for a very low openness favouring almost only the influence of those held in high esteem. An increase of the openness decreases the strength of the positivity bias until it disappears. It is especially important when the number of peers discussed during a meeting is low or in absence of gossip. The positivity bias can be suppressed only if agents are open enough to the influence of people held in low esteem, and not only to the influence of agents held in high esteem.

Above the importance of the openness, the change in the strength of the positivity bias differs a lot depending on the openness and the vanity and influence coefficients. Two various forms of positivity bias have been initially identified in the first study of the Leviathan which points out the importance of the vanity and influence coefficients, as well as the openness. The largest one is specific of the egality pattern. It is associated to a very low propagation coefficient of influence for a large vanity one. The agents maintain themselves with a good self-opinion in a dynamic relational equilibrium between few friends which flatters them and which are flattered in return, and a large number of foes which punishes them and which are punished in return. For these particular parameter values, the number of friends and foes is similar for every agent. Foes are agents held in low esteem while friends are agents held in a higher esteem compared oneself. The number of foes can be computed analytically as shown in (Deffuant et al 2013).

The second form of positivity bias has been identified in (Deffuant et al 2013). On the contrary to the previous one, it is associated to a value of the influence coefficient higher than zero while the vanity coefficient is zero. The higher is someone's self-opinion, the larger is her influence propagation coefficient (since the other's opinion of her is very close to this self-opinion). The large influence is due to the asymmetry of the propagation coefficient computation ruled by the openness giving more influence to some agent held in high esteem. Because of this difference, when an agent self-opinion is higher than her reputation, the others have less influence on the self-opinion than when the self-opinion is lower than the reputation (everything else being equal). However, the effect of this average difference between the self-opinion and the reputation depends on the value of the agent's reputation: the highly valued agents tend to lead the other's opinions and, with the statistical bias for a self-opinion higher than the reputation, they tend to increase their reputation. This is the contrary for the badly valued agents who tend to naturally decrease their self-opinion, only by the effect of the propagation coefficient.

The general tendency of the model to generate more negative opinions has then been explained. Indeed, the vanity process enhances the tendency of self-opinions to be higher than the reputations. The small statistical positive bias for self-opinion that is due to the opinion propagation observed in the second "positivity bias" case leads, on average, the agents to consider themselves as (slightly) undervalued by the others, thus they devalue them by vanity in return. This is very similar to the process that we observed for a close to zero coefficient of influence and a large coefficient of vanity, but it is slower because of the averaging effect of the opinion propagation.

(Huet 2013b) has shown this general tendency is due to the form of the vanity function targeted everyone with the same strength. Indeed it can be changed if people held in high esteem are preferentially sanctioned or rewarded compared to those held in low esteem. Such a modification leads people viewing themselves majorly positively, or negatively, depending on the values of the parameters.

III. Material and methods

A. The model

We consider a set of N agents, each agent i is characterised by her list of opinions about the other agents and about herself: $(a_{i,j})1 \leq i,j \leq N$. We assume $a_{i,j}$ lies between -1 and +1 , or it is equal to nil if the agent i never met j and nobody has talked to i about j yet. At initialisation, we suppose that the agents never met, therefore all their opinions are set to nil. When opinions change, we always keep them between -1 and +1, by truncating them to -1 if their value is below -1 after the interaction, or to +1 if their value is above +1.

The agents interact in uniformly and randomly drawn pairs (i, j) and at each encounter, we apply two processes: the face-to-face management, implying influence attempts and vanity between the two agents meeting each other; and the gossip, consisting in influence trials about people they know.

We follow the people's interactions considering a time range called iteration. We assume one iteration, i.e. one time step t →t + 1, is N/2 random pair interactions (each agent interacts N times on average during one iteration).

We now describe in more details what occurs during a pair meeting. We first start with gossip, then continue with the management of the face-to-face before summarizing iteration and related interactions.

Gossip: agents discuss their peers

Let us assume that agents i and j have been drawn. During an encounter, we suppose that agent j propagates to i her opinions about herself (j), about i, and about k agents randomly chosen among her acquaintances. Moreover, we suppose that if i has a high opinion of j, then j is more influential.

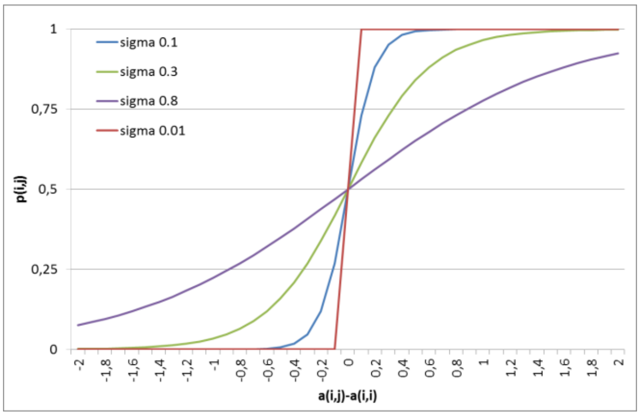


Figure 1. Examples of variations of the propagation coefficient $p_{i,j}$ when $a_{i,j}$ - $a_{i,i}$ varies, and for four values of the parameter σ. When σ decreases, this function tends towards a threshold function returning 0 for negative entries and 1 for positive entries.

This hypothesis is implemented by introducing a propagation coefficient, denoted $p_{i,j}$, which is based on the difference between the opinion of i about j ($a_{i,j}$) and the opinion i about herself ($a_{i,i}$). It uses the logistic function with parameter σ. If $a_{i,j}$ = nil (j is unknown to i), we assume that i has a neutral opinion about j and we set $a_{i,j} \leftarrow 0$. Let us also observe that, at the initialisation, an agent has no opinion about herself ($a_{i,i}$ = nil), before she takes part in a first encounter, thus we also set $a_{i,i} \leftarrow 0$. Then we compute the propagation coefficient $p_{i,j}$, which rules the intensity of the opinion propagation from j to i :

$$p_{ij} = \frac{1}{1 + \exp\left(- \frac{a_{ij} - a_{ii}}{\sigma} \right)}$$

The parameter σ, called openness, defines the slope of the function close to $a_{i,j}$ - $a_{i,i}$ = 0. Figure 1 represents the value of $p_{i,j}$ when the difference $a_{i,j}$ - $a_{i,i}$ varies (between -2 and +2), for three different values of parameter σ. One can observe that $p_{i,j}$ tends to 1 when $a_{i,j}$ - $a_{i,i}$ is close to 2 (i values j higher than herself), and tends to 0 when it is close to -2 (i values j lower than herself). Indeed, when σ is small, p_{ij} rapidly changes from 0 to 1. When σ is large, this change is progressive.

A parameter ρ controls the impact of the coefficient $p_{i,j}$.

The agent i modifies her opinion about the agent z that j talked about applying the influence coefficient ρ by the propagation coefficient to the difference between what j told about z and what she thinks of z. However, i has no direct access to the opinion of j and can misunderstand j. To take into account this difficulty, we consider the perception of i as the value a_{jz} more or less a uniform noise drawn between $-\delta$ and $+\delta$ (δ is a model parameter). This random addition then corresponds to a systematic error the agents make regarding the others' opinions. More formally, the process can be written in pseudo-code as follows:

ALGORITHM N°1

Gossip(i, j)
Repeat k times:
Choose randomly z taking into account $a_{jz} \neq$ nil, $z \neq i$, $z \neq j$.
If a_{iz} = *nil*, $a_{iz} \leftarrow 0$

$$a_{iz} \leftarrow a_{iz} + \rho p_{ij}(a_{jz} - a_{iz} + \text{Random}(-\delta, +\delta))$$

Random (-δ, δ) returns a uniformly distributed random number between -δ and +δ, that can be seen as a noise that distorts the perception that i has about j 's opinions. The parameter δ rules the amplitude of this noise.

The face-to-face activates influence attempt and vanity

During their first meeting, i and j don't know each other and their opinions are nil. Then, they instantaneously become 0 which is the neutral opinion. This initiates the meeting dynamics and allows influence and vanity.

Indeed, when agents i and j meet, they talk about themselves: i talks about herself and j, while j talks about herself and i. This direct exchange implies two processes occurring at the same time: influence of each of them on what they think about themselves and the other, and a vanity process applied by the listener to the talker. This vanity process expresses that agents tend to reward the agents that value them more positively than they value themselves and to punish the ones that value them more negatively than they value themselves. Then, added to the influence i received from j regarding what she thinks about j, the agent i compares her self-opinion a_{ii} to the opinion j tells about her a_{ji}. If the perceived opinion of the other (j) is higher than her self-opinion, i increases her opinion of j (reward). Else i decreases her opinion of j (punishment).

Parameter ω rules the importance of the vanity process. The modification of *i*'s opinion of *j* is assumed as simply depending on the difference between the opinion of *i* about herself and the opinion of *j* about *i* (modified randomly slightly).

The face-to-face can be formally described in pseudo-codes as follows:

ALGORITHM N°1

Face-to-face(*i,j*)
if $a_{ii} = nil$, $a_{ii} \leftarrow 0$
if $a_{ij} = nil$, $a_{ij} \leftarrow 0$

$$a_{ii} \leftarrow a_{ii} + \rho p_{ij} (a_{ji} - a_{ii} + \text{Random}(-\delta, +\delta))$$

$$a_{ij} \leftarrow a_{ij} + \rho p_{ij} (a_{jj} - a_{ij} + \text{Random}(-\delta, +\delta)) + \omega(a_{ji} - a_{ii} + \text{Random}(-\delta, +\delta))$$

During the interaction, face-to-face(*i*,*j*) and face-to-face(j,i) are successively applied.

Summary

Finally, the model has 7 parameters:

- *N*, the number of agents;
- δ, maximum intensity of the noise when someone is alluded to;
- σ, the reverse of the sigmoidal slope of the propagation coefficient, called the openness;
- ρ, the parameter controlling the intensity of the coefficient of the influence process (applied to the propagation coefficient p_{ij});
- *k*, the number of acquaintances an agent talked about during a meeting – they are randomly chosen among her acquaintances;
- δ, maximum intensity of the noise when someone is alluded to;
- ω, the coefficient of the vanity process.

The following algorithm describes one iteration: *N*/2 random pairs of agents are drawn, with reinsertion, and we suppose that each agent influences the other during the encounter.

ALGORITHM N°3

Repeat *N*/2 times:
Choose randomly a couple (*i,j*) with *i* chosen according to her probability to talk and *j* chosen uniformly in the population (in the basic model, the probability of *i* to talk is a constant)
Save the opinions which are going to change in temporary variables to ensure the update during the *i* and *j* meeting is synchronous
Face-to-face(*i,j*)
Face-to-face(*j,i*)
Gossip(*i,j*)
Gossip(*j,i*)

The update is synchronous: every opinion changes occurring during a meeting are computed based on the value of opinions taken at the beginning of a pair meeting.

B. Hypothesis and methods

We aim at studying the impact of a heterogeneous probability to talk of agents in the Leviathan model. To do so, the model can be changed in different manners and we consider several hypothesis or variants, going from the simplest to some more complex ones.

This section describes our hypothesis as well as the corresponding experimental design and the measured indicators. A following subsection describes the results.

Hypothesis

We compare three hypotheses to the basic Leviathan model for which the probability to talk of an agent is the same for every agents. In the two first hypotheses, the probability to talk of an agent is computed at the beginning of the simulation and remains constant over the time of the simulation. In the third hypotheses the talk probability changes during the simulation depending on the agent's self-esteem.

- hypothesis "Uniform": the probability of an agent is picked out at random following a uniform law;
- hypothesis "Power": the probability of an agent is picked out at random following a power law with a parameter which remains constant 1.1;
- hypothesis "depends on self-esteem" with a parameter *f* corresponding to the frequency of update of the agent's probability to talk depending on her self-esteem. This frequency is given in terms of number of meetings without updating her probability to talk – two values for *f* are tested: 20,000 and 1 (i.e. the probability to talk is computed every 20,000 meetings or every meeting).

The two first hypotheses correspond to a situation in which the probability to talk is an agent's trait. The last one is more situational and the probability to talk depends on the agent's self-opinion at a given time. To test our hypotheses, we elaborate the following experimental design.

C. Experimental design

The model includes 7 parameters and it is difficult to make an exhaustive study in the complete parameter space. Considering the knowledge we already have onto the dynamics and the behaviour of the Leviathan model, we decide to vary our parameters as described above. These variations ensure a sufficient representativeness of the various behaviours of the model.

- *k* the number of discussed acquaintances takes the values 2, 5, 10, 15;
- σ the openness, ruling the slope of the logistic function determining the propagation coefficients takes the values 0.1, 0.4, 2 ;

- ρ ruling the intensity of the overall influence by being applied to the propagation coefficient takes three values: 0.1, 0.3, 0.5, 0.7, 0.9;
- ϖ ruling the intensity of the vanity: 0.02, 0.1, 0.2, 0.4, 0.6, 0.8, 1;
- *N*, the size of the population: 40 and 100;
- δ the intensity of noise disturbing the evaluation of other's opinions takes only one value: 0.2

For each set of parameter values, we run the model for 300,000 iterations (one iteration corresponding to *N*/2 random pair interactions), and we repeat this for 10 replicas.

D. Measuring indicators

From iteration 100,000 to 300,000, we measure every 5,000 iterations a group of values allowing us to make conclusions about the impact of a heterogeneous probability to talk. The measures, averaging over times of a run and over the 10 replicas give us indicators.

We measure the mean self-opinion and reputation of the population of agents as well as these means for four different subsets of agents. These subsets correspond to the:

1. The 25 % talking the least;
2. The 25 % talking less (without the first subset);
3. The 25 % talking more (without the last subset) ;
4. The 25 % talking the most;

We also diagnosed the dynamic behavioural patterns.

IV. Results of the study through simulations

This section presents the influence of the various hypotheses regarding the probability to talk of agents. A first subsection shows an overview of these impacts. A second one investigates how these impacts relate to the dynamic population patterns diagnosed in Deffuant et al (2013). Finally we analysed the trajectories of the observed correlations for the most representative patterns.

A. An overview of the various hypotheses

The figure 2 presents the average results obtained over the totality of the experimental design for each hypothesis we consider. We notice from this figure two main results.

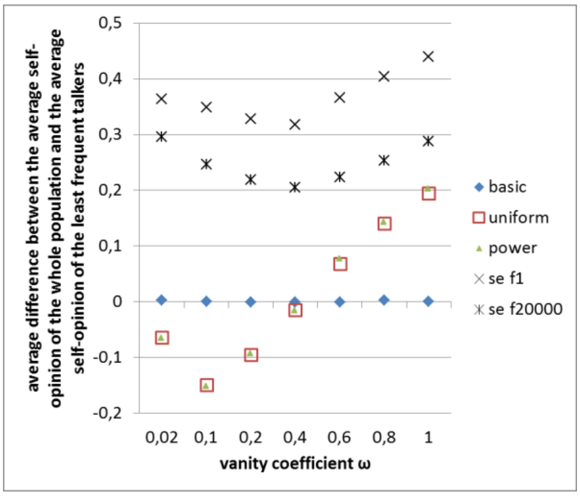


Figure 2. Average difference of self-opinion between average everyone's and the average value of the least frequent talkers for the various tested value of ω and for the basic model in which the probability to talk is the same for everyone (blue diamonds), a probability to talk picked out at random in a uniform law (red square), a probability to talk picked out at random in a power law with a parameter valued 1.1 (green triangle), a probability to talk depending on the agent's self-esteem and updated every 20000 face-to-face meetings (black stars) and every meeting (black crosses).

The first one is that every hypothesis allows reproducing the results exhibiting by the social psychology literature. Indeed when the average self-opinion of the least frequent talkers is lower than the average self-opinion of the most frequent talkers, the difference is positive: the figure shows positive values for every results for $\omega \geq 0.4$ and the uniform or the power hypothesis, as well as those for the probability to talk depending on the agent's self-esteem. It means **even the simplest solution consisting in considering only an initial probability to talk picked out at random in a uniform law is sufficient to reproduce the result we are looking for: "rare" talkers and low self-opinions are correlated.** When the probability to talk depends on the self-esteem of each agent, the effect is larger whatever the frequency *f* of the update of this probability even if it tends to be slightly smaller for a large value of *f*.

The second result is that the inverse correlation can be also observed in the model: it is possible that the "rare" talkers have a higher self-esteem than the average self-esteem of the population. Indeed, for the basic and uniform hypotheses and $\omega < 0.4$, the values are negative indicating that the average self-opinion of the least frequent talkers is higher than the average self-opinion of the whole population.

As the results vary with ϖ, we assume the dynamic behavioural pattern, defined by the value of ϖ and ρ can be a good way to better diagnose the impact of an heterogeneous probability to talk. Then to go further, we are going to look in which way these two contrary correlations relate to the dynamic behavioural patterns of the population identified in (Deffuant et al., 2013).

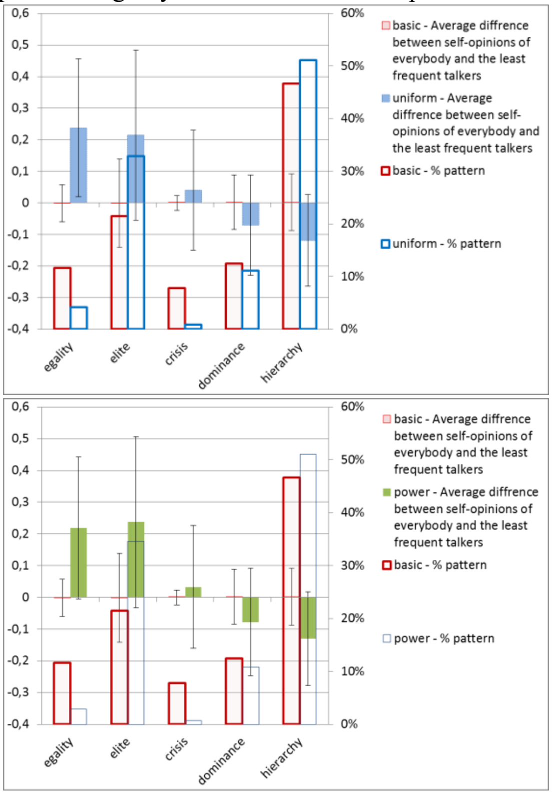
B. Using the population patterns to describe

Figures 3 and 4 show the relation between the two types of correlations between "rare" talkers and self-esteem we found, and the dynamic behavioural patterns of the population presented in the literature review section II.

Figures 3 shows three important results:

- **The "rare" talkers are disfavoured in terms of self-esteem in the non-reputational patterns in which the equilibrium is based on privileged relationship between small subgroups of people (ie the average difference is positive whatever the hypothesis).** Moreover, one can notice for these non-reputational patterns that it is quite impossible to really distinguish the case of an initial difference in the probability to talk which corresponds to an agent's trait from the case the probability to talk depends on the self-esteem of the agent. Indeed, even if the strength of the average is slightly different in the various hypotheses, it varies in the same way depending on the pattern.

- The pattern "elite" is always favoured in terms of probability to appear**,** whatever the hypothesis. Then **the only fact to give a differentiated probability to talk to people makes the pattern "elite" much more probable in the parameter space**. On the contrary, the patterns "egality" and "crisis" are less probable.



Figures 3. Link between the nature of the correlation between self-esteem and the probability to talk given by the average difference of self-opinion between average everyone's and the average value of the least frequent talkers, and the dynamic behavioural pattern for, from the top to the bottom right, compared to the basic case of a similar probability to talk for everyone: a probability to talk picked out at random in a uniform law, a probability to talk picked out at random in a power law with a parameter valued 1.1. The "empty" bars give the density of each patterns (density given on the right vertical axe), while the shadow ones give the nature of the correlation (value given on the left vertical axe). The error bars correspond to one standard-deviation for the indicator of the nature of the correlation.

- **The "rare" talkers are favoured in terms of self-esteem in the reputational patterns in which a consensus is reached on everyone values for the case the probability to talk is an agent's trait**.

Figure 4 shows how the self-esteem varies for lower talkers in the dynamic patterns for the hypothesis where probability to talk depends on self-esteem. Also, it shows the distribution over patterns is close to the hypothesis in which probability to talk is an individual's trait: we especially observe the higher probability of the pattern elite compared to the basic hypothesis in which everyone has the same probability to talk.

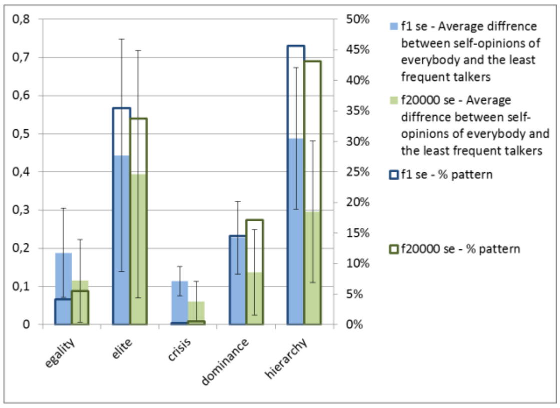
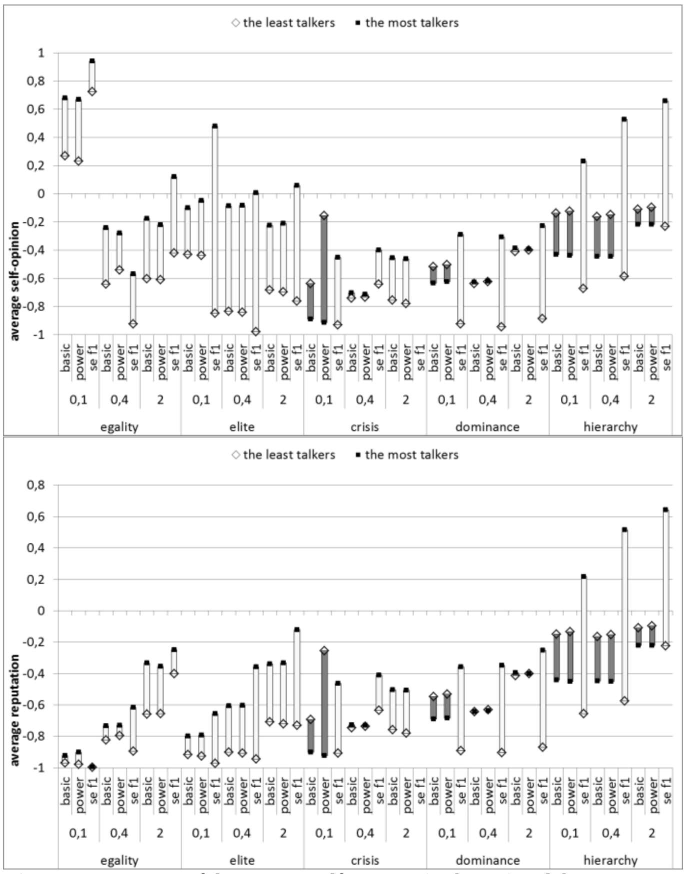


Figure 4. Link between the nature of the correlation between self-esteem and the probability to talk given by the average difference of self-opinion between average everyone's and the average value of the least frequent talkers, and the dynamic behavioural pattern for, a probability to talk depending on the agent's self-esteem and updated every 20000 face-to-face meetings and every meeting. The "empty" bars give the density of each patterns (density given on the right vertical axe), while the shadow ones give the nature of the correlation (value given on the left vertical axe). The error bars correspond to one standard-deviation for the indicator of the nature of the correlation.



Figures 5. Variation of the average self-opinion (at the top) and the average reputation (at the bottom) for the dynamic behavioural patterns and the various hypotheses (presented at the bottom of the figures) for the two extreme groups of talkers (the least frequent (diamonds), the most frequent (black plain squares). Distance bars between the result for the most frequent talkers and the least frequent talkers are darker when the "rarer" talkers have an higher self-esteem, empty on the contrary.

The figures 5 allow to precise when a "rare" talker is susceptible to be a part of the leader group if the probability to talk is an individual's trait (ie if the probability to talk does not dynamically depend on the agent's self-opinion, conditions "power") [corresponds to the darkest distance bars between the result for the most frequent talkers and the results for the least frequent talkers]. From the middle to the right, we can observe that the average self-opinion and reputation are higher for "rare" talkers [dark grey bars] for the hierarchy pattern but also for the crisis and the dominance patterns when σ is low (equal to 0.1).

Figures 5 also show that the "rare" talkers have always the lower self-opinion for the patterns "egality" and "elite", but also for the patterns "crisis" when σ is large enough (>0.1) and the probability to talk is an individual's trait. Crisis (and dominance) are sort of transitory pattern in the parameter space between the two majorly present patterns that are elite and hierarchy. They often appear as transitory during the time of a simulation. That is why they are susceptible to show the two types of correlations between probability to talk and self-opinions depending on which kind of equilibrium they are close to or temporarily come from: elite or hierarchy.

Finally, to have an explanation about why such correlations appear in the case the probability to talk is an individual's trait, we're going to study the trajectories of the two most representative patterns of these correlations: elite and hierarchy.

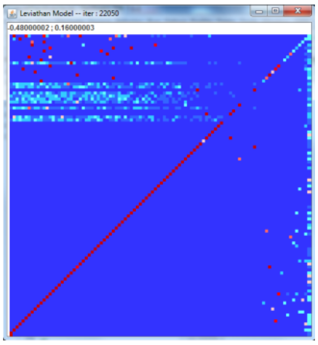
C. Looking at the trajectories to understand

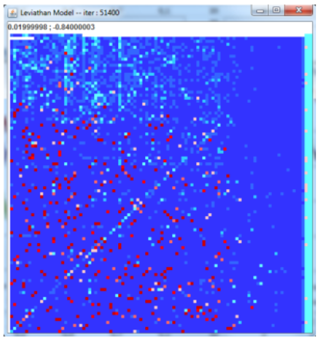
We present in more details what occurs for the patterns elite (or a mixed egality/elite) and hierarchy since they produce the two types of correlations we are interested in. We begin with the correlation coherent with the literature: "rare" talkers have a low self-opinion.

In order to see what occurs, we use a matrix representation in which the opinion list of each agent is represented as the row of a *N*x*N* square matrix. The element $a_{i,j}$ from line *i* and column *j* is the opinion of agent *i* about agent *j*. Then the column *j* represents the opinion on *j* which can be seen as the reputation of *j*. In the following representation, the agent's representations are ordered following their probability to talk. The most frequent talkers is located at the bottom line and her reputation can be read in the first left column. The last column and the top line correspond to the least frequent talker. We use colours to code the opinions: blue for negative and red for positive opinions with light colours meaning that the absolute value is close to 0. This representation provides all the information about the state of the population at a given time step.

Egality and elite

Figures 6 and 7 show the mixed pattern egality/elite (figures 6) and the pattern elite (figure 7) at the equilibrium. In the figures 6, we clearly see an inner square corresponding to two possible descriptions of the egality pattern (from zero on the left, to a lot of "friends" on the right, depending on the value of σ (see Deffuant et al 2013 for more explanations and the description of the patterns given in II)). This square is defined by the 75% more frequent talkers and constitute the elite part of the pattern elite.





Figures 6. Mixed dynamic behavioural pattern egality/elite: on the left k=5, δ=0.2, N=100, σ=0.1, ρ=0.1, ϖ=0.4, and on the right right k=4, δ=0.2, N=100, σ=0.4, ρ=0.3, ϖ=0.8. The agents' frequency of talk decreases from the left to the right; the least frequent talker is the last agent on the right

The 25% least frequent talkers (whose reputations are on the right and opinions are at the top of the figure) represents the second category agent who have a negative self-opinion and a moderately positive opinion of the elite members.

The figure 7 shows the same two groups. It shows how the decreasing of the probability to talk affects how people are seen by others (visible from the left to the right: from majorly positive views to only negative views). This is clear from these representations that the most frequent talkers develop some symmetrical positive privileged relations between themselves while the least frequent talkers are despised by the 75% more frequent talkers and constitute the elite part of the pattern elite. The 25% least frequent talkers (whose reputations are on the right and opinions are at the top of the figure) represents the second category agents who have a negative self-opinion and a moderately positive opinion of the elite members.

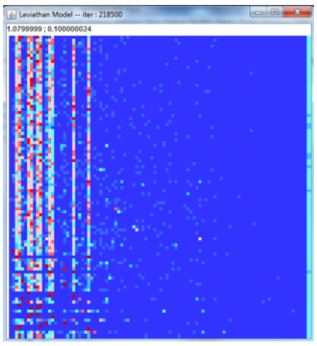
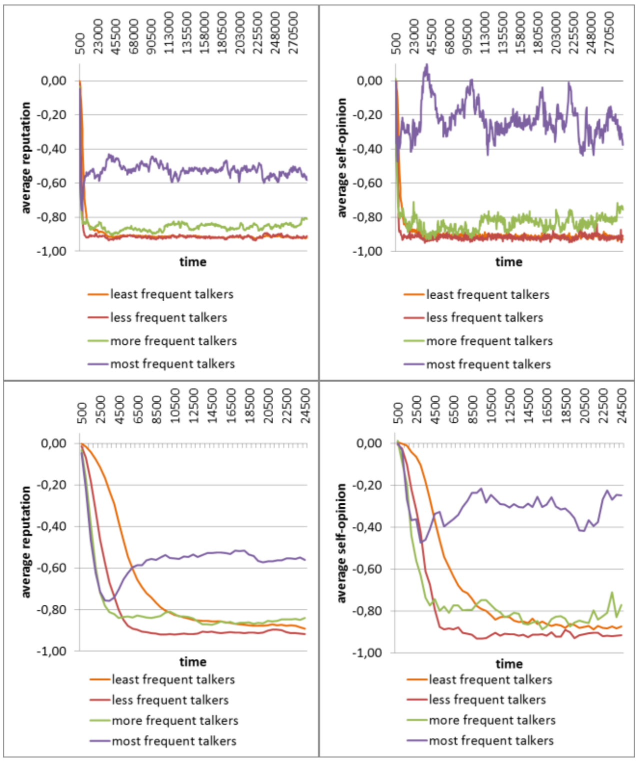


Figure 7. Pure dynamic behavioural pattern elite for k=5, δ=0.2, N=100, σ=0.3, ρ=0.3, ϖ=0.7. The agents' frequency of talk decreases from the left to the right; the least frequent talker is the last agent on the right

The figures 8 show the temporal trajectory of the pure elite pattern presented in the figure 7. We observe the time evolution during a replica of a simulation of the average reputations and the average self-opinions of the four quarters of agents defined by their frequency to talk. We can see how quick in the first iterations (see the figures at the bottom) everyone despise everyone due to a very high vanity coefficient. However, around 4000 iterations, the most frequent talkers begin to stabilise each other by rewarding symmetrically themselves (or a subpart of themselves) while sanctioning the others. These "most" frequent talkers have the "most" frequent occasions to talk to each other and reward each other. That is the way they maintain a better self-opinion than the average one. The "rare" talkers who have the lowest probability to reward each other are on the contrary the ones having the lowest self-opinion.



Figures 8. Temporal trajectory of the dynamic behavioural pattern elite for a replica of a simulation with parameters k=5, δ=0.2, N=100, σ=0.3, ρ=0.3, ϖ=0.7. Average reputation on the left, average self-opinion on the right with at the top the total trajectory, at the bottom only the first 25000 iterations

We're now investigating the hierarchy pattern to better understand why the inverse correlation appears between agent's self-opinion and the probability to talk.

Hierarchy

In the hierarchy pattern, the "rare" talkers have the average better self-opinion when the probability to talk is an agent's trait. Figure 9 shows a typical hierarchy pattern at the equilibrium state. We can observe that the reputations of the most frequent talkers (on the left) are very contrasted compared to the ones of the least frequent talkers (on the rights) which vary from slightly negative to positive. It appears less frequent talkers are protected from sanctions of deceived very positive agents compared to agent who talks frequently.

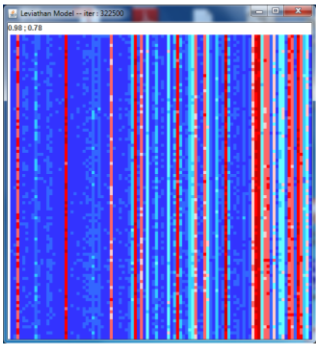
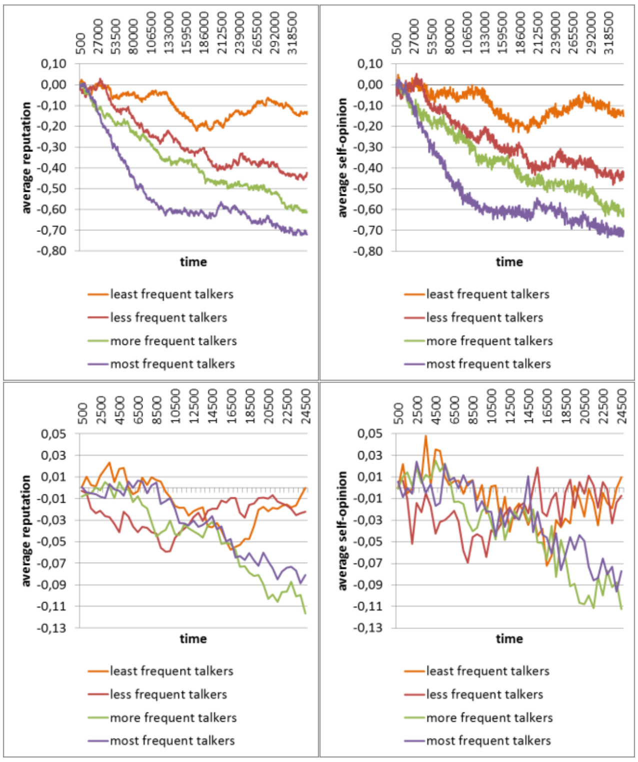


Figure 9. Pure dynamic behavioural pattern hierarchy k=15, δ=0.2, N=100, σ=0.4, ρ=0.7, ϖ=0.2. The agents' frequency of talk decreases from the left to the right; the least frequent talker is the last agent on the right.

Figures 10 confirm this latter hypothesis. Indeed it shows for the same typical hierarchy pattern presented in fig. 9 how evolve over the time for a replica the average reputation (on the left) and the average self-opinion (on the right) of the population. At the beginning (see the bottom figures at about 12500 iterations), the less frequent talkers are less punished and then remain more positive or closer to 0 on average. They are less rewarded in the interaction, but also less punished. It makes them more stable, also more in line with others in terms of reputation. Even when they talk, as they occupy an intermediate opinion, their distance to the others make them less punished or rewarded as well as remaining influent. That is why they have a better self-opinion and can have a greater chance to become a leader.



Figures 10. Temporal trajectory of the dynamic behavioural pattern hierarchy for a replica of a simulation with parameters k=15, δ=0.2, N=100, σ=0.4, ρ=0.7, ϖ=0.2. Average reputation on the left, average self-opinion on the right with at the top the total trajectory, at the bottom only the first 25000 iterations

V. Synthesis and discussion

In the Leviathan model, we tried to consider various hypotheses giving agents heterogeneous probability to talk to the others. We consider some cases in which the probability to talk is an agent's trait, and others in which the probability to talk of an agent is more situational, depending on the self-opinion of this agent at a given time. We aimed to reproduce the results of (McCroskey, Daly, Richmond and Falcione 1977) regarding the correlation between an apprehension to communicate and a low self-esteem as well as a low reputation. We show even the simplest solution consisting in considering only an initial probability to talk picked out at random in a uniform law is sufficient to reproduce the result we are looking for: "rare" probability to talk and low self-opinions are correlated. This simplest solution from the modelling point of view corresponds to an agent's trait hypothesis.

However, if the correlation is always reproduced for a situational probability to talk depending on self-opinion, this depends on the global dynamics when the hypothesis corresponds to an agent's trait. This global dynamics is given by the dynamic behavioural patterns identified in Deffuant et al, 2013. Indeed, for the non-reputational patterns based on privileged relationships between subgroup(s) of agents who have a positive self-opinion, a low probability to talk is correlated to a low self-opinion. On the contrary, for the reputational patterns in which agents are hierarchized with one or more positive leaders, a low probability to talk is correlated to a high self-opinion.

We showed that in the non-reputational patterns, the equilibrium is based on the maintenance of privileged relationships which are quite symmetrical of people having a positive opinion of each other despite a negative opinion of all the others. When they meet each other, they confirm and reinforce their self-positive opinions by mutual influence but also by rewarding each other (or at least very slightly sanctioning). These meetings allow them to resist to the others' contempt. Thus they maintain themselves at a sufficiently high level of influence since they keep a higher status compared to the majority of others. In comparison, someone talking less can't develop a quite symmetrical relationship since she is exposed to the influence of others, especially those talking more, while they have rare occasions to influence in return and really help to maintain a positive self-view. That is why the "rare" talkers have a lower self-esteem.

We also noticed some changes in the distribution of dynamic behavioural patterns over the parameter space due to the heterogeneity of the probability to talk. The pattern "elite" is always favoured in terms of probability to appear, whatever the hypothesis. Only to give a differentiated probability to talk to people makes the pattern "elite" much more probable in the parameter space. On the contrary, the patterns "egality" and "crisis" are less probable. The "crisis" one is even close to disappear. This global result about the distribution of patterns over the parameter space sounds quite realistic and tends to confirm an heterogeneous probability to talk should be consider in the Leviathan model.

The "rare" talkers are favoured in terms of self-esteem in the reputational patterns in which a consensus is reached on everyone's value for the case the probability to talk is an agent's trait.

In the reputational patterns, when the probability to talk is an agent's trait, the "rare" talkers have a higher self-esteem than the average one. They are less rewarded in the interaction, but also less punished. It makes them more stable, also more in line with others in terms of reputation. Even when they talk, as they occupy an intermediate opinion, their distance to the other makes them less punished or rewarded as well as remaining influent. That is why they have a better self-opinion and a greater chance to become a leader.

Finally, the model proposes that it is very different for individuals to talk less frequently with others than the average:

1. because of their personal traits, as shyness for example (McCroskey 1982);
2. because they want to protect their low self-esteem from contempt and influence (Wood and Forest 2011).

Indeed, following our Leviathan model, the first one can lead in some circumstances to a high self-esteem, and sometimes to a leader position, while it can't in the second one. If being intrinsically a "rare" speaker, not looking for social contact, is a disadvantage in terms of self-esteem in societies which are structurally based on close positive relationships, it is not in societies highly hierarchized, even those based on a unique despiser leader.

We didn't find until now elements of literature supporting this last result which does not seem "unrealistic". This deserves further investigations.

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Simulating Extortees: Group Structures and Reasoning Modes

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***Abstract*—Extortion is a unique crime in that it involves a long-term interaction between the victim and the perpetrator. It is also an interesting crime in that it seems to afflict whole communities, cities or even countries. Extortion is often modelled as an interdependent choice between extorter and extortee using a game theoretic framework. Although a game theoretic model takes into account the first uniqueness of a long-term relationship but leaves out the social influence factors that can make extortion endemic within a social group or society. In this paper we present an agent-based model which looks at the decision making of extortees from a social perspective, transforming the traditional extortion game into a collective problem.**

I. Background

The kind of extortion in this paper is the kind executed by organised crime groups such as the Italian Mafia: the request of protection money from entrepreneurs, usually small businesses like restaurants and shops. Extorters usually ask for a relatively small amount of money on a monthly basis, promising to protect the entrepreneur against criminals. There are other kinds of extortion such as kidnapping and blackmail, which we are not concerned with here as the dynamics are rather different. Much of the literature on extortion rackets uses game theory to operationalise extorter and entrepreneur decision-making [1]; [2]. What is usually operationalised is a game matrix between an extortee, who can decide to pay or not and an extorter, who can decide to punish or not. Although modelling this interaction as an interdependent choice makes intuitive sense, the interaction with the extorter is not the only interaction extortees participate in: As usually extorters have several extortees, there is also in interaction between extortees, albeit an indirect one. The structure of this interaction is as follows: for each individual extortee it is more beneficial to pay the money requested by the extorter than to be punished. However, if none of the extortees paid, extorters might soon leave them alone as it would not be profitable to keep on punishing. This interaction is also an interdependent choice of the form of a common good's problem.

This paper discusses a model of extortion racket systems that focuses on the decision space of extortees. Using the framework of team reasoning [3]; [4]; [5] the simulation model explores the consequences of a traditional individual utility maximisation and a utility maximising decision from a group perspective.

II. Model

There are two kinds of agents: *Extorters* and *entrepreneurs*. Extorters approach an entrepreneur with an extortion request. Entrepreneurs decide whether to pay or refuse payment, depending on the monetary utility of paying or not. The decision procedure is:

$$\text{If } p \times a \times d < m \text{ refuse, pay otherwise,} \quad (1)$$

where p is the perceived punishment probability, a an entrepreneur's attitude to risk, d the possible damage caused by punishment and m the amount of money requested by the extorter. p and a are rational numbers between 0 and 1. The attitude-to-risk (a) is normally distributed over the entrepreneurs at initialisation of the model and static. p is set to 1 when an entrepreneur observes a punishment in its neighbourhood and step-by-step reduces by 0.01 each step no punishment is observed. d is set at 1M monetary units. On the right hand side of the inequality m is the amount of money requested by the extorter. Entrepreneurs decide intermittently whether they want to continue paying the extorter or start resisting.

Extorters punish non-payment but punishment costs so they they can only punish if their wealth is greater than the cost of punishment. We implement three punishment regimes leading to different levels of punishment.

1) Whenever an entrepreneur resists there is a punishment from the extorter. (High level of punsihment.)
2) An extorter punishes resistance unless they observed a punishment in their neighbourhood in the last round. (Medium level of punishment and feedback of neighbourhood structure.)
3) An extorter only punishes if the number of entrepreneurs who resist its extortion demands is greater than the number of acquiescent entrepreneurs. (Medium level of punishment and feedback between resistance and punishment.)

Money is injected into the system exogenously at the entrepreneurs' payday in which each gets a mean income of 300 (normally distributed). The pizzo m is set at 50; extorters are also paid on payday.

This model is seen as a basic implementation of an interdependent choice game tree in which entrepreneurs decide to pay or not depending on the monetary utility of either action. Extorters punish or not depending on the punishment regime. The main parameters we vary are the punishment regime and the neighbourhood radius, i.e., the level and the deterrence reach of punishment. This model implements individual utility maximisation and running the simulation shows that individualist utility maximisation is able to recreate a stylised fact of extortion rackets: high levels of compliance with low levels of punishment. Only if the reach of deterrence is rather low, does resistance become more prevalent but a low reach of deterrence, equivalent with a lack of information, is very unrealistic as people talk and the media reports attacks on entrepreneurs.

To operationalise team reasoning we implement the following decision function:

$$\text{If } p \times a \times d < G \times m \text{ refuse, pay otherwise.} \quad (2)$$

The left hand side of this inequality is the same as in (1). On the right hand side is the sum of pizzo paments m the group would pay if they all paid. If it is better for the group not to pay, collectively minded agents resist the extorter.

The above decision mechanism is implemented on two social structures, one being a networked structure, i.e., the relevant group is constructed by taking all agents within a certain radius (cf. [6]), the other a set of transitive groups achieved by partitioning the grid into a number of fields.

We implement societies with different levels of collectively minded agents. For these societies we looked again at punishment regimes and neighbourhood radii but also at the influence of group size and the mix of individualistic and collectively minded agents in the society. First results show that groups have to be sufficiently large to make a difference to the resistance outcome. The effect of group size is slightly dampened if groups are transitive but not significantly different. This result is a result on the rather stripped down operationalisation of 'team reasoning' we employ. But literature on trust and groups shows that groups in which people think collectively and keep cooperating need to be rather small [7].

III. Conclusions

It seems rather intuitive that to get rid of extortion, people have to stop paying extorters. We have preliminary results that show that the goal of increased resistance might be obtained by making people consider the group payoff (team reasoning) rather than just reason about their own utility in particular in the case of far reaching deterrence. The results, however, also show that the size of the group has to be rather large for to make a significant difference to levels of resistance. One of the starting points for this simulation was the rise of the *Addio Pizzo* movement, first in Sicily but spreading to all areas affected by the Mafia.[1] *Addio Pizzo* has managed to raise levels of resistance in the population of entrepreneurs. We thought that the explanation might be that entrepreneurs feel part of a group changing their decision mechanism to a collective one. An interpretation of our results is that only institutionalised groups can make a difference in this setting as trust will be engendered through the social norms governing the group. *Addio Pizzo* would thus make a difference as they bring the group size an entrepreneur feels part of up to a relevant level (cf. [8] for a study on the interaction of trust, norms and group size).

Future work is to look at the dynamics of resistance more closely, e.g. to investigate the effect of clustering of collectivist agents (i.e. "bleeding the extorter dry"), having more sophisticated implementations of team reasoning and to analyse the networked and transitive group constructions in more detail.

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Rewinding the Dynamics between two Japanese Ancient Descents: -What would happen from the Jomon to the Yayoi Periods in Japan-

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***Abstract*—In this study, through a simple agent-based simulation (ABS) model, we examine the problems experienced by Chinese-Korean immigrants in the formation of the agricultural culture of the Yayoi period (300 BC–250 AD). We focus on two problems: 1) The sex ratio of the immigrants, and 2) who played the major role in agricultural culture in the Yayoi period. The simulation model demonstrates that when most initial immigrants were males and many native Jomon people introduced an agricultural culture in the early stage, it is more probable that the majority of people 300 years later were those with the same traits as the immigrants. These results suggest that the initial immigrants—primarily males—and those who played the major role in the agricultural culture in the early Yayoi period included many native Jomon people. Such results will influence the literature on archaeology.**

I. Introduction

THE Yayoi period (300 BC–250 AD) is the era when rice agriculture began for the first time in Japan about 2,000 years ago. The Yayoi culture was established consequent to the integration of the Jomon culture, a former Yayoi culture, when they lived in the region as hunters and gatherers. it is stated that the agricultural culture was imported from China-Korea. In addition, in anthropological morphology, the human bones of the Yayoi period and Jomon period (14,000 BC–300 BC) differ. Therefore, it is considered that the people from China-Korea had a large genetic influence on the Yayoi people.

Thus, in the formation of the Yayoi culture, when agriculture became the social and economic bases of society, the presence of Chinese-Korean immigrants (Trai-zin in Japanese) was important. However, several problems pertaining to the immigrants remain in Japan's anthropology and archaeology. Specifically, these problems question: 1) the immigrants' place of origin, 2) the initial immigrant population size, 3) the sex ratio of the immigrants, and 4) whether the native Jomon people or immigrants played the major role in the formation of agricultural culture in the Yayoi period.

Regarding the first question, anthropological and archaeological research considers the Korean Peninsula as the immigrants' place of origin. However, for the second question, two hypotheses propose the immigrants' population size as either large or small. The larger immigrant population size is because, as explained, the human bones of the Yayoi period and Jomon period differ. Hanihara [1] estimates that the total immigrant population size over a period of 1,000 years ranged from about 3 million to 10 million people based on a back calculation of the estimated population of the subsequent period. On the other hand, the smaller immigrant population size is because in the beginning of the Yayoi period, the characteristics of pottery and stone tools retain the style of the Jomon period. As such, the size of the immigrant population is not considered large enough to change the characteristics of pottery and stone tools.

Addressing the third question on the sex ratio of the immigrants, a leading hypothesis postulates that the immigrants were primarily male [2]. One reason for this hypothesis is that, as mentioned, the characteristics of pottery and stone tools retain the Jomon style in the beginning of the Yayoi period. This means that if Jomon females made the pottery, then male immigrants mated with native Jomon females. Regarding the immigrant population size, this hypothesis considers that even if the population was large, since the immigrants were primarily males, the characteristics of pottery and stone tools did not change rapidly.

Finally, regarding the fourth question as the most important problem, whether the native Jomon people or Chinese-Korean immigrants played the major role in the formation of agricultural culture in the Yayoi period has been the source of a long controversy. This is an important research problem pertaining to the anthropology and archaeology of Japan [3]. Some anthropologists advocate that the native Jomon people assimilated the agricultural culture as a new culture, thus playing the major role in Yayoi agricultural culture. As explained, this assertion is because in the beginning of the Yayoi period, the characteristics of pottery and stone tools retained the Jomon style. Based on this, a small immigrant population size is assumed and the major role player in Yayoi agricultural culture is considered the native Jomon people, who comprised the majority of the population. Conversely, some anthropologists insist that the ancient Chinese-Korean people immigrating to Japan brought with them a systematic agricultural culture. As the population grew, their descendants became major role players in Yayoi agricultural culture [4]. This insistence is because the human bones of the Yayoi period and Jomon period differ in anthropological morphology. Based on this, they assume that the immigrant population size was large enough to have a significant impact genetically. Thus, the immigrants played the major role in Yayoi agricultural culture. This dualistic thinking has recently been revised. It is now thought that agricultural society was a collaborative process begun by both the Jomon people and immigrants [3].

To resolve these problems, an examination of population trends and the food production system of the Jomon people and descendants of the immigrants since the agricultural introductory period is needed. However, in the Northern Kyushu region, where agricultural culture began, human bone material from the late Jomon period (1000 BC–300 BC) to the early Yayoi period (300 BC–0 AD) is missing, despite the beginning of agricultural culture during that time.

Among these questions, resolving the problems of the initial immigrant population size and who played the major role in Yayoi agricultural culture, Nakahashi *et al*. [5], [6]—based on discriminant analysis of human bone material—point out that people bearing similar traits to the immigrants accounted for about 80% of the total population in the middle Yayoi period (300 BC–300 AD). Furthermore, using a mathematical equation model, they proposed ancient population dynamics up to the middle Yayoi period. Consequently, when giving the difference in the population growth rate between the native Jomon people and immigrants, they suggested that even a small number of immigrants could account for the large majority a few hundred years later. That is, unlike conventional studies, these studies demonstrated the possibility that even a small initial immigrant population can explain why the human bones of the Yayoi period and Jomon period differ in anthropological morphology. Kataoka *et al*. [4] also estimated the population growth rate based on who inhabited house remains, which was determined by the plan of the house remains, the site location, and the settlement composition. They suggested that only the immigrants could account for the large majority a few hundred years later; therefore, only the immigrants could play the major role in Yayoi agricultural culture. Genetically, these results support the contention that immigrants played the major role in agricultural culture.

These studies are remarkable in that they present objective results through a quantitative approach using mathematical models. However, a few unresolved problems remain. First, these studies are premised on a model in which the native Jomon people and immigrants were partially segregated. Even if a mixed group of Jomon people and immigrants is assumed, a small mixed group population size is estimated with a low ratio of native Jomon people in the group. This assumption is unreasonable if there was no barrier prohibiting marriage and contact, and mating was possible between the Jomon people and immigrants. That is, the effects of random mating between these groups were ignored. Second, they assumed that genetic traits and the food production system were not separated. Therefore, these studies did not consider the diffusion of the food production system. The fertility rate depends on the food production system [7]; thus, it is possible that the population growth rate also depends on subsistence culture. These studies are therefore not able to address the fundamental problem: who played the major role in agricultural culture.

In addition, the problem of the immigrant sex ratio is an important unresolved issue. As mentioned, one leading hypothesis postulates that the immigrants were primarily male, this because in the beginning of the Yayoi period, the characteristics of pottery and stone tools retained the Jomon style. This means that if native Jomon females produced the pottery, then male immigrants mated with native Jomon females. Nakahashi *et al*. [5], [6] calculate that the majority of females in the mixed group comprising native Jomon people and immigrants are Jomon females. However, these studies originally assume a small mixed group; thus, they are unable to estimate the sex ratio of the total immigrants. Furthermore, this hypothesis is inconsistent with the fact that the haplotype frequency of the Jomon people's maternal mitochondrial DNA (mtDNA) differs significantly from that of the Yayoi period people because of the genetic influence from Chinese-Korean people [8]. We therefore believe that the low ratio of immigrant females makes it difficult to change the frequency of mtDNA between Jomon and Yayoi period people. In other words, that in the beginning of the Yayoi period the characteristics of pottery and stone tools retain the Jomon style is inconsistent with the significant changes of the haplotype frequency of mtDNA between Jomon and Yayoi period people. Therefore, the problem of the immigrant sex ratio cannot be resolved through the conventional static model method.

Based on this discussion of previous research, in this study, which is a comparative study of the mathematical model of Nakahashi *et al*. [5], [6], we assume that: 1) at first, a large number of native Jomon people and a small number of Chinese-Korean immigrants coexisted in the Northern Kyushu region, and 2) 300 years later, people bearing the traits of the immigrants accounted for 80% of the total population. Based on these assumptions, we examined the problem of who played the major role in the Yayoi agricultural culture using agent-based simulation (ABS). The ABS incorporates both random mating and diffusion of the agricultural culture. In addition, we examined the problem of the immigrant sex ratio by adding the pottery style and mtDNA inheritance models to our simulation model.

II. Simulation Model

A. Description of the Model

Our simulation model is described according to Overview, Design concept, and Details (ODD) protocol [9], [10]. The protocol is intended to address the criticism that agent-based models lack reproducibility. Furthermore, it aims at improving the integrity and standardization of description.

B. Agent and State Variables

The agent is an ancient person and has the following variables.

1. ID number and spatial placement

The agent has an “ID number” and “Coordinate position [*X*, *Y*]” information respectively in a two-dimensional space. In our simulation model, space is not real space but an abstract space, because our study mainly treats the relative diffusion between agricultural culture and trait genes. Therefore, the size of space in our simulation is defined by the speed of diffusion of agricultural culture as described below.

2. Sex

The agent is “Male” or “Female.”

3. Life expectancy and Age

The agent is given a “Life expectancy” based on the table of mortality when the agent is created (born). If the “Age” of the agent is greater than the life expectancy, the agent is removed (dies). We created the table of mortality to reflect the infant mortality rate until recent years of 20% into the mortality table of the Jomon people [11]. We also presume in our simulation model that the mortality table is the same for the Yayoi and Jomon people.

4. Food production system

The food production system variable for the agent is “Hunting and Gathering” or “Agriculture.” The food production system changes from “Hunting and Gathering” to “Agriculture” through the diffusion of agriculture assuming that the cold climate from the late Jomon to early Yayoi period introduced the opportunity for this conversion.

5. Institution of marriage

The institution of marriage variable for the male agent is “Monogamous” or “Polygamous.” The institution of marriage for the Jomon period is unknown. However, for the Yayoi period, polygamous marriage is assumed based on descriptions in “Gishi-Wazin-Den,” which was written by the ancient Chinese on Yayoi period customs: There are some males of high status who have four or five wives, and even some males of normal status who have two or three wives. We postulate that sustaining more than one wife—polygamous marriage—requires a surplus of food. Therefore, in our simulation model, if the male agent includes both “Polygamous” and a high food production system “Agriculture,” then the agent marries three female agents. A new agent (child) inherits the institution of marriage from the father agent.

6. Pottery style

The pottery style variable is either “Jomon style” or “Immigrant style.” Considering the hypothesis that females made the pottery, a new agent (child) inherits the pottery style from the mother agent in our simulation model.

7. Trait genes

The trait gene determines trait characteristics. Originally, it was thought that trait characteristics are determined by involving many genes in a complex manner. However, to simplify this for the simulation, in our simulation model, following Nakahashi *et al*. [5], [6], it is assumed to be composed of major pair alleles. The alleles comprise the “Jomon-type gene (J)” and “Immigrant-type gene (T).” When a new agent (child) is created (born), the agent inherits either of the father agent’s alleles and either of the mother agent’s alleles. In other words, the combination of alleles of an agent is “JJ,” “TT,” or “JT.” According to these combinations, each agent is classified as one with Jomon people or immigrant traits. Specifically, a “JJ” agent comprises traits of the Jomon people, a “TT” agent comprises immigrant traits, and a “JT” agent displays mixed traits (mixed people). In addition, mixed people are determined as those comprising immigrant traits at a given ratio.

8. MtDNA macrohaplogroup

The mtDNA haplogroup variable for an agent is "macrohaplogroup N" or "macrohaplogroup M." The mtDNA is the cell organelle DNA of mitochondria, is inherited maternally, and is relatively easy to extract from human bone remains. Therefore, mtDNA analysis is a useful way to investigate the origin of the maternal line of ancient people. The mtDNA of people in East Asia is broadly classified into macrohaplogroup N or macrohaplogroup M [12], [13]. Results of mtDNA analysis of human bone remains were recently accumulated in Japan. A major difference between Jomon and Yayoi period people is evident in the frequency of mtDNA macrohaplogroup N and M [8]. Specifically, for Jomon period people, the frequency of mtDNA macrohaplogroup N is about 50%, and about 50% for the macrohaplogroup M. On the other hand, for Yayoi period people, the frequency of mtDNA macrohaplogroup N is about 20%, while macrohaplogroup M is about 80%. In our simulation model, when a new agent (child) is created (born), the agent inherits the mtDNA macrohaplogroup from the mother agent as described below.

C. Process Overview and Scheduling

Our simulation model proceeds in an annual time step. In our simulation model, the annual time step is a year. Each year, the three sub-models of each agent are executed in turn as follows: Diffusion of agricultural culture rule, Marriage rule, and Moving rule. In addition, each agent is processed in a random order within each year.

D. Design Concepts

Our simulation model corresponds to 7 of the 11 design concepts of ODD protocol (Table I). Our simulation model is simple, thus, we think that the description of the model and design concepts in this paper is sufficient to indicate reproducibility.

TABLE I.
DESIGN CONCEPTS

No.	Design concepts	Elements
1	Basic Principles	Trait gene was diffused by the increase of population based on the food production system under the diffusion of agricultural culture ・For the diffusion of the food production system, we apply the infection model (SI model) ・For the increase of people, we apply Malthus' theory ・For the inheritance of the trait gene, we apply Mendel's laws
2	Emergence	Diffusion of agricultural culture changes the composition ratio of each trait gene type of agricultural culture holder, the diffusion rate of Jomon-style pottery and the frequency of mitochondrial DNA macrohaplogroup M
3	Adaptation	If an agent is near the other agent with agricultural culture, it introduces an agricultural culture in a given rate
4	Sensing	・Recognizing whether a male agent is near the other agent with agricultural culture ・Recognizing whether an agent is near the female agent
5	Stochasticity	・Life expectancy ・Spatial placement ・Mitochondrial DNA macrohaplogroup ・Introduction of agriculture ・Selection of female agent for marriage ・Sex of child agent ・Combination of trait gene ・Move in random direction
6	Collectives	Number of agents created is determined by the number of agents with "hunting and gathering" and "agriculture"
7	Observation	・Ratio of people with immigrant trait ・Diffusion rate of agricultural culture ・Composition ratio of each trait gene type of agricultural culture holder ・Diffusion rate of Jomon-style pottery ・Frequency of mitochondrial DNA macrohaplogroup M

E. Sub-models

1. Diffusion of agricultural culture rule

Agricultural culture is diffused from a neighboring other agent and through inheritance from a parent agent. In the case of diffusion from a neighboring other agent, if the agent's food production system is "Hunting and Gathering," from all the neighboring other agents with "Agriculture" within given radius cells, the agent's food production system will be "Agriculture" based on given probability. Conversely, in the case of inheritance from a parent agent, by the marriage rule described below, when a new agent (child) is created (born), the agent inherits the food production system from the father or mother agent. In this study, inheritance from the father or mother agent is simulated.

2. Marriage rule

A new agent (child) is created (born) by the marriage of a male and female agent. The male agent is married to a female agent randomly selected from all female agents within three surrounding cells. Furthermore, a new agent is created according to the population growth rate of the mother agent's food production system. The new agent is created at the same spatial placement as the mother agent. The sex of the new agent is allocated as male and female with a 50% probability, and the new agent has a life expectancy and 0 age. For the trait gene, as explained, the new agent inherits either of the father agent's alleles and either of the mother agent's alleles. In addition, the new agent inherits the food production system from father or mother agents, the institution of marriage from the father agent, and pottery style and mtDNA macrohaplogroup from the mother agent. Moreover, as mentioned, only when the male agent is both "Polygamous" and "Agriculture," the male agent can be married to three female agents.

3. Moving rule

Within each step, an agent moves one cell in random directions in a space of the simulation.

F. Initialization

1. Time span of simulation

The time span of our simulation is 300 years (300 steps) from the early Yayoi period to the middle Yayoi period. This value is the same as that of the representative example of calculation in Nakahashi *et al*. [5]. While, as the result of Accelerator Mass Spectrometry (AMS) radiocarbon dating, a new hypothesis postulates the start of the Yayoi period as 500 years earlier than conventional hypotheses, no clear conclusions have yet been reached. Therefore, in this study, the time span is 300 years, which is a more stringent condition for the demographic transition in which the small size of the immigrant population could account for the large majority a few hundred years later.

2. *Population growth rate based on the food production system*

The population growth rate of the agriculture people is higher than that of the hunting and gathering people. We simulate the two cases for the growth rate of each population as follows. Each population growth rate for the first case (high rate case) has the same value as that of the representative calculation example in Nakahashi *et al*. [5]. Each population growth rate for the second case (low rate case) has the lowest value in Nakahashi *et al*. [5].

First case (high rate case): the population growth rate of hunting and gathering people is 0.1% per year, while agriculture is 1.3% per year.

Second case (low rate case): the population growth rate of hunting and gathering people is 0.1% per year, while agriculture is 0.5% per year.

3. *Speed of the diffusion of agricultural culture*

The speed of the diffusion of agricultural culture in our simulation comprises the range of cells of the diffusion and introduction rate. The range of cells of diffusion corresponds to the distance for cultural exchange to occur while in contact with each other; thus, we assumed three degrees: "Narrow (1 cell)," "Moderate (3 cells)," and "Wide (5 cells)." The introduction rate corresponds to the difficulty of introducing an agricultural culture; thus, we assumed four degrees: "Impossible (0%)," "Difficult (0.1%)," "Medium (0.5%)," and "Easy (1%)." This level of difficulty does not refer to the difficulty of agricultural techniques, but to an adequate environment and culture needed to accept the agricultural culture as a new culture. These values are set assuming that even when the range of cells is "Narrow" and the introduction rate is "Difficult," approximately 300 years are needed for the most agents to have "Agriculture."

4. *Inheritance of the food production system from a parent*

The inheritance of a food production system from a parent is unknown. Therefore, to investigate the extent of the simulation result impacted by inheritance either from the father or mother, we simulate the two cases as follows.

First case (father): a new agent (child) inherits the food production system from the father agent.

Second case (mother): a new agent inherits the food production system from the mother agent.

5. *State variables of the initial Jomon people and immigrants*

The simulation run starts with the initial Jomon people and immigrants, the state variables of which are described below.

a) Initial Jomon people

Trait gene: "JJ"
Food production system: "Hunting and gathering"
Institution of marriage: "Monogamous"
Pottery style: "Jomon style"
MtDNA macrohaplogroup: Referring to Shinoda [8], 50% have "macrohaplogroup N" and 50% have "macrohaplogroup M."

b) Initial immigrants

Trait gene: "TT"
Food production system: "Agriculture"
Institution of marriage: "Monogamous" or "Polygamous" in each simulation case
Pottery style: "Immigrant style"
MtDNA macrohaplogroup: In total, 62.5% have "macrohaplogroup M" and 37.5% have "macrohaplogroup N." The haplogroup frequency of the immigrants' mtDNA is unknown. However, because it is thought that the immigrants arrived via the Korean Peninsula, in this study, the frequency of macrohaplogroup of the current people of the Korean Peninsula [8] is used as that of the immigrants.

6. *Spatial placement of the initial Jomon people and immigrants*

It is assumed that the initial immigrants arrived from northern coastal areas at the earliest stage. Therefore, in this study, the initial immigrants are densely positioned on one point at the start of the simulation run. To investigate the extent of the simulation result impacted by this assumption, we simulate the two cases in the spatial placement of the initial Jomon people and immigrants as follows.

First case (dense distribution): the initial Jomon people are uniformly randomly placed, while the initial immigrants are placed on the center of the upper side of space [*X: 25, Y: 50*], assuming that they came from the northern coastal area.

Second case (dispersed distribution): Both the initial Jomon people and initial immigrants are uniformly randomly placed.

7. *Number of initial Jomon people and immigrants*

The number of initial Jomon people is 200 agents and immigrants 1,800 agents, referring to the ratio of 9:1 of initial Jomon people and immigrants in the representative calculation example in Nakahashi *et al*. [5].

8. *Sex ratio of initial Jomon people and immigrants*

As mentioned, a leading hypothesis states that the immigrants were primarily male. Therefore, to discuss the sex ratio of initial immigrants, we simulate three cases in the initial immigrants' sex ratio as follows. In contrast, the male and female ratio of initial Jomon people is equal.

First case (same): the number of males for initial immigrants is 100 agents and the number of females is 100 agents.

Second case (more): 150 male agents and 50 female agents

Third case (majority): 175 male agents and 25 female agents

9. *Ratio determining "JT" mixed people as those with immigrant traits*

If agents are mixed people with the "JT" trait gene, then they display immigrant traits at the given ratio. We simulate two cases for this ratio as follows.

First case (100%): people with immigrant traits at a ratio of 100%

Second case (50%): people with a 50% ratio of immigrant traits

In the first case, they are determined as immigrants based on the assumption that a person with even a small amount of immigrant traits has immigrant traits.

G. Number of Simulation Cases and Evaluation Index

The total number of simulation cases is 441 cases. This figure refers to cases combining each of the above parameters (Table II) added to the representative example of a simple increase of calculation in Nakahashi *et al*. [5]. The simple increase of calculation is a model based on the assumption that the number of Jomon people and immigrants increased separately without random mating and cultural exchange between them.

For the number of simulation runs, cases combining "agricultural population growth rate: 1.3%" and "spatial placement of the initial Jomon people and immigrants: dispersed distribution" were run once, considering computational costs. The other cases were run ten times. The random seed value of these ten runs was the same among cases.

The main evaluation index in our simulation results was the ratio of people with immigrant traits within all agents. It was reported [5] that with regard to demographic transition in the middle Yayoi period, the ratio of people with immigrant traits was 80% or more. Therefore, determining if the ratio 300 years later (steps) is close to 80% or more is a measure of demographic transition in our simulation. In this study, we refer to the ratio for each run of each case. In addition, in the simulation case where demographic transition occurred, to discuss who played the major role in Yayoi agricultural culture, we illustrate a time series of the diffusion rate of agricultural culture and composition ratio of each trait gene type of agricultural culture holder. Moreover, the diffusion rate of Jomon-style pottery and the frequency of mtDNA macrohaplogroup M are compared among these cases. For the diffusion rate of Jomon-style pottery, considering that in the beginning of the Yayoi period the characteristics of most pottery retained the Jomon style, we investigate if the diffusion rate of Jomon-style pottery is higher. Furthermore, with regard to the frequency of mtDNA macrohaplogroup M, considering that the frequency of macrohaplogroup M of the Yayoi period people was about 80%, we determine whether the frequency of macrohaplogroup M is higher.

III. Results and Discussion

Of the 441 cases, 111 demonstrated a more than 80% ratio of people with immigrant traits 300 years later (steps).

In the case of the representative example of a simple increase of calculation in Nakahashi *et al*. [5], the ratio of people with immigrant traits was 78.9%. This case is without random mating and cultural exchange between the native Jomon people and immigrants.

In the following sections, when referring to random mating and cultural exchange between the Jomon people and immigrants, we refer to differing results in the cases of "spatial placement of initial immigrants," "institution of marriage," "speed of the diffusion of agriculture," and "sex ratio." As such, we describe only results of cases common in "inheritance of food production system from a parent: mother" and "ratio determining "JT" mixed people as those with immigrant traits: 100%."

A. Spatial Placement of Initial Immigrants

In cases where both the initial Jomon people and initial immigrants are uniformly randomly placed, the ratio of

TABLE II.
VALUES OF PARAMETERS

Initialization parameters	Values
Time span of simulation	[300 years(steps)]
Population growth rate of hunting and gathering people	[0.1%]
Population growth rate of agricultural people	[1.3%], [0.5%]
Range of cells of the diffusion	[Narrow: 1 cell], [Moderate: 2 cells], [Wide: 3 cells]
Introduction rate of agricultural culture	[Impossible : 0%], [Difficult : 0.1%], [Middle : 0.5%], [Easy : 1.0%]
Inheritance of food production system from a parent	[Father], [Mother]
Institution of marriage of the initial Jomon people	[Monogamous]
Institution of marriage of the initial immigrants	[Monogamous], [Polygamous]
Spatial placement of the initial Jomon people	[Dispersed distribution]
Spatial placement of the initial immigrants	[Dispersed distribution], [Dense distribution]
Sex ratio of the initial immigrants (Male, Female)	[Same: 100, 100], [More: 150, 50], [Majority: 175, 25]
Sex ratio of the initial Jomon people (Male, Female)	[900, 900]
Ratio determining the mixed people as those with immigrant traits	[100%], [50%]

people with immigrant traits does not reach 80%, then that is considered a measure of demographic transition (Fig. 1, Fig. 2). Generally, cases where the speed of diffusion of agricultural culture is slow (e.g. the range of cells of diffusion: "Narrow [1 cell]" and the introduction rate: Difficult [0.1%]) indicate a higher ratio of people with immigrant traits. On the other hand, cases where the speed of diffusion of agricultural culture is rapid (e.g. the range of cells of diffusion: "Wide [5 cells]" and the introduction rate: Easy [1%]) indicate a lower ratio of people with immigrant traits.

For the dense distribution of immigrants, some cases attain the 80% ratio of people with immigrant traits 300 years later as a measure of demographic transition (Fig. 3, Fig. 4). The immigrants in these cases are all "Polygamous." We provide more information on these cases in the following sections.

The reason demographic transition does not occur in the case where both the initial Jomon people and immigrants are uniformly randomly placed is because there are many points of agricultural culture diffusion. Agricultural culture is diffused among the native Jomon people at the early stage, and the Jomon population increases at the high rate of agricultural people. Therefore, even in the case where the population growth rate of agricultural people differs, the same result is shown (Fig. 3, Fig. 4). To generate demographic transition, our results show the probability that the immigrants lived at high population densities and that only a part of the neighboring native Jomon people made contact with them.

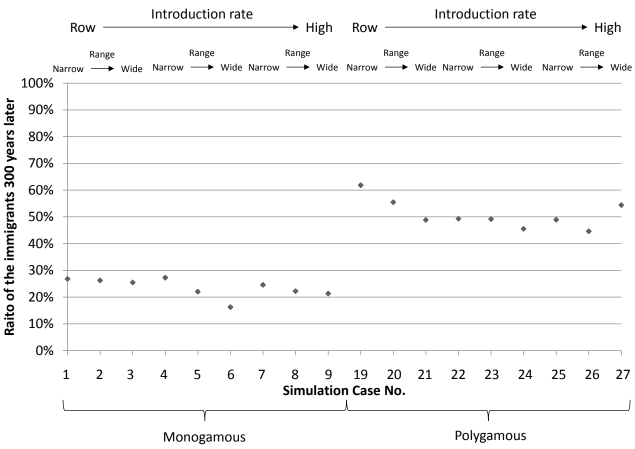

Fig. 1 Ratio of people with immigrant traits 300 years later in the cases of dispersed distribution and a 1.3% agricultural population growth rate

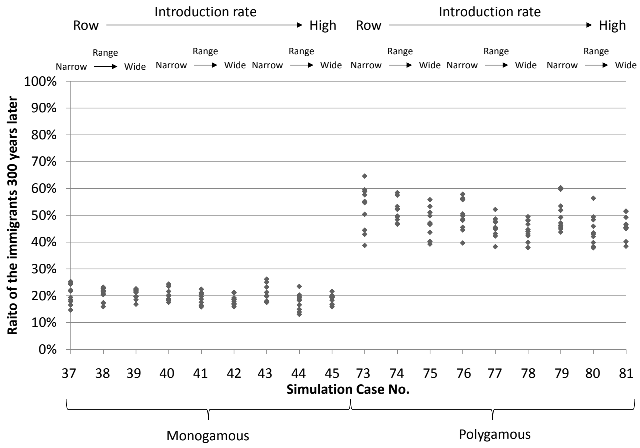

Fig. 2 Ratio of people with immigrant traits 300 years later in the cases of dispersed distribution and a 0.5% agricultural population growth rate

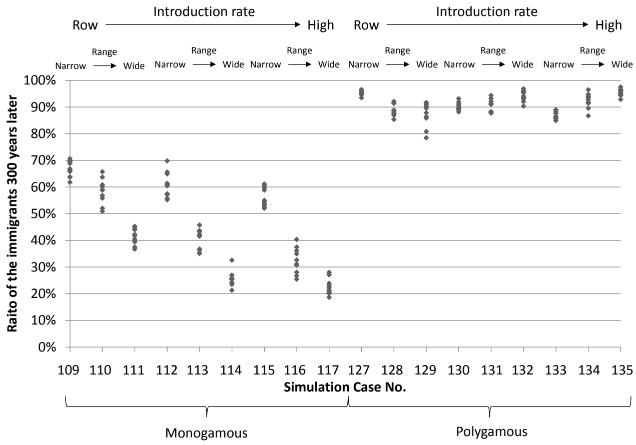

Fig. 3 Ratio of people with the immigrant traits 300 years later in the cases of dense distribution and 1.3% of agricultural population growth rate

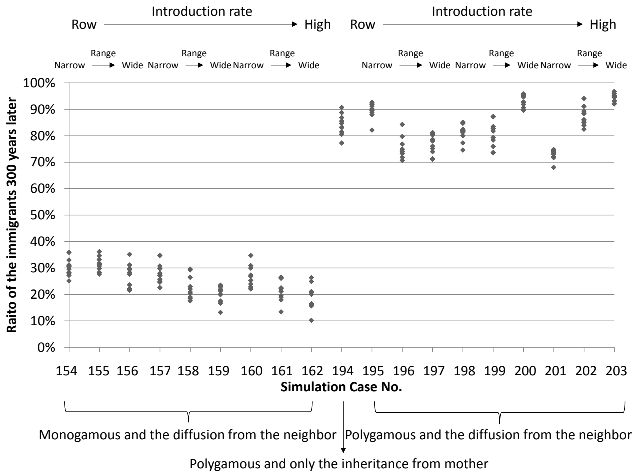

Fig. 4 Ratio of people with immigrant traits 300 years later in the cases of dense distribution and a 0.5% agricultural population growth rate

B. Institution of Marriage and Speed of Agricultural Diffusion

1. Cases of monogamous marriage and diffusion from neighboring other agents

In cases of the dense distribution of immigrants, the monogamous marriage and the diffusion of agriculture from neighboring other agents, the ratio of people with immigrant traits 300 years later does not attain the 80% needed to indicate demographic transition (Fig. 3, Fig. 4). The reason is the same as described earlier. Once agricultural culture diffused among the native Jomon people at the early stage, their population increased at the high rate of agricultural population growth. Therefore, also in these cases, cases in which the diffusion of agricultural culture is slow indicate a higher ratio of people with immigrant traits, while cases with rapid diffusion of agricultural culture evidence a lower ratio of people with immigrant traits. Considering these results, even if assumed that marriage would take place preferentially within the population, because the agricultural culture is diffused among native Jomon people when the trait gene is diffused only within the population, demographic transition would not have occurred.

2. Case of polygamous marriage and only inheritance from a parent agent

In the case of the polygamous immigrants where agricultural culture is only inherited from a parent agent (not diffused from a neighboring other agent), even when the agricultural people's population growth rate is 0.5% of the lower rate, in some cases the ratio of immigrants 300 years later attains 80% (Fig. 4). If the initial immigrants were "polygamous," demographic transition is probable. In addition, considering these results, even if the agricultural people's population growth rate was lower, it would be enough to infer that demographic transition occurred. That is, demographic transition in which people with immigrant traits came to account for the majority a few hundred years later could occur by the diffusion of the trait gene in polygamous marriage assuming a low population growth rate for the agricultural people. Given that agricultural technology was not mature at that time, a 1.3% population growth rate for agricultural people may be too high. Therefore, these results indicate a high consistency for demographic transition even when the agricultural people's population growth rate is low. In addition, as described above, when employing the hypothesis that the start of the Yayoi period was 500 years earlier, even the lower rate of population growth could generate demographic transition.

However, in these cases, the diffusion rate of agricultural culture 300 years later is very low (about 25%), because agricultural culture is inherited only from either father or mother. Moreover, the composition ratio of each trait gene type of the agricultural culture holder is the immigrant-type "TT" or mixed-type "JT." Therefore, when people with the mixed-type "JT" are determined as those with immigrant traits at a ratio of 100%, they would dominate agricultural culture, meaning it is not diffused among those with Jomon people traits.

3. Case of polygamous marriage and diffusion from the neighboring other agent

In the case with the polygamous immigrants and agriculture that is not only inherited from a parent agent but also diffused from the neighboring other agent, the ratio of people with immigrant traits 300 years later varies depending on the speed of the diffusion of agricultural culture. When the population growth rate of the agricultural culture people is 0.5% of the lower rate, some slow-speed agricultural culture diffusion cases do not attain the 80% ratio of people with immigrant traits 300 years later (Fig. 4). In contrast, in cases demonstrating significant speed in agricultural culture diffusion, the 80% ratio of people with immigrant traits 300 years later is attained. When the population growth rate of the agricultural people is 1.3% of the higher rate, regardless of the speed of agricultural culture diffusion, the ratio of people with immigrant traits 300 years later attains 80% in all cases (Fig. 3). Even so, the rapid speed of agricultural culture diffusion is higher in the ratio of people with immigrant traits 300 years later.

These results demonstrate that in the case of polygamous marriage and the diffusion of agriculture, the wider diffusion of agricultural culture more easily generates demographic transition. The reason is that there is a time lag between the diffusion of agricultural culture and polygamous marriage, and this time lag influences the increasing population of the Jomon people and immigrants. Specifically, the dense distribution of immigrants means that the number of immigrants increased at the earliest stage, and in this process, agricultural culture diffused among the Jomon people. However, polygamous marriage remained an immigrant trait as it was inherited from the father. Consequently, the neighboring Jomon people came to have an agricultural culture. Furthermore, in the situation where the immigrants' neighbors with an agriculture culture display a higher population growth rate, the immigrant trait gene type is diffused through polygamous marriage. In other words, it is necessary for the wider diffusion of the immigrant trait gene type that the immigrants' neighbors demonstrating an agricultural culture display a higher population growth rate.

As for the composition ratio of each trait gene type of agricultural culture holder in these cases, in slow agricultural culture diffusion cases, at the early stage, those with the Jomon-type "JJ" and the immigrant-type "TT" were slightly mixed. The mixed-type "JT" then came to account for most agricultural culture holders by marriage (Fig. 5). On the other hand, in cases demonstrating significant rapid agricultural culture diffusion and demographic transition, at the earliest stage, agricultural culture holders were only those with the immigrant-type "TT." However, shortly thereafter, those with the Jomon-type "JJ" became the majority (Fig. 6). Following that, the mixed-type "JT" became the most through marriage. These results show the probability that even if agricultural culture was widely diffused among the Jomon people, demographic transition could be generated.

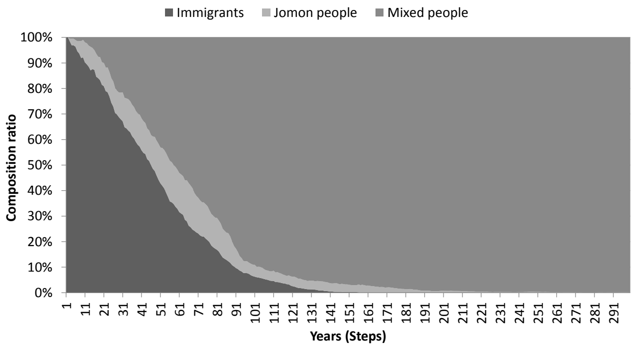

Fig. 5 Composition ratio in agricultural culture holders (No. 196)

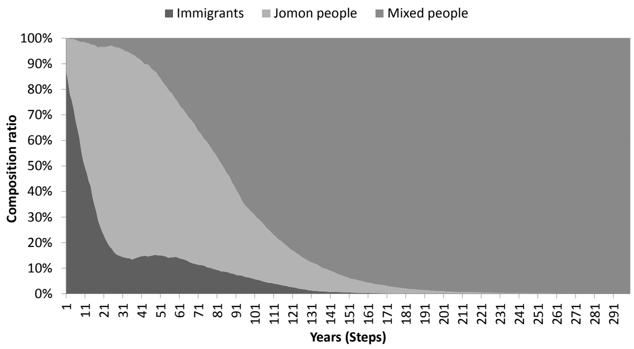

Fig. 6 Composition ratio in agricultural culture holders (No. 203)

C. Sex Ratio of Initial Immigrants

With regard to the sex ratio of initial immigrants, regardless of the population growth rate of the agricultural people and the inheritance of agriculture either from father or mother, generally, cases where the immigrants are primarily male demonstrate a slightly higher ratio of people with immigrant traits 300 years later than cases comprising equal numbers of males and females. In addition, in the ratio of Jomon pottery 300 years later, there are slightly more cases in which immigrants are primarily male, this being close to archaeological fact (Fig. 7, Fig. 8, Fig. 9). However, in the frequency of the mtDNA macrohaplogroup, there is no clear difference between cases where immigrants are primarily male and cases with equal numbers of males and females (Fig. 10, Fig. 11, Fig. 12). The reason is that the frequency of the mtDNA macrohaplogroup is largely influenced by random genetic drift. Conversely, these results show that when the immigrants are primarily male, the haplogroup frequency of the maternal mtDNA could significantly change. Our results find that even when the number of female Jomon people is one-tenth of the female immigrants, when the number of immigrants is increased, the frequency of mtDNA macrohaplogroup changes significantly. Based on this, with regard to the sex ratio of the initial immigrants, higher consistency is evident when immigrants are primarily male. That is, our simulation results support the hypothesis that the immigrants were primarily male.

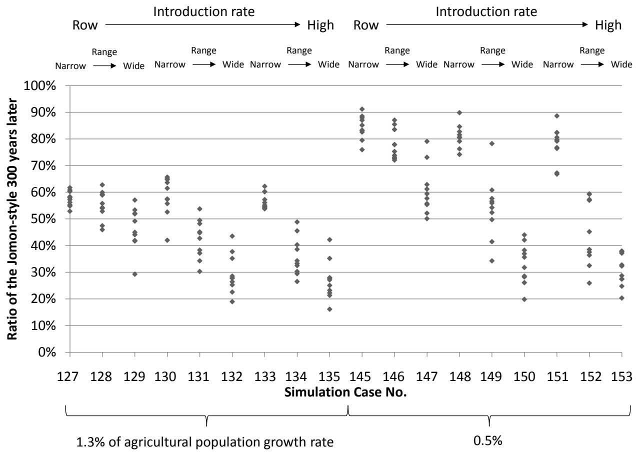

Fig. 7 Ratio of Jomon-style pottery 300 years later in cases comprising equal numbers of males and females

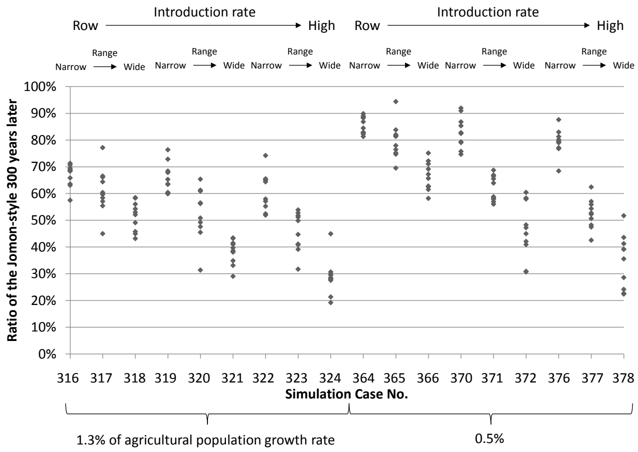

Fig. 8 Ratio of Jomon-style pottery 300 years later in in the cases where male is the more

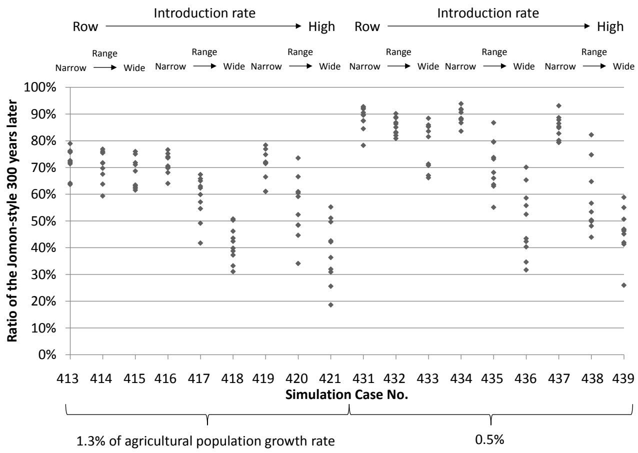

Fig. 9 Ratio of Jomon-style pottery 300 years later in the cases where male is the majority

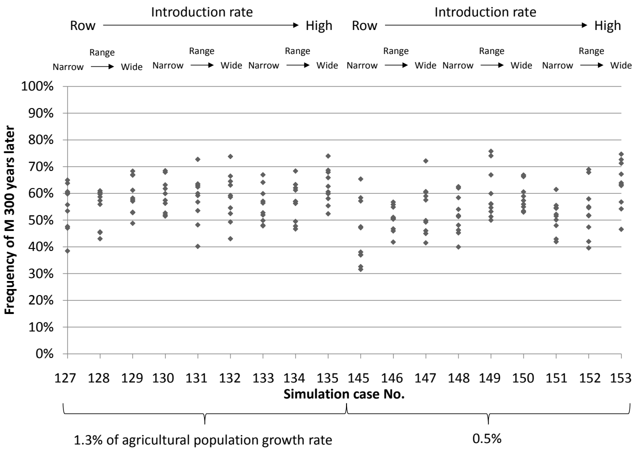

Fig. 10 Frequency of macrohaplogroup M 300 years later in cases comprising equal numbers of males and females

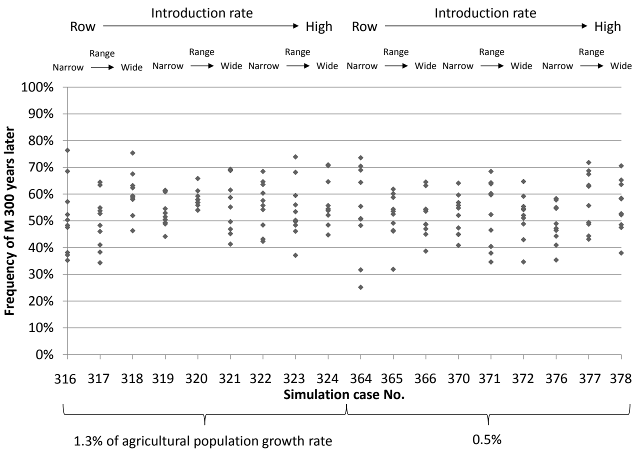

Fig. 11 Frequency of macrohaplogroup M in 300 years later in the cases where male is the more

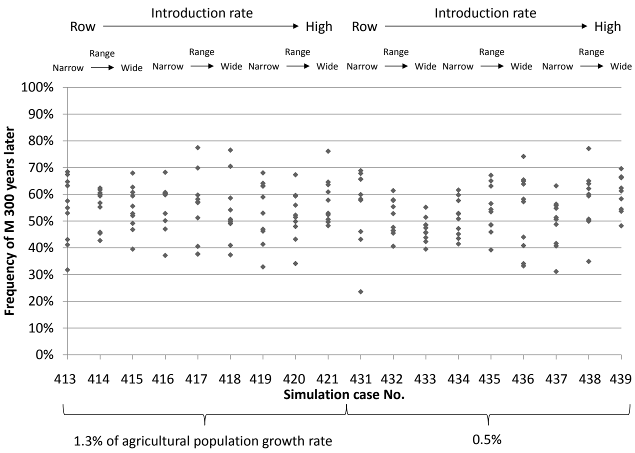

Fig. 12 Frequency of macrohaplogroup M in 300 years later in the cases where male is the majority

D. Who Played the Major Role in the Formation of Agricultural Cultures?

With regard to the problem of who played the major role in the formation of agricultural cultures in the Yayoi period, in the case where a large number of native Jomon people and a small number of immigrants at first coexisted, and where people with immigrant traits came to account for 80% of the total a few hundred years later, our simulation results show the three probable cases described above. In the first case, the immigrants are polygamous and the agricultural culture is only inherited from a parent agent (not diffused from the neighboring other agent). In this case, agricultural culture holders at the early stage are those displaying immigrant or mixed people traits. In this case, the immigrants played the major role in the formation of agricultural culture. In the second case, the immigrants are polygamous and agricultural culture is either inherited from a parent agent and diffused from the neighboring other agent. However, agricultural culture diffusion is slow. In this case, the agricultural culture holders at the early stage comprise many immigrants and few Jomon people. Here, as for the first case, immigrants played the major role in the formation of agricultural culture. In the last case, agricultural diffusion is significantly rapid. In this case, the majority of agricultural culture holders are the immigrants at the earliest stage, but shortly thereafter, become the Jomon people at the early stage. Here, few immigrants and many Jomon people played the major role in the formation of agricultural culture.

Of these three probable cases, the last is most consistent with anthropological and archaeological fact for the following reasons. In the first case, the diffusion rate of agriculture is too low. Considering that the diffusion of agricultural culture began from the North Kyushu region, it is difficult to assume that the diffusion rate at the place of the origin of agriculture in Japan was low. Comparing the second and last case, even when the population growth rate of agriculture is high, the rapid speed of agricultural culture diffusion is higher in the ratio of people with immigrant traits 300 years later. In addition, when the population growth rate of agricultural people is low, in cases demonstrating slow agricultural culture diffusion, some do not attain the 80% ratio of immigrants 300 years later. As mentioned, considering that agricultural technology was not mature at that time, the 1.3% population growth rate of agricultural people may be too high. Therefore, the highest consistency is found in cases where even the lower population growth rate could generate demographic transition through rapid agricultural culture diffusion.

However, when investigating the ratio of Jomon-style pottery 300 years later, there are more cases of slow agricultural culture diffusion than cases demonstrating rapid diffusion (Fig. 7, Fig. 8, Fig. 9). This is because in cases of slow agricultural diffusion, there is a longer time to increase the prevalence of immigrant-style pottery; thus, the ratio of immigrant-style pottery increases. In our simulation model, only the vertical spread of the inheritance of pottery style from the mother is considered. The horizontal spread of diffusion from the neighbor is not considered. However, even if the vertical spread of pottery style is considered in our simulation model, it goes without saying that this simulation model shows a higher ratio of Jomon-style pottery 300 years later than the model described in this study. Much remains unknown with regard to the manner of diffusion of pottery style; thus, our simulation model is not enough and leaves room for improvement.

However, important is that even when only the inheritance of pottery style from the mother is included, our simulation results indicate a majority Jomon-style pottery 300 years later. That is, our simulation results are consistent with anthropological and archaeological fact that people with immigrant traits became the majority, while conversely; the Jomon-style pottery retained its majority.

IV. Concluding Remarks

We described the ABS and discussed its meaning in historical and archaeological literature. In previous sections, to facilitate understanding of the factors affecting the behavior of the simulation results, the simple model and extreme settings were presented. However, in the case where a large number of native Jomon people and a small number of immigrants at first coexisted, people with immigrant traits became the majority a few hundred years later. As such, several hypotheses are verified and a novel hypothesis proposed. The former refers to hypotheses that the immigrants lived at high population densities and only a part of the neighboring native Jomon people made contact with them, and that the immigrants were polygamous and primarily male. The latter is the hypothesis that when agricultural culture diffused among the native Jomon people, the few immigrants and many Jomon people played the major role in the formation of agricultural culture.

Regarding the hypothesis that the immigrants lived at high population densities and only a part of the neighboring native Jomon people made contact with them, no archaeological evidence yet indicates an immigrant-only colony [3], [5]. However, our results regarding this hypothesis could also be explained by the possibility that an extremely low population density of Jomon people at the time resulted in the settlement of immigrants there [4]. This is also supposed by the possibility that the Jomon population significantly decreased, as evident in the small number of remains of the late Jomon period [14].

Advances in DNA analysis and further excavation in the future could verify hypotheses that immigrants were polygamous and primarily male, and the novel hypothesis that when agricultural culture diffused among the native Jomon people, a few immigrants and the many Jomon people played the major role in the formation of agricultural culture. Hypotheses that the immigrants were polygamous and primarily male cannot be directly verified, but could be indirectly verified by investigating the genetic diversity of the paternal Y chromosome of ancient human bone remains.

Discovering the bone remains of people with Jomon traits along with artifacts showing the existence of agricultural culture could support the hypothesis that when agriculture diffused among the native Jomon people, a few immigrants and many Jomon people played the major role in the formation of agricultural cultures. In fact, although agricultural artifacts have not been discovered, human bone remains with Jomon people' characteristics were discovered at a Korean-type tomb at the Otomo site in Northern Kyushu.

For the problem of who played the major role in the formation of agricultural culture in the Yayoi period, our simulation results indicate that the few immigrants and many Jomon people fulfilled this role. This shows that within the framework where even a small number of immigrants generated demographic transition [5], [6], the idea that agricultural society was a collaborative process begun by both Jomon people and immigrants making a living population [3] has a high consistency.

As points of attention, the hypotheses in this study have shown only some probabilities. The results of our simulation were generated through a model based on several assumptions. The results could change if employing different assumptions. In addition, the ratio of immigrants 300 years later, a prerequisite of our simulation, relied on the results of Nakahashi *et al*. [5]. Therefore, if the discriminant used in their study varies, a different interpretation of the results of our study is required. By the way, demographic transition may be caused by plague and war in addition to a differing population growth rate; however, because there is no archaeological evidence, these are not considered in our simulation model [5].

Finally, we believe that the ABS model and results of this study are widely applicable beyond the time and region, because this study dealt with the universal themes of population dynamics after introducing agricultural culture. Furthermore, this study is the first application of ABS to the problem of anthropology and archaeology in Japan. For the problem of Japan's anthropology and archaeology, it is difficult to use the ABS used in famous pioneering studies on factors regarding the residence transition of the Anasazi tribe [15]. In most anthropology and archaeology cases in Japan, the data, especially paleo-environmental records, are not present in abundance unlike in these studies. However, even if there are less data as in this study, ABS is able to compensate; therefore, it has the potential to become a powerful tool in anthropology and archaeology in Japan.

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Population spread and cultural transmission in Neolithic transitions

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***Abstract*—The classical wave-of-advance model is based on Fisher's equation. However, this approach leads to an unbounded wave-of-advance speed at high reproduction rates. In contrast, an integro-difference model leads to a finite upper bound for the speed, namely the maximum dispersal distance divided by the generation time. Intuitively, this is a very reasonable result. This demic model has been generalized to include cultural transmission (Fort, PNAS 2012). We apply this recent demic-cultural model to determine the percentages of demic and cultural diffusion in the Neolithic transition for two case studies: (i) Europe, and (ii) southern Africa (Jerardino et al., submitted 2014). The similarities and differences between both case studies are interpreted in terms of the three mechanisms at work (population reproduction, dispersal and acculturation).**

I. Introduction

THE Neolithic transition in Europe has been analyzed quantitatively since the seminal work by Ammerman and Cavalli-Sforza [1]. Because the oldest Neolithic sites are located in the Near East, Ammerman and Cavalli-Sforza [1] fitted a straight line to the dates of European sites versus their distances to a Near Eastern site (Jericho). In this way they estimated a speed of about 1 km/y. Later Ammerman and Cavalli-Sforza [2,3] applied a model due to Fisher [4] to the spread of preindustrial famers. They found that this model predicts a speed of about 1 km/y, i.e. similar to the observed one. This indicates that a process based mainly on demic diffusion (spread of populations) agrees with the archaeological data in Europe. Here we report on models with a more refined description of population spread than Fisher's model [5,6]. We also recall a recent model that incorporates the effect of cultural diffusion, i.e. the spread of ideas (hunter-gatherers becoming farmers) instead of populations [7]. This demic-cultural model is then compared to the archaeological data on the Neolithic spread in Europe and southern Africa.

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II. Limitations of Fisher's Model

Consider a population of preindustrial farmers, initially located in some region. Assume they can disperse into other regions that are also suitable for farming but initially empty of farmers. The next generations of farmers will, in general, disperse away from their parents. Then Fisher's model predicts that a wave of advance (also called a front) of farmers will form and propagate with the following speed [4]

$$s_F = 2\sqrt{a_N D_N}\ , \tag{1}$$

where a_N is the initial reproduction rate of Neolithic farmers (which is easily related to their net fecundity and generation time) and D_N is the diffusion coefficient of Neolithic farmers (which is easily related to the probability that farmers disperse away from their parents as a function of distance). Equation (1) is very useful. Ammerman and Cavalli-Sforza [2,3] used observed values for a_N and D_N into Eq. (1) and found that Fisher's model predicts a speed of about 1 km/y, i.e. similar to the observed one for the Neolithic transition in Europe.

In recent years, Fisher's model has been refined [5]. Note that Eq. (1) predicts that, for a given value of D_N, the speed increases without bound ($s_F \to \infty$) for increasing values of the initial reproduction rate ($a_N \to \infty$). This is counterintuitive because, for a given value of D_N, the dispersal behavior of the population is fixed. Thus individuals can disperse up to some maximum distance, $\Delta_{\max}$. Then we should expect that (no matter how large is a_N) the speed s_F should not be faster than $s_{\max} = \Delta_{\max}/T$, where T is the time interval between two subsequent migrations (mean age difference between parents and their children). An integro-difference cohabitation model solves this problem [5-7]. Then Eq. (1) is replaced by a more complicated and accurate equation. However Fisher's speed, Eq. (1), is very useful as a first approximation. It is even quite accurate for some pre-industrial farming populations. For example, for the Yanomano [8] Fisher's speed (1.22 km/y) yields an error of only 6% relative to the integro-difference cohabitation model (1.30 km/y). In other cases, Fisher's speed is not so accurate. For example, for the Issocongos [8] Fisher's speed (0.56 km/y) yields an error of 30% relative to the integro-difference cohabitation model (0.80 km/y).

III. POSSIBLE FORMS OF THE CULTURAL TRANSMISSION TERM

The demic models above can be extended by including cultural transmission. Then Fisher's speed, Eq. (1) is generalized into [7]

$$s = 2\sqrt{\left(a_N + \frac{C}{T}\right) D_N} \,, \tag{2}$$

where C is the intensity of cultural transmission (defined as the number of hunter-gatherers converted into farmers per farmer during his/her lifetime, in the leading edge of the front, i.e. a region where the population density of farmers is very low) [7]. In the absence of cultural transmission ($C = 0$), Eq. (2) reduces to Fisher's speed, Eq. (1), as it should.

Equation (2) and other models with cultural transmission take into account that hunter-gatherers can learn agriculture not only from incoming farmers, but also from converted hunter-gatherers, i.e. former hunter-gatherers that have (partially) become farmers (as well as their descendants).

An integro-difference cohabitation model with cultural transmission leads to a more complicated equation than Eq. (2), and generalizes the integro-difference model summarized in the previous section [7].

Both demic-cultural models (i.e., Eq. (2) and the integro-difference cohabitation model) are based on cultural transmission theory [9], which shows that the number of hunter-gatherers converted into farmers per farmer during his/her lifetime is [7]

$$\frac{\Delta P_N}{P_N} = \frac{f\, P_P}{P_N + \gamma\, P_P} \,, \tag{3}$$

where P_N and P_P are the population densities of Neolithic farmers and Mesolithic hunter-gatherers, respectively, and f and γ are cultural transmission parameters. In the leading edge of the front ($P_N \approx 0$), Eq. (3) becomes

$$\frac{\Delta P_N}{P_N} = C \,, \tag{4}$$

with $C = f / \gamma$.

A comparison to other approaches is of interest here. In Ecology a widely used model is based on Lotka-Volterra equations, which assume that the interaction between two populations (ΔP_N) is proportional to their population densities [10],

$$\frac{\Delta P_N}{P_N} = k\, P_P \,, \tag{5}$$

where k is a constant. This model has the problem that $\Delta P_N / P_N \to \infty$ if $P_P \to \infty$, which seems inappropriate in cultural transmission, for the following reason. Assume that a farmer converts, e.g., 5 hunter-gatherers during his lifetime ($\Delta P_N / P_N = 5$) if there are $P_P = 10$ hunter-gatherers per unit area. Then Eq. (5) predicts that he/she will convert $\Delta P_N / P_N = 50$ hunter-gatherers if there are $P_P = 100$ hunter-gatherers per unit area, $\Delta P_N / P_N = 500$ hunter-gatherers if there are $P_P = 1000$ hunter-gatherers per unit area, etc. Contrary to this, intuitively we expect that there should be a maximum in the number of hunter-gatherers that a famer can convert during his/her lifetime, i.e. that $\Delta P_N / P_N$ should have a finite limit if $P_P \to \infty$. This saturation effect is indeed predicted by Eq. (3), as shown by Eq. (4). Thus we think that Eq. (3) is more reasonable than the Lotka-Volterra interaction, Eq. (5).

This point has important consequences because for Eq. (3) the wave-of-advance speed is independent of the carrying capacity of hunter-gatherers, $P_{P\,\max}$ (see, e.g., Eq. (2)). In contrast, for the Lotka-Volterra interaction the wave-of-advance speed does depend on $P_{P\,\max}$. For example, if Fisher's model is generalized by including the Lotka-Volterra interaction, the front speed is [11] (see also [10] for a similar model)

$$s = 2\sqrt{\left(a_N + \frac{k\, P_{P\,\max}}{T}\right) D_N} \,. \tag{6}$$

The point is that, in contrast to Eq. (2), Eq. (6) depends on $P_{P\,\max}$. The same happens if the integro-difference cohabitation model (which is more precise than Fisher's model) is generalized by including the Lotka-Volterra interaction [6]. These results are not surprising because in the front leading edge ($P_N \approx 0, P_P \approx P_{P\,\max}$) Eq. (5) becomes $\Delta P_N / P_N = k\, P_{P\max}$, which depends on $P_{P\,\max}$ (whereas Eq. (4) does not).

Finally, some language competition models use population fractions (rather than population densities) and interaction terms with non-linear powers of P_N and P_P [12]. We first consider the linear case. In one such model, Eq. (5) above is replaced by [13]

$$\frac{\Delta P_N}{P_N} = \frac{\eta\, P_P}{P_N + P_P} \,, \tag{7}$$

with η a constant. Equation (7) is a special case of Eq. (3), thus the wave-of-advance speed is independent of $P_{P\,\max}$ also in this model [13]. It can be argued that the complete model in Ref. [13] is useful for modern populations but not for the Neolithic transition, because it assumes the same carrying capacity for both populations. But a model that allows for different carrying capacities [14] also leads, in the linear case, to an equation with the form of Eq. (7). In conclusion, some models originally devised to describe language competition also lead to the conclusion we have stressed above, namely that the wave-of-advance speed is independent of $P_{P\,\max}$.

For completeness, in the non-linear case the following two limitations of the language-competition models discussed in the previous paragraph [12-14] should be noted in the context of the Neolithic transition.

(i) In the non-linear case, Eq. (7) above is generalized into [13]

$$\Delta P_N = \frac{\eta\, P_N^{\ \alpha}\ P_P^{\ \beta}}{(P_N + P_P)^{\alpha+\beta-1}} \qquad (8)$$

with $\alpha \geq 1$ and $\beta \geq 1$ [12]. Thus $\Delta P_N \to 0$ if $P_P \to \infty$, i.e. $\Delta P_N / P_N$ does not have a finite, non-vanishing limit (except in the linear case $\alpha = \beta = 1$, see Eq. (6)). Alternatively, for the Abrams-Strogatz model in Ref. [14], namely

$$\Delta P_N = \kappa \left[\sigma\, P_P \left(\frac{P_N}{P_N + P_P} \right)^a - (1-\sigma) P_N \left(\frac{P_P}{P_N + P_P} \right)^a \right], \qquad (9)$$

where $\sigma < 1$ is called the status of language N and $a \geq 1$ is the resistance to language change, we obtain a negative limit for $\Delta P_N / P_N$ if $P_P \to \infty$, which is counterintuitive [13] (except again in the linear case, $a = 1$). The main point here is that neither of both non-linear models displays the saturation effect discussed above.

(ii) Whereas Eq. (3) was derived from cultural transmission theory, the non-linear models introduced to describe language competition [12-14] (Eqs. (8)-(9)) were not.

The non-linear models given by Eqs. (8)-(9) compare favorably to observed data in non-spatial linguistic systems [12,13], and may be applicable to other modern instances of cultural transmission. Perhaps the effects of mass-media, schools, etc. in modern societies avoid the saturation effect discussed above. Such effects are not included in the cultural transmission theory leading to Eq. (3) [7].

In any case, due to reasons (i) and (ii) above, for the Neolithic transition we prefer not to apply language-competition non-linear models, Eqs. (8)-(9), neither the Lotka-Volterra interaction, Eq. (5). Instead, we apply cultural transmission theory, Eq. (3) (or its frequency-dependent generalizations, which take into account the conformist effect but lead to the same conclusions [7]).

We stress that the conclusion that the wave-of-advance speed is independent of the hunter-gatherer population density $P_{P\,\max}$ follows from cultural transmission theory, and is ultimately due to the fact that there should be a maximum number of hunter-gatherers converted to agriculture per farmer (or converted hunter-gatherer) during his/her lifetime (this is the saturation effect discussed above).

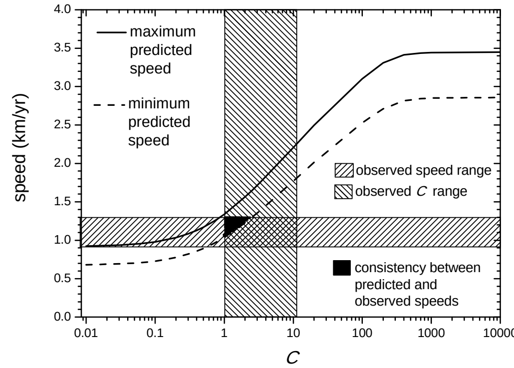

Fig. 1 The speed of the Neolithic transition, as a function of the intensity of cultural transmission *C*. The horizontal hatched rectangle is the observed speed range of the Neolithic transition in Europe. Adapted from Ref. [7]

IV. Europe

The integro-difference cohabitation model that refines Eq. (2) has been applied to the Neolithic transition in Europe [7]. The results are reproduced in Fig. 3. Note that without taking into account the effect of cultural transmission ($C = 0$), the predicted speed is about 0.8 km/y (0.7-0.9 km/y), whereas for consistent values of C the speed increases up to 1.3 km/y. Thus the cultural effect is about 40% (more precisely, 40±8% [7]).

V. Southern Africa

In this case the Neolithic transition was a shift from hunting-gathering into herding (not into farming and stockbreeding as in Europe), the speed is substantially faster than in the European case and, in agreement with Fig. 1, the cultural effect is more important [15].

VI. Conclusion

We have discussed wave-of-advance models of the spread of the Neolithic under demic and/or cultural diffusion. Such models lead to the conclusion that this spread was mainly demic in Europe, but mainly cultural in southern Africa. Because the reproductive and dispersal behavior of both populations was likely similar [15], this difference could be due to a higher ease for hunter-gatherers to learn herding in comparison with farming [15].

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Modelling Energy-Consuming Social Practices as Agents

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I. Introduction

Household energy use and personal transport account for a considerable proportion of total energy use and of greenhouse gas emissions. For example, in Europe about 35% of all primary energy use and 40% of all greenhouse gas emissions come from private households [1]. Given the vital importance of reducing greenhouse gas emissions from energy use, the dynamics of household energy demand and consumption have become a matter of considerable interest.

Following [2], the discussion of energy consumption and efficiency in the domestic sector usually takes the form of highlighting either practice-related behaviour or the potential of technological innovation. Although it touches on aspects of the latter, this paper has its main focus on the former, which according to [3] has so far has been underrepresented despite being able to make a significant difference with respect to energy consumption [4].

The paper presents some initial ideas about an agent-based model for simulating practice-related aspects related to household energy consumption. For this purpose it draws upon the vast body of social science literature discussing determinants of human lifestyles and how lifestyle changes could be promoted (see [5]–[7] for examples). It adopts a *Social Practice Theory* (SPT) approach, which in recent years has received increasing attention by researchers and policy makers, because—instead of placing individual trait driven behaviour and decision making at the centre of analysis—it puts the spotlight on how, at given points of time, broader collectives of practices establish and achieve everyday objectives.

In the next section this approach and its relevance for the study of domestic energy consumption are presented. One of the conclusions drawn is that so far no simulation model accounting for the different aspects of social practices exists, which is why we aim to close this gap and present our idea of a social practice agent-based model (ABM) in Section III. The paper closes with a short summary and proposals for future work.

II. Social Practice Theory

Over the last 40 years there have been numerous attempts to identify the determinants of human behaviour in order to direct it into more pro-environmental channels (see e.g. [4], [8] for reviews). This work has attempted to identify individual's beliefs, attitudes and values and use them as predictors of behaviour, so that they can be modified to promote behaviour change. Fundamental to this work is the assumption that behaviour is the outcome of a rational process undertaken by rational individuals.

The most widely cited of these approaches is the *Theory of Planned Behaviour* [9] which argues that behavioural intention, which precedes actual behaviour, results from interactions between an individual's attitude towards the behaviour in question, their beliefs about what others think about the behaviour—the subjective norm—and their perceived level of control over the behaviour, or perceived behavioural control. However, in recent years this approach, which indirectly suggests that, provided that the necessary cognitive components can be identified and modified, a desired behaviour change will follow, has been subject to substantial criticism. One of the main reasons is its lack of consideration of habitual behaviours and the social and material contexts in which people perform their actions [4].

In contrast to these behavioural models, which focus solely on individual agency, SPT adopts Giddens's [10] theory of structuration which seeks to find a balance between structure and agency. Giddens concludes that human agency and social structures are shaped recursively. As activities emerge and are enabled by structures of rules and meanings, these structures are constantly re-enforced and legitimised in the flow of human action. Consequently, it is the practices themselves, featuring both structures and agents, not two independently given sets of phenomena, that form the basis of our social arrangements. As Giddens [10, p. 2] argues:

> The basic domain of study of the social sciences. . . is neither the experience of the individual actor, nor the existence of any form of societal totality, but social practices ordered across space and time.

Attention is therefore no longer focused on individual decision making, but on 'the doing' of various social practices and the inconspicuous consumption that forms an integral part of many practices [11]. As a result, the individuals become the 'carriers' of social practices rather than the centre of attention [12] . Central to practice theory is the idea that it is through these engagements with practice that individuals come to understand the world around them and develop a more or less coherent sense of self [13].

Despite this focus on 'Practical Consciousness' [10], practice theory does not suggest that individuals are completely passive. Instead it argues that they are skilled agents who actively negotiate and perform practices in the course of their daily lives. In terms of reducing the environmental impact of consumption, practice theory suggests that transforming practices to make them more sustainable is a far more effective approach than simply persuading individuals to make different decisions. As Warde [13] notes, "the principal implication of practice theory is that the sources of changed behaviour lie in the development of practices themselves".

Although these basic principles can be applied to almost all theories of practice, there is 'no unified practice approach' [12]. Nevertheless, there are a number of common features that are becoming established as 'core' components. It is universally agreed that practices are made up of a number of different *elements*, which are linked together. While there is some debate regarding precisely what constitutes an element and what the key elements which make up a practice are, there is a growing consensus around Shove's [14] understanding of practices as being made up of three core elements. The first of these: *materials*, encompasses objects, infrastructures, tools, hardware and the human body itself. The second element: *competence*, is drawn from what Giddens [10] describes as practical consciousness, deliberately cultivated skill and shared understandings of good or appropriate performance in terms of which specific enactments are judged. The final element: *meaning*, is a combination of what Reckwitz [12] describes as mental activities, emotion and motivational knowledge [14]. It also includes social norms, shared beliefs that dictate how members should behave in a particular context [15]. Essentially the meaning element refers to the social and symbolic significance of participation at any one moment.

A simple example often used to explain how practices evolve is 'showering'. Showering is a relatively recent method of cleaning oneself that has rapidly evolved in many western countries over the last fifty years. Previously, it was considered the norm to take a bath once or twice a week. However, over the past 50 years bathroom infrastructure has changed to incorporate showers (*materials*). There have also been corresponding changes associated with 'normal' levels of personal hygiene (*meanings*) along with conventions related to the way in which people prepare themselves for the day ahead (*competence*) [16]. As these elements have come together and been regularly repeated by skilled actors one aspect of everyday life has been transformed, evolving into the new and now standard practice of showering.

Showering has become a routinized part of daily life for billions of people living in western society and deeply integrated into everyday life. Furthermore, as the practice is performed by more people and new associated products become available (such as shower gels) the practice continues to evolve.

In summary, SPT de-emphasises the idea of studying human behaviour in favour of exploring how social practices are ordered across space and time. Social practices emerge, evolve and eventually die out as a result of the reconfiguring of their component elements and their reproduction by skilled practitioners.

In this paper we put particular emphasis on this two-way dynamic and the self-perpetuating nature of practices by describing an approach to modelling the practices and their dynamics as an ABM.

In the next section we present this social practice ABM and introduce the idea that because of their self-perpetuating nature and their active role in the downward causation, practices can be modelled as agents.

III. Conceptualising A Social Practice ABM

Although there is some published work mentioning (and even outlining the idea of) social practices (e.g. [17]), most papers either focus on the learning of the individual agents about the actions of their neighbours (and then their utility considerations about what they have learnt), or demonstrate the propagation of habits within an agent society using different social network structures and neighbourhood typologies.

What is however missing in all current models is the consideration of the role these practices have themselves in shaping a system, not only by promoting more agents to carry out practices and repeating them, but also by encouraging industry to develop products that support these practices, which in turn makes it 'easier'[1] for the actants[2] to carry out the practice. Thus, although sometimes claiming differently, most papers aiming at analysing social practices fail to address and explain this feedback loop and the dynamics of practices, such as how practices are emerge, evolve over time, influence other practices and possibly die out.

In this paper we look into exactly this issue and focus on the micro-macro dynamics present in the above described setting. Phrasing it in the classical micro-macro terminology used in ABM research, social practices emerge as a result of the interaction between elements at the micro and macro levels. Micro level acts affect (strengthen/weaken) macro level elements (e.g. following a shared rules reinforces that rule). In the other direction, macro level elements constrain/encourage micro level acts (a shared rule is more likely to be followed). Thus, there is a two-way link between the micro and macro levels (both up- and down- ward causalities are present).

We identify four main processes which need to be considered when designing a social practice ABM:

- households performing practices,
- the spread of these practices to other households,
- the development of products for practices by households, and
- the adoption of products for their practice performances by households.

[1]The term 'easier' can have several meanings in this context ranging from more convenient, less difficult and cheaper to less time consuming or more in accordance with social conventions, more encouraged, and less sanctioned.

[2]We use the term 'actant' to refer to anything that does things. This could be a person, but also a machine such as a washing machine.

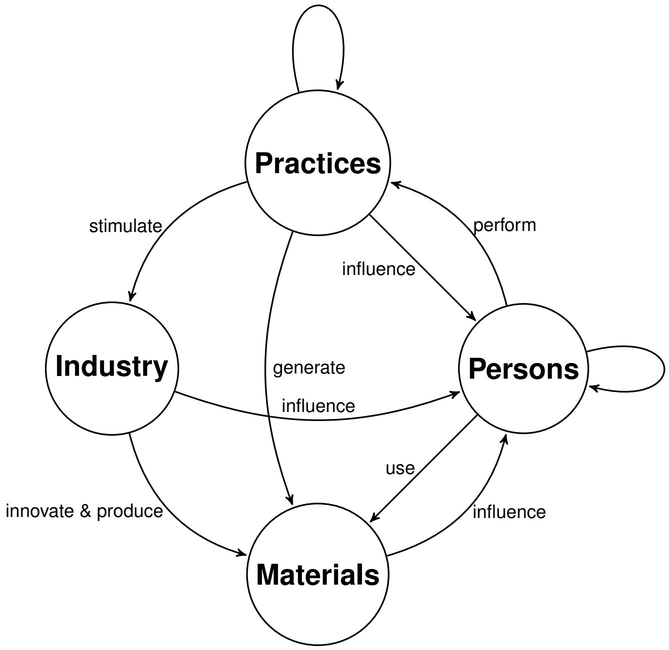

Fig. 1. Components of the Social Practice ABM

To make these points more specific, recall the following points of the showering example:

- Showering is a social practice that is regularly performed by households.
- The regular performance of the showering practice by households has resulted in a general change of understanding of cleanliness in the population, which in turn had an influence on people's perception of what the right amount of cleaning/washing is, which in turn resulted in a change of household cleanliness practices towards more showering.
- The spread of the showering practice furthermore resulted in it becoming of interest to industry, which developed new products for the practice in the hope of making profits.
- These new products had an influence on the perceived 'easiness' of the performance of showering by households, which thereby influence the showering practice.

Figure 1 summarizes these dynamics by means of arrows. It also shows the four components the links affect: (i) households (ii) social practices (iii) industry (iv) materials.

In our ABM, of these four components, the first three are conceptualized as agents, whereas the last one is represented as 'features' or 'artefacts' of the environment. For our definition of agency we follow the ideas of Macy and Willner [18] who proposed four criteria for agency in ABMs:

1) Autonomous Behaviour: Systemic patterns emerge not as a result of central planning, authorities or institutions, but as a result of the interactions between the individual actants in the system.
2) Interdependence: The different agents in a system influence each other.
3) Agents follow simple rules.
4) Adaptive and backward-looking behaviour: Agents adapt by imitation, replication, and so on, but not by calculating the most efficient action.

While defining households and industry as agents is not unusual, we also apply this definition to the practices and hence model them as agents in the system. Thus, different social practices can show individual autonomous influences on the system in the sense that their system influences are not centrally planned and coordinated, but result from the individual characteristics of the social practices and the environment they are situated in. Similarly, social practices not only influence other practices (e.g. the showering practice might for example influence the laundry practice in terms of more towels being used and therefore requiring washing). We only use a simple behavioural rule for practices, in which it tries to increase the number of its performances by households. Practices can change, for example as a result of changes in the elements the households use when performing the instances of practices (e.g. adopting power showers). New practices can be 'born' (e.g. the showering) if new elements appear and are being used (e.g. the shower as product) or if old practices are being recombined in a new way.

Having outlined the elements of the ABM, how does it work in detail? In the ABM the household agents are represented as decision trees, which have certain competences and meanings as part of their properties. The nodes in the decision tree are either conditions referencing elements (a combination of competences, meaning and materials from the environment) or they are acts that can be performed (if the node is a leaf node). At each time step of the simulation, the agents work through the decision tree nodes to reach a leaf node, which yields a decision to perform an action. If the action is regularly repeated, this generates a social practice (or alters an existing one). After performing an act (using an evaluation function specific to the domain) the household agent evaluates it by obtaining a score of 'easiness'. This easiness measure is used in a learning algorithm that enhances the decision tree to consolidate the agent's competence and the meaning it associates with different (combinations of) acts.

On the macro level, the social practice agents have the ability to influence the know-how and meanings of household agents. The strength of their influence depends on the frequency of their performance by households, i.e. the more a practice is performed, the stronger its influence on the household agents.

In addition (and again in relative relation to their influencing strength) the social practice agents can foster the generation of material elements for the practices and trigger the consideration of innovations by industry agents. These industry agents are set up similarly to the household agents, i.e. they are represented as decision trees. When triggered by a social practice agent, an industry agent will work through to its leaf nodes, where it has to make the decision about whether to create a new material for a practice or whether to create more material for an existing practice (possibly using economies of scale for the latter). The materials created (together with a description of its intended use) are placed as an artefact in the environment, where it can be used by the household agents. The household agents will use a new material if it makes the performance of practices easier for them[3]. The more a product is being used, the more positive feedback the industry agent receives, which it can account for in its learning about the 'market' for new materials. The adoption of new materials by household agents (in combination with their competences and meanings properties) can result in them changing their performances, which in turn can affect the social practice agents, to close the micro-macro loop.

IV. Summary and Future Work

In this paper we have outlined an initial idea for an energy-consuming social practices ABM. The novelty of our approach is that, because of their important role in their own spreading, we model the practices themselves as agents and link them both to the performances of households and to industrial product development.

At the current stage, the model has been conceptualized and is currently being implemented as a first version using a single practice only. In the future we aim to advance our model to account for several practices and the relations between them. For this purpose we have identified five specific social practices and we are currently collecting qualitative empirical data on them by means of walking interviews:
(i) heating, (ii) laundry, (iii) television watching, (iv) cooking, and (v) electronic communication.

The reasons for choosing these five practices are that not only are they often mentioned when household energy efficiency is being discussed, but they are also interlinked, both on a practice level (e.g. electronic communication has resulted in more home-office work, which in turn has resulted in thebhome being heated during the day), and on an elements level (e.g. cooking and heating both require water). Our aim is to combine our qualitative interview data with quantitative individual energy consumption data collected in households to get a better picture of the relationship between actual and perceived energy consumption in households.

We aim to provide our models to policy makers to help their understanding of practice issues. We have recently discussed these ideas with staff of the UK Department of Energy and Climate Change and will integrate their input into a first prototype of our model.

Acknowledgment

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[3]Household agents do not necessarily need to use materials in the way they were intended by industry.

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A spatially explicit agent-based model of opinion and reputation dynamics

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***Abstract*—Key in spatial planning are opinion dynamics (the exchange of opinions between agents and the consecutive updates in opinions by individual agents). A number of possibly relevant factors that are commonly excluded in well-known models of opinion dynamics are peer pressure, localized opinion formation through isolation, and the reputation of the agents involved. We present a model of agents with a fixed spatial location (e.g., a household) in a "village" who are capable of only local interactions with their neighbours. There exist nonlinear feedbacks between updates in opinion and reputation, which are described by smooth mathematical functions. Sensitivity analysis is used to quantify the contributions of different factors to the convergence of opinions within the "village".**

I. Introduction

Spatial planning is aimed at land use development that fulfills current and future societal needs. Traditionally spatial planning is considered to be a linear process in which selected actors have to obtain consensus about common goals. In practice, spatial planning is a non-linear, dynamic process involving many, heterogeneous stakeholders. Actors have diverse and changing goals and motivations, and influence each other via direct and indirect communication. Opinion dynamics - the exchange of opinions between social agents - thus play a crucial role in spatial planning [1].

Models of opinion dynamics are commonly based on physical diffusion principles which average neighbouring quantities [2], [3], [4], [1]. An 'if-then-else' condition is implemented to operationalize the concept of a 'social distance' between interacting agents, i.e., if two agents disagree too much then no opinion averaging is occurring. There are however a number of factors that may be relevant in spatial planning which may significantly influence opinion dynamics, such as:

- *Reputation*, i.e., 'higher' ranking agents will also more likely be more dominant in their interactions, resulting in biased opinion exchanges.
- *Peer pressure*, i.e., solitary agents with one opinion confronted with two or more agents that share a different opinion will also often change their opinion more than the group of agents.
- *Empathy*, i.e., the 'ease' with which an agent listens to others and is willing to accept their opinion.
- *Isolation and spatial effects*, i.e., in a spatial land-use context agents are often fixed at a spatial location (e.g., a farm or household) with a limited action radius. They are thus more likely to interact with neighbouring agents than with others agents (even in the current Internet era).

We present a spatially explicit agent-based model of a "village" of limited size consisting of agents with a fixed spatial position (e.g., a "household") and no outside contacts. Agents can only interact with their direct neighbours - opinion dynamics are thus localized. Agents have an initial opinion on a scale from 0 to 1 about an abstract subject. They also have a reputation, an opinion acceptance rate, and a reputation acceptance rate. It is furthermore probable that reputation dynamics - the change in ranking of agents - in turn depends on opinion dynamics. Agents who share opinions will often also hold each other in high regard, while agents who strongly disagree will often also dislike each other. Opinion dynamics and reputation dynamics thus are connected in feedback mechanisms. Finally, the update in opinion and reputation in time occurs according to functions that are based on social distance (difference in opinion) and difference in reputation in a smooth fashion (i.e., without 'if-then-else' constructs).

A. Model description

The whole model is implemented as a cellular automaton with field size $N_x \times N_y$ where each 'cell' represents an agent with a fixed location. There is 'diffusion' of the quantities 'opinion' $X^t_{x,y}$ and 'reputation' $Y^t_{x,y}$, both bounded between 0 and 1, where x and y indicate spatial location.

1) Main spatial equations: The field rules are

$$X^{t+1}_{x,y} = X^t_{x,y} + A_{x,y} \sum Y'^t_{x,y} \left(f(X'^t_{x,y} - X^t_{x,y}) \right) \ , \qquad (1a)$$

$$Y^{t+1}_{x,y} = Y^t_{x,y} + B_{x,y} \sum X'^t_{x,y} \left(g(Y'^t_{x,y} - Y^t_{x,y}) \right) \ , \qquad (1b)$$

where $'$ denotes the Von Neumann neighbours (i.e., the 4 neighbouring agents influence the agent simultaneously, while at the boundaries we use boundary conditions to close the field), and f and g are functions described below. The agent opinion adoption rate $A_{x,y}$ and the agent reputation acceptance $B_{x,y}$ are individual agent properties and hence have a spatial location that remain fixed in time. Unlike well-known opinion dynamics models agents undergo simultaneous and biased updating, i.e., some agents adapt their opinion (and reputation) more than others in an interaction. For notational convenience the explicit time and space dependence of variables and parameters are now droppped.

2) Opinion update function: The function f for agent opinion updating is given as

$$f(X' - X) = sgn(X' - X)\left(-(X' - X)^2 + 1\right)e^{-r(X'-X)^2}, \quad (2)$$

where *sgn* (signum) conserves the sign of the difference in opinion (because of the square the sign would be otherwise lost). This function is evaluated separately for each neighbour before the agent opinion is updated. Maximum opinion exchange occurs in the limit $|X' - X| \to 0$ (i.e. two agents practically share an opinion, although no convergence will then occur anymore). If the opinions diverge maximally (namely 1 or -1) there is no exchange of opinion. The function is generic, i.e., only basic aspects of agent interactions are considered. Parameter r is a measure of social distance. For $r \to 0$ the function becomes a parabola (crossing the x-axis at 1 and -1), while for increasing r there is a decrease in social distance (see Fig. 1).

3) reputation update function: The reputation of an agent is updated according to function g, which is given as

$$g(Y' - Y) = (u(-(Y' - Y)^2 + 1)e^{-w(Y'-Y)^2}) - v, \quad (3)$$

which is again a generic function, depicted in Fig. 2. The parameters u, v and w have arbitrary values. It is assumed that neighbours with similar reputation will 'flock together', while agents of dissimilar social status do not hold each other in high regard. As status in principle is unbounded it is required to re-scale variable S at every iteration to keep both status and opinion bounded between 0 and 1.

II. Model results

A. Model behaviour

An example of how opinions change dynamically is depicted in Fig. 3. Each agent is indicated by a distinct colour. The dynamics of reputation for the exact same simulation is given in Fig. 4. In this example after 1000 iterations there are still 3 distinct opinions. Although opinions still change after some time, reputation seems to converge to some steady state very fast. Interesting switches in reputation occur between agents who quickly come to a shared opinion with each other. For instance, the black, green, and pink agents quickly share an opinion. Interestly, while the black agent starts with having by far the lowest reputation of the three, he rises quickly to being the most dominant agent within the village! As the shared opinion of these three agents still changes after their opinion merger, it stands to reason that the black agent must be dominant in this opinion change. Further scrutiny reveals that black is in fact the agent in the middle of the village and has both a relatively high agent opinion change adoption rate A and agent reputation acceptance rate B, thus fulfilling a key role in the (local) opinion dynamics.

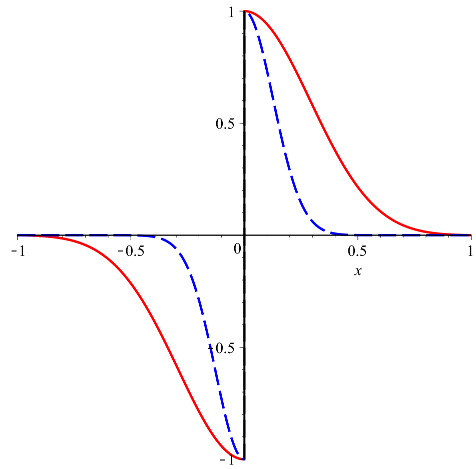

Fig. 1: Function f to translate the difference in opinion X between two agents to opinion convergence. The x-axis gives the difference in opinion between two agents. Note that the function is "squeezed" more as the value of r is larger, i.e., the social distance is smaller then. In solid red $r = 5$, in dashed blue $r = 30$.

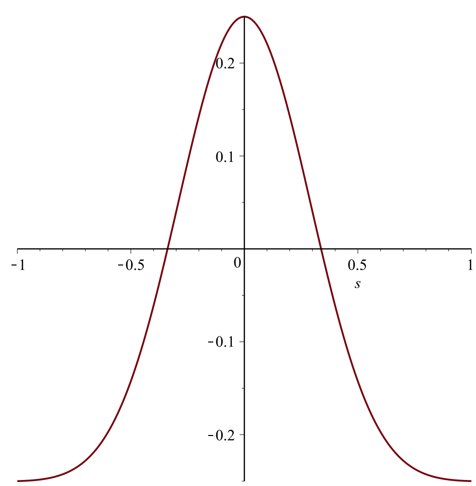

Fig. 2: Function g to translate the difference in reputation Y to reputation convergence or divergence. The x-axis gives the difference in reputation between two agents. When agents are 'equal' they tend to listen to each other - birds of a feather flock together - while very 'unequal' agents show strong disdain for each other.

B. Model analysis

A significant number of runs were extended far beyond 1000 iterations, and their results suggest that eventually under all conditions the system converges to one shared opinion in a small village. Indeed, although function f visually seems to be zero very quickly for large values of r, there is still an incremental convergence for any difference in opinion smaller than the maximum difference of 1. As the model is purely deterministic, given enough iterations opinions will eventually merge. It is therefore relevant to look at the influence that various factors have on the rate of convergence.

Sensitivity analysis [5] has been used to quantitatively analyze how model behaviour is affected by changes in different factors. The output of interest is n, the number of distinct opinions at time t divided by the total size of the village (i.e., this is a discrete output variable). Obviously, n has a minimal value of $(N_i \times N_j)^{-1}$, i.e., there is always one distinct opinion. Fig. 5 shows a one-at-a-time analysis of n within a small "village" of 3×3 after a 1000 iterations, in which r is the varied factor - all other parameters are fixed, as are the bounds on the initial distributions - for 25 runs per value of r. Depicted in red is the mean of these runs, open diamonds indicate the most common value, and blue crosses indicate the minimum and the maximum value from the sets of 25 runs.

There is a clear increase in the mean for increasing r, which is to be expected. There is a 'step-up' value where the minimum number of distinct opinions goes from one to two, i.e., the end-time of 1000 iterations is not sufficient even for such a small village to converge to one opinion. Also, the number of distinct opinions clearly increases for increasing r. However, no strong nonlinearities or tipping points seem to occur within the considered parameter range.

We also consider global sensitivities by performing a variance-based sensitivity analysis [5], [6]. The assumed distributions for initial conditions are uniform $\mathcal{U}(m \mp d)$, where m is the average value and d the variance around this average value. For $X[0]$ and $Y[0]$ draws were made from $\mathcal{U}(0,1)$, while for A and B draws were a bit arbitrary from $\mathcal{U}(0,2)$. The factors varied in the sensitivity analysis are social distance r, and $d_{X[0],Y[0],A,B}$ (i.e., respectively variance in the opinions $X[0]$, reputation $Y[0]$, opinion adoption rates A, and acceptance rates B). Sampling has been done from a hyperdimensional 'chessboard', i.e., parameters are taken from a limited set of combinations from p with equi-distant steps. For each set of fixed values 10 simulations have been run.

The global variance-based sensitivity is given as

$$S_p = \frac{E(Var(n|p))}{Var(n)} \; , \tag{4}$$

where p is the input under consideration, E is the expected value, and the other parameters are considered to be 'unknown'. Marginals can be ignored as only uniform distributions have been used. Observe that the time point is fixed in this analysis, i.e., one has to do the same type of analysis for each different selected time point. The results of the global variance-based sensitivity analysis are given in Fig. 6, in which the sensitivity of n is given in time. Not surprisingly, the sensitivity of n to the initial distribution of opinions $X[0]$ (grey) is high, however, it is significantly smaller than 100 %. In other words, a significant portion of the variance in n is explained by interactions between inputs. The sensitivity to $X[0]$ decreases in time, while the influence of the opinion acceptance rate A (black) and later the social distance r (red) increases. Observe, that an increasing portion of the total

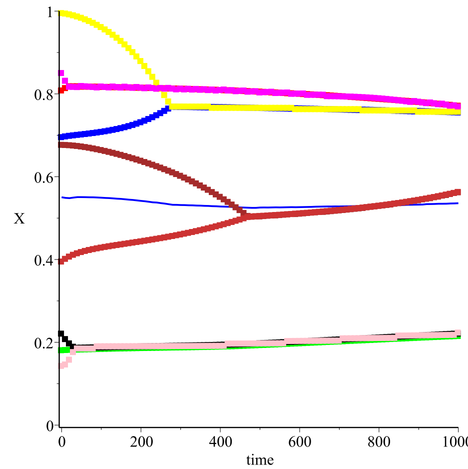

Fig. 3: A simulation of changes in opinions X up to 1000 iterations for $r = 15$ in a "village" of 3×3. Different colours indicate different agents. In this example there are still three clearly distinct opinions at the end-time.

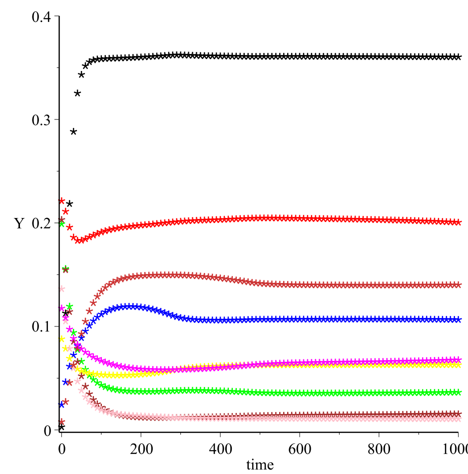

Fig. 4: The dynamics of Y (reputation) for the same simulation as X (Fig. 3).

variance has to be explained from higher-order interactions.

III. Discussion

Although agents in the model always seem to converge to one opinion eventually, the number of iterations before convergence occurs can vary strongly, depending on different factors. For practical purposes it may be intractable to allow for a large number of iterations, e.g., in real spatial planning it may be realistic to have a certain end-point, and thus more than one distinct opinion to be considered.

Of the considered factors that may influence opinion dynamics (reputation, peer pressure, empathy, and spatial isolation effects) not all have been investigated properly. Of the considered parameters not surprisingly the most influential is the initial opinion distribution, but it is not at all a 100 %, and furthermore this sensitivity decreases in time. Instead, the importance of the social distance (r) and opinion acceptance rate (A) increase. Furthermore, a significant portion of the variance in opinions is not explained by single-order effects. Two parameters that remain to be explored in more depth are the size of the village and the radius of communication with neighbours. For large enough village sizes opinions may in practice never really converge because of local isolated patches. Such patches then would have no real opinion exchange anymore with their neighbours outside the patches, resembling the behaviour of models that show segregation of agents, such as the well-known Schelling model. Effects of spatial segregation should be confirmed by a more extensive sensitivity analysis that includes the village size as variable factor.

The above in turn also raises another relevant point, namely how to perform a spatially explicit sensitivity analysis. The method applied here considers only an aggregate output (the number of distinct opinions), but it may be obvious that because of the local interactions there are spatiotemporal correlations which need to be considered. Currently the development and application of methodologies for spatial sensitivity analysis is limited because of the conceptual and numerical difficulty of dealing with spatial structure in model analysis, which in turn results in a common absence of spatial sensitivity analyses [7].

Our model currently considers agents with a spatially explicit fixed position but with a non-spatial opinion. However, in spatial planning agents typically differ in their opinions about different locations, for instance, two agents may agree on one location but disagree on another. Future model extensions will incorporate this spatially explicit opinion difference. Also, the current version of the model is fully deterministic - barring the randomly drawn initial conditions - but it is plausible that internal noise - such as misconception about each other's opinions - as well as outside interference will prevent convergence towards one shared opinion. The addition of noise may result in a 'natural' social distance which in many other models is imposed explicitly as an 'if-then-else'-construct. The functions for opinion and reputation change are now very generic and not grounded in any social theory other than very basic assumptions about opinion and reputation dynamics. However, as the exchange of opinion and reputation is 'decoupled' from the update other exchange functions can be 'inserted' which are based on social theory or experiments. Future model extensions may also include different descriptions of the exchange of opinion and reputation.

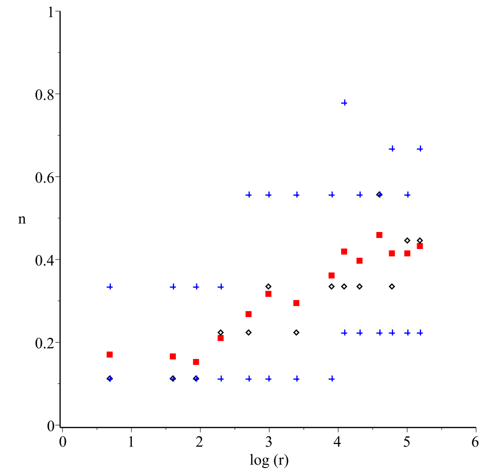

Fig. 5: A plot of n as function of $ln(r)$ for a village of 3×3 after 1000 iterations. Red solid box is mean, open diamond is mode, and blue crosses are minimum and maximum values out of 10 runs. There is a 'step-up' point around $ln(4)$ where the minimum number of distinct opinions is two instead of one.

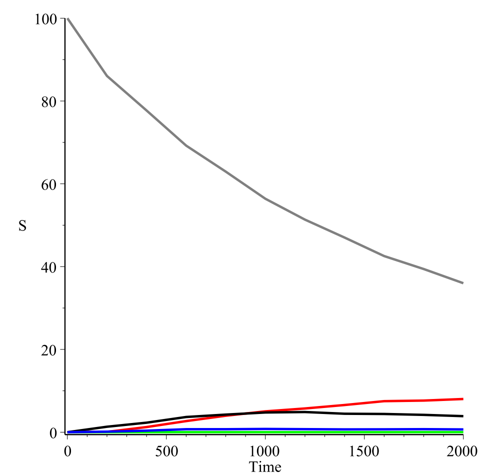

Fig. 6: A plot containing the global time-dependent variance-based sensitivity of n for several inputs, namely r (red), $d_{X[0]}$ (grey), $d_{Y[0]}$ (green), d_A (black), d_B (blue). A significant portion of the variance in n is not explained by single-order effects, i.e., higher-order (interaction) effects have to be investigated.

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DITCH: A Model of Inter-ethnic Partnership Formation

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Abstract—**This paper describes an agent-based model of inter-ethnic partnership formation. Inter-ethnic marriage, both a cause and a consequence of immigrant integration, is generally used to imply that the social distance between groups is low and, by extension, that community cohesion is high. Using a descriptive agent-based modelling approach, we seek to investigate the processes of partner selection in diverse communities, focusing on individual preferences, opportunities for contact, and group norms to uncover how these may lead to differential rates of inter-ethnic marriage.**

I. Introduction

OVER the past decade social scientists have become increasingly interested in what insights the science of complex physical and biological systems seem to provide for our understanding of social systems and practices. The “Social Complexity of Immigration and Diversity” (SCID) project has attempted to integrate the apparent advances of complexity science approaches through the development of Agent-Based Models (ABMs) of the complex social phenomena under considerations.

In this paper, we use ABMs to model inter-ethnic partnerships, seen as a both a cause and consequence of immigrant integration [1] and inter-group relations [2], in Britain. We draw our rules on existing sociological evidence stating that both individual-level preferences (via assortative mating [3]), opportunities for contact (via diversity, group size, population size and sex ratios [4] [5]), and family and kin networks [6] [7] are important drivers of inter-ethnic partner choice. Such influences have been measured quantitatively in Britain [8] [9], but never to our knowledge in a dynamic setting as can be provided by ABM.

Marriage ‘markets’ lend themselves readily to agent-based modelling – they allow the exploration of the ways in which ‘bottom-up’ psychological inputs (individual agents choosing specific mates) lead to ‘top-down’ demographic outcomes (population level patterns of marriage and mate selection) [10]. The emergence of meso-level social processes, which are neither directly scalable from individual preferences nor readily predictable from population-level patterns, appears to be a key feature of marriage processes, and has been of some interest to agent-based modellers in the past [11], [12].

II. Related Work

Existing agent-based models of marriage have tended to concentrate on the emergence of population-level patterns from a relatively small set of agent preferences. One of the earliest models [13] used a single generic rankable trait to explore partnering mechanisms. Later models, such as MADAM (Marriage and Divorce Annealing Model) [14] and the ‘Wedding Ring’ model [11], included a number of generic mate relevant traits and heuristic processes such as social pressure and aspiration. Matching in these models is homophilic (and, therefore, assortative) and involves elements of satisficing (i.e. agents do not wait to find a ‘perfect’ mate, rather one who is ‘good enough’). Walker & Davis [12] produced a model of inter-ethnic marriage rates in New Zealand and, unlike previous models, utilised unit-level micro data from the New Zealand census. The model considers a fixed cohort of single 18-30 year olds, assigning male agents a random social network of female potential partners. Partnerships are formed between the best-matched agents with regard to similarity of age and education levels, a stochastic attraction factor and a macro ‘social pressure’ mechanism. Whilst this is the most sophisticated agent-based analysis of the dynamics of inter-ethnic marriage, it consistently over-estimates the rate of exogamy when compared to census data, which indicates ‘... that there is some degree of ethnic preference that is not being captured by the model’ [12: 6.4].

III. Model Description

Our approach with developing the DITCH (“Diversity and Inter-ethnic marriage: Trust, Culture and Homophily”) model has been to start with a simple model that includes only processes and data essential to modelling (inter-ethnic) partnership formation, but which can be easily extended when necessary. The model is therefore constrained to simulating a cohort of – at model initialization -- single

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agents aged 18-35 years who search for a suitable partner within their social network.

In the current model version agents are characterised by five traits:

1. Gender (male or female). This is initialised randomly, with 50% chance each of being male or female.
2. Age (18-35). This is initialized according to an age distribution taken from the UK Census 2001.
3. Ethnicity (one of four discrete values representing abstract ethnicities: w, x, y, z). This is initialized randomly according to the proportions specified via a model parameter (*eth-proportions*).
4. Compatibility (a real number between 0 and 1 modelling "chemistry" between agents; the closer their compatibility scores, the more compatible are the agents). This is initialized uniformly randomly between 0 and 1.
5. Education (an integer in [0,4] representing education level with 0: none, 1: level 1 (some GCSEs), 2: level 2 (GCSEs), 3: level 3 (A-Levels), 4: level 4/5 (university degrees)). This is initialized according to distributions particular to ethnic group and gender taken from the UK Census 2001. Each abstract ethnicity (w, x, y, z) is assigned an ethnic group via the model parameters *ethnicity-w*, *ethnicity-x*, *ethnicity-y*, *ethnicity-z*.

Agents also have preferences for partners with certain traits. These are expressed as follows:

1. Gender: opposite gender. (We assume a strictly heterosexual world for now.)
2. Age: a range of +-2 to 10 years centered on the agent's own age. This is initialized randomly.
3. Ethnicity: a preference value for each of the four represented ethnicities, with a slight bias towards the agent's own ethnicity. These are initialized randomly with values between 0 and 1; making sure that the agent's own ethnicity receives the highest value.
4. Compatibility: a range of +- 0.05 to 0.5 centered on the agent's own compatibility value. This is initialized randomly.
5. Education: Instead of having a preference for a particular education level, we assume that agents prefer their potential partner to not differ too much from their own education level. Education preference is therefore expressed as a preference for the difference in education level (from 0 to 4). This is initialized via a normal distribution with mean 0 and standard deviation between 0 and 4 (set via the model parameter *sd-education-pref*).

Agents employ their social network to look for potential partners. Since agents are 18-35 years old at model initialization, at least some of the social links between agents need already be established. These can be ties with friends, family, neighbours or colleagues; the model does not differentiate between different types of links. To start agents off with a plausible social network newly created agents are trying to find an empty cell on the grid next to one of their own ethnicity. Only if that is not possible, they pick a random free cell. This results in clustering of minorities. Agents then form links with some of their neighbours. After this, a Schelling-like segregation is run for 50 ticks to let agents segregate according to age and then form links with some of their neighbours again. This attempts to achieve a social network where agents have cross-ethnic links to agents of a similar age ("school friends") and same-ethnic links to agents of a wider age range ("family", "neighbours").

The social network changes over time with agents forming new links and dropping old links. Each tick an agent has a chance of 50% to form a new link with either the most similar (with regard to age, ethnicity and education) friend of a randomly picked friend (95%) or a random stranger (5%). There is also a small chance (5%) to drop a randomly picked link (except for marriage links).

Agents utilise their social network to find potential partners of the opposite gender and within their preferred age range. Each tick, agents who are still single and not currently dating anyone start looking in their immediate links (level 1) and widen their search further outwards (level 2: friends of friends, level 3: friends of friends of friends, etc.) if they cannot find at least 3 potential partners. They then choose one of those 3 potential partners randomly to go on a "blind" date. The depth of the search (level 1, 2, 3…) is determined by the model parameter *love-radar*.

During a date, the two agents determine if they are satisfied with their potential partner based on the 'public' traits gender, age, ethnicity and education. While the suitability of gender and age have already been determined in the partner search, each agent now checks if their partner's ethnicity and education level are acceptable. This is the case if the difference in education falls within an agent's preferred difference and if a random number in [0,1] is smaller than the agent's preference value for their partner's ethnicity (the preference values for ethnicities are thus interpreted as probabilities).

If both agents are satisfied with their partner they will start dating, i.e. they will not continue to look for potential partners. The duration of the dating period follows a normal distribution with mean *mean-dating* and standard deviation *sd-dating* (both model parameters).

After the dating period is over, agents proceed to the next stage: they try out for marriage. This means, that they reveal their compatibility value to each other. If both agents' partner's compatibility score lies within their preferred range, the agents have a high chance of partnering:

$1 - |compatibility_1 - compatibility_2|$.

As compatibility scores get closer the probability increases towards 1. This process is derived from 'the mate searching game' [15]. If agents partner successfully, they remain in the model to keep the social network intact, but are no longer available as potential partners for others.

Agents update their preferences based on their dating experiences. An unsuccessful blind date will widen the preferred age range slightly (by 0.1) and negatively affect the preference for the other agent's ethnicity (reduced by 0.01), whereas a successful date will boost the preference value for the other's ethnicity by 0.01 (to a maximum of 1.0). After an unsuccessful marriage test the agents will expand their preferred compatibility range scores slightly (by 0.05) to mimic the idea that unsuccessful dating events encourage us to become less fussy in our preferences. The influence of dates on preferences can be controlled via the model parameter *update-threshold*. If this is set to values > 1 the change in preferences only happens after the specified number of (un-)successful dates.

This model has been implemented in NetLogo, using a monthly time step.

IV. Preliminary Results

This section provides some sample results and parameter tests to illustrate how the current model is functioning and its relative accuracy when compared to validation data. These results and tests are based on runs using scenarios derived from sample areas representing different typologies of ethnic diversity within local and urban authorities in England & Wales, based on the number of ethnic groups and the proportion of the population from a 'White: British' background. Within the sample areas the four largest ethnic groups were selected (if over 1% of overall population) and their proportions weighted to add to 100%. The sample areas are as follows (with weighted ethnic group proportions):

- *Super-diverse* sample: Newham, London
  Sample populations: White: British (WB): 30.5%; Asian/Asian British: Indian (A/ABI): 25.1%; Asian/Asian British: Bangladeshi (A/ABB): 22%; Black/Black British: African (B/BBA): 22.4%
  Inter-ethnic marriage rate (2011 UK Census): 21.13%

- *Cosmopolitan* sample: Trafford, Greater Manchester
  Sample population: WB: 90.2%; White: Other (WO): 3.2%; A/ABI: 3.1%; Asian/Asian British: Pakistani (A/ABP): 3.5%
  Inter-ethnic marriage rate: 12.81%

- *Bifurcated* sample: Bradford, W. Yorkshire
  Sample population: WB: 71.1%; WO: 3.3%; A/ABI: 2.9%; A/ABP: 22.7%
  Inter-ethnic marriage rate: 8.09%

- *Parochial* sample: Cheshire West & Chester
  Sample population: WB: 98%; WO: 2%
  Inter-ethnic marriage rate: 6.33%

- *National*: England and Wales
  Sample population: WB: 90%; WO: 5%; A/ABI: 2.8%; A/ABP: 2.2%
  Inter-ethnic marriage rate: 10.47%

A. Finding 1: Homophilic networks increase the number of marriages across all scenarios and reduce the rate of inter-ethnic matches

Fig. 1 illustrates how moving from a random social network (blue) to one based on age and ethnicity (red) increases the overall number of marriages; this is likely to be due to the initial sorting process in assigning homophilic social networks, which brings suitable matches 'closer' to each other – increasing the probability of them dating and marrying. All figures show the results of 30 runs of 120 ticks (10 years) each with the parameter *love-radar* set to 1 for runs 1-10, 2 for runs 11-20 and 3 for runs 21-30.

However, whilst homophilic networks increase the overall number of marriages, they decrease both the mean proportion and variance of cross-ethnic matches (see Fig. 2). This is due again to the higher level of homophily – ensuring that agents are more likely to date (and, thus, marry) co-ethnics, and reducing the element of chance (variance) in the nature of initial social networks.

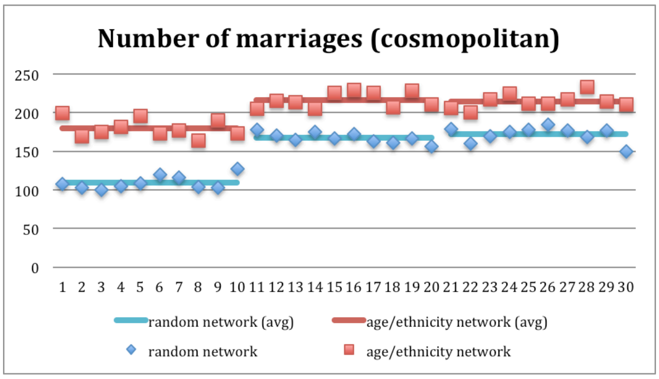

Fig. 1: Number of marriages using a random social network (blue) or a social network applying homophily based on age and ethnicity (red; see section III).

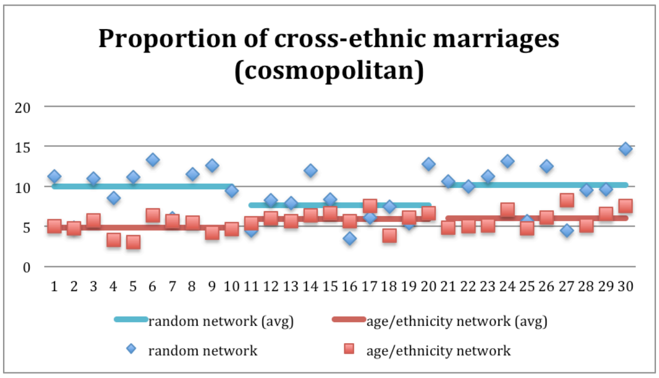

Fig. 2: Proportion of cross-ethnic marriages using a random social network (blue) or a social network applying homophily based on age and ethnicity (red).

B. Finding 2: Increasing the 'love-radar' from 1 to 2 increases the number of marriages in all scenarios and reduces variance, but not the mean average of inter-ethnic marriages (though this effect is dampened in homophilic networks)

The 'love-radar' controls the social distance an agent will look for a potential partner. A setting of 1 indicates agents will only look for 'dates' amongst those one node away from them (effectively close friends). This group will be exhausted quickly and only occasionally refreshed through social network growth. A setting of 2 indicates agents will expand their search for 'dates' to two nodes away (effectively friends of friends), thus significantly increasing their dating pool. Increasing the 'love-radar' further seems to have little additive effect.

The key change can be seen at tick 11 in Fig. 3 – note also the effect is substantially more pronounced in the random network (blue) runs, where similar agents are more likely to be socially removed from one another.

C. Finding 3: Different areas have different rates of inter-ethnic marriage and, where there is a substantial ethnic minority, these rates map well to 'real world' data

The four sample areas behaved broadly as expected, with the inter-ethnic marriage rate increasing as the proportion of minority ethnic groups grows (see Fig. 4). However, whilst the 'real-world' inter-ethnic marriage rate matched well with the rates in bifurcated and super-diverse samples, it was less accurate in areas with a number of small minority ethnic groups. This may be caused by the proportional increase in the majority population where a large number of small ethnicities are removed from the weighted sample (such as in the 'cosmopolitan' and 'national' scenarios). This suggests we can be broadly satisfied with the model performance so far on this measure. However, whether the model fares as well in more subtle measures is still to be explored in more depth.

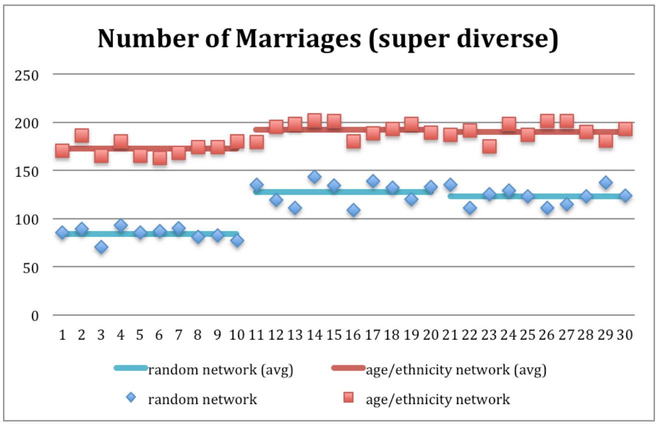

Fig. 3: Number of marriages using a random social network (blue) or a social network applying homophily based on age and ethnicity (red).

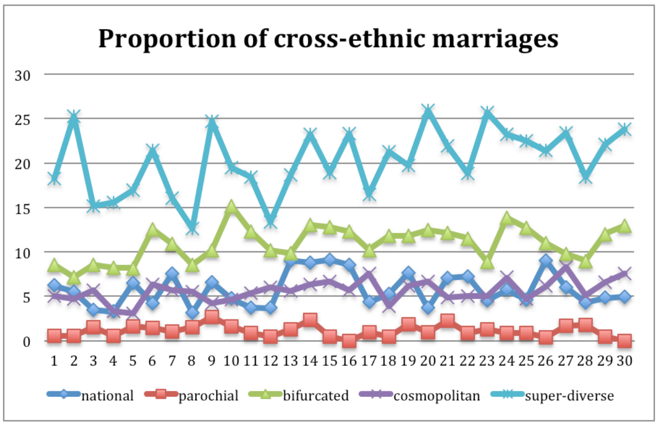

Fig. 4: Proportion of cross-ethnic marriages across the five different scenarios.

V. Conclusion and Outlook

The current model appears to be already relatively well matched to 'real-world' data. As Finding 1 shows, social networks and homophily play a large part in this, especially in social groups which practise a 'free market' model of marriage where any individual is free to partner with any other member of that social group. However, anthropologists have long recognised the importance of 'culture-based marriage norms', which restrict the available choice of partner to some extent and thus may have a profound impact on the emergence and development of inter-ethnic partnering within a mixed community. Our next step will therefore be to add marriage norms to the existing model to allow us to investigate what effects contact and marriage rules have on the inter-ethnic marriage rate.

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An agent-based Model to Study Customers' Engagement with Brands from a Service-Dominant Logic Perspective

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***Abstract*—We present an Agent-based Model to study customers' engagement with brands from a Service-Dominant Logic perspective. Customer Engagement has gained attention recently in the study of customer loyalty as a process that enables to understand and measure the impact of the depths of customers emotional responses to consumption situations on their intention to retain with a particular brand. However, there is no adequate research that deeply investigate the process of engagement, especially in dynamic, competitive and complex market environments. We address this research gap by creating an agent-based artificial market model. In doing so, we base our model on** *Service-Dominant Logic*, **which offers a novel lens to look at markets and their interactions and on the** *customer engagement process model* **of Bowden to implement customers engagement with a brand. This paper basically presents a logical discussion on the formulation of the model and some initial outcomes.**

I. Introduction

Why customers leave brands is an interesting question of all time. In competitive markets, it is possible to see very often the collapses of once giant firms despite their attempts to improve the features of their brands. Even though researchers generally agree that the customer loyalty is the driving force behind their repeat purchases, there is no consensus on what causes loyalty [1]. Traditionally, loyalty has been seen as caused by customers' satisfaction on a brand, determined by the extent of confirmation/disconfirmation of expectations [2]. However, this popular and widely used ideology has been challenged by research that points out even the satisfied customers will defect [3]. Research on *affect*, such as *customers' delight* [4], has attempted to overcome some of the limitations of these purely cognitive approaches by drawing a distinction between mere satisfaction, and stronger and more positive emotional responses toward consumption [1].

The concept of *engagement* describes an emotional attachment of someone with something, which has been linked to a number of positive consequences in the management literature [1]. For example, Enrique et al. [5] recognizes the importance of proper conceptualization and evaluation of website engagement of online consumers. Moreover, employee engagement is argued to be positively related to individuals' attitudes, intentions and behaviors [6], and subsequently to business results such as job satisfaction, low absenteeism and high organizational commitment and performance [7]. This leads to the suggestion that the study of customer engagement with brands would help answering the critical question of what causes customer loyalty. For this endeavor, Bowden [1] proposes a conceptual framework of the process of customer engagement, which incorporates satisfaction into a much richer process model of engagement that causes loyalty.

However, the process of engagement and its impact on customer loyalty needs to be studied in a dynamic and competitive environment with complex interactions among service providers and customers in order to attain a better understanding. This emphasizes the need of developing simulation models of artificial markets, in which customer engagement with service providers occurs dynamically based on the outcomes of individual interactions among market entities. Thus, *Agent-based Modeling* approach [8] proves to be a potential candidate in this endeavor.

The agent-based model presented in this paper represents an artificial market based on the concepts of *Service-Dominant Logic*, which has recently emerged as an alternative mindset to the traditional *Goods-Dominant Logic* [9]. The Service-Dominant logic (S-D Logic) views markets as *systems of resource integrating actors* who exchange competences in the form of services. Thus, the S-D logic rejects the distinction between goods and services by viewing every offering (i.e. a tangible product or an intangible service) as a means of delivering a service [10]. Moreover, S-D logic's recognition of value as being co-created at the time of use instead of being exchanged at the time of purchase makes it a suitable approach to study the impact of emotional responses of consumers at consumption situations on their loyalty. In other words, the co-created value at the time of use would influence the emotional attachment of consumers with service providers.

The artificial market represented by our agent-based model comprises customer and service provider agents of one particular service. Each service provider agent is assumed to represent a particular brand in the market. The agents are designed as *service systems*, which is an abstract term used in *Service Science, Management and Engineering (SSME)* [11] to define actors in a market environment based on S-D logic [12]. Thus, a brand is considered as a service provider agent in a particular market. Consumption choice decisions of customer agents are hence based on their loyalty with each service provider at a situation of choice, which is implemented as stemming from a continuous process of engagement. We use the *customer engagement process model* presented by Bowden [1] as the basis to implement the process of engagement of customer agents. Using this artificial market model, we intend to study the process of customer engagement and emergence of loyalty in dynamic and competitive markets. The objective of this paper is to explain the modeling details through a logical discussion.

The subsequent sections of this paper are organized as follows. In *section two*, we review some relevant literature for this research and in *section three*, we present a hypothetical use case scenario of service system interactions from the hotels industry to enhance the clarity of the agent-based model. The next section, *section four*, contains the details of our model. In *section five* we present some basic simulation results of our model while *section six* provides a a conclusion with implications for future work.

II. Literature Review

This section contains the literature relevant for the work presented in this paper. Since this is an interdisciplinary research, we brief the necessary concepts of all relevant domains.

A. Agent-based Modeling

Agent-based modeling takes the generative approach in social science, in which a generativist looking forward to explain the emergence of macroscopic societal regularities, such as norms or price equilibrium, would like to know how the decentralized local interactions of heterogeneous autonomous agents could generate the given regularity [8]. Generally, the interdependency, emergence and non-linearity inherent in the underlying processes make it difficult for humans, unassisted by computer simulations, to effectively reason about the consequences of actions in a complex system [13]. An agent-based model enables to generate a would be world [14], in the form of a computer simulation, in which a group of heterogeneous, autonomous, bounded rational agents interact locally in an explicit space [8]. The creation of such silicon surrogates of real-world complex systems allows researchers to perform controlled repeatable experiments on the real McCoy [14].

Artificial markets has been a popular and emerging form of *agent-based social simulation*, in which agents represent consumers, firms or industries interacting under simulated market conditions [15]. According to Zenobia et al. [15], there are several promising applications of artificial markets such as forecasting future market behavior, exploring market dynamics, conducting massively parallel market analysis, gaming organizational strategies for volatile new markets, and profiling products and services which do not currently exist, but which markets are poised and ready to accept. Furthermore, the recent proliferation of *social networks* have boosted the interest of studying the *diffusion of innovations* through agent-based modeling. For example, Lee et al. [16] studies pricing and timing strategies such as *time to market* and *time to discount* of a new product using agent-based simulations of behavioral consumers. Consumer agents of that model make purchase decisions for a new product referring to the characteristics of the current product they use and to the recommendations of the peers in their social network. However, Baptista et al. [17] argues although a number of agent-based models of consumer behavior have been proposed in recent years the advantages of this approach are yet to be fully grasped by the business simulation community. This statement can be related in particularly to the emerging domain of *service-dominant logic* as only a handful of agent-based models have been developed based on service-dominant logic.

B. S-D Logic and Service Systems

Service-Dominant logic is regarded as the provider of the right perspective, vocabulary and assumptions for modern service research [11]. It adopts the systems approach to the study of markets by defining markets as systems of resource integrating actors who interact by exchanging services and co-creating value [10]. The difference between Service-Dominant logic and the traditional Goods-Dominant logic involves a philosophical discussion on value in the foundation of economics [18]. According to Vargo et al. [18], the traditional Goods-Dominant logic focuses on the value-in-exchange where as the Service-Dominant logic focuses on the value-in-use. Thus, the firms that believe in Goods-Dominant logic would focus on producing goods (or its intangible counterpart - services) in surplus with embedded value and distributing that surplus to maximize profits through economies of scale. In contrast, firms that adopt a Service-Dominant logic mindset would focus on increasing adaptability, survivability and system wellbeing through competitive value propositions that primarily involve applied operant resources (i.e. knowledge and skills) and support realizing value in use. Table 1 presents the foundational premises of Service-Dominant logic and Table 2 presents a comparison of Service-Dominant logic and Goods-Dominant Logic.

According to Service-Dominant logic, a service is an exchange of resources either in tangible or intangible form [9]. In other words, any tangible or intangible offering in the market is a means of offering a service by one actor to another. Central to S-D logic is value co-creation, in which it argues that value cannot be added to a service upfront but has to be co-created by the beneficiary at the time of use [12]. More precisely, in a service interaction, the service provider makes a service offer using its resources through a value proposition

TABLE I
FUNDAMENTAL PREMISES OF SERVICE-DOMINANT LOGIC

Premise ID	Fundamental Premise
FP1	Service is the fundamental basis of exchange
FP2	Indirect exchange masks the fundamental basis of exchange
FP3	Goods are a distribution mechanism for service provision
FP4	Operant resources are the fundamental source of competitive advantage
FP5	All economies are service economies
FP6	The customer is always a co-creator of value
FP7	The enterprise cannot deliver value, but only offer value proposition
FP8	A service centered view is inherently customer oriented and relational
FP9	All social and economic actors are resource integrators
FP10	Value is always uniquely and phenomenologically determined by the beneficiary

and the customer (beneficiary) co-creates the value of that service with the help of resources possessed by him or her. This new mindset of S-D logic has been acknowledged as having a staggering potential to continue to be a catalyst for important research in the field of services [19].

The abstract notion of *service system* [12] enables defining actors of service markets based on S-D logic. In other words, a market could be viewed as a population of interacting service systems of different kinds. According to Maglio et al. [11], anything ranging from individuals, firms and agencies to worlds and planets could be a service system. A service system is characterized by a value proposition, which helps it to agglomerate its resources in different dimensions and interact with other service systems by exchanging resources [12]. Hence, a market comprising service providers (firms) and their customers could be viewed as a platform, on which *service provider service systems* interact with *customer service systems* co-creating value.

The process of interaction between two service systems has been presented as a model of ten possible outcomes in the ISPAR (Interact-Serve-Propose-Agree-Realize) model [12]. In the ISPAR model, an interaction can be either a service interaction or a non-service interaction. Service interactions are value co-creation interactions where each service system engages in three main activities: (1) proposing a value co-creation interaction to another service system (proposal), (2) agreeing to a proposal (agreement), (3) realizing the proposal (realization). A non-service interaction may involve a welcoming behavior such as exchanging pleasantries on the street or an unwelcoming behavior such as committing a crime. Non-service interactions basically acts as determinants of future value co-creation interactions. Figure 1 is an illustration of the ISPAR model.

TABLE II
COMPARISON OF GOODS-DOMINANT LOGIC AND SERVICE-DOMINANT LOGIC ON VALUE CREATION

	Goods-Dominant Logic	Service-Dominant Logic
Value driver	value-in-exchange	value-in-use or value-in-context
Creator of value	Firm, often with input from firms in a supply chain	Firm, network partners and customers
Process of value creation	Firms embed value in ”goods” or ”services”, value is ’added’ by enhancing or increasing attributes	Firms propose value through market offerings, customers continue value-creation process through use
Purpose of value	Increase wealth for the firm	Increase adaptability, survivability, and system wellbeing through service (applied knowledge and skills) of others
Measurement of value	The amount of nominal value, price received in exchange	The adaptability and the survivability of the beneficiary system
Resources used	Primarily the operand resources (i.e. tangible resources)	Primarily operant resources (i.e. intangible resources such as knowledge and skills), sometimes transferred by embedding them in operand resources-goods
Role of firm	Produce and distribute value	Propose and co-create value, provide service
Role of goods	Units of output, operand resources that are embedded with value	Vehicle for operant resources, enables access to benefits of firm competences
Role of customers	To ’use-up’ or ’destroy’ value created by the firm	Co-create value through the integration of firm provided resources with other private and public resources

C. Customer Engagement

In today’s highly dynamic and interactive business environment, the role of *customer engagement (CE)* in co-

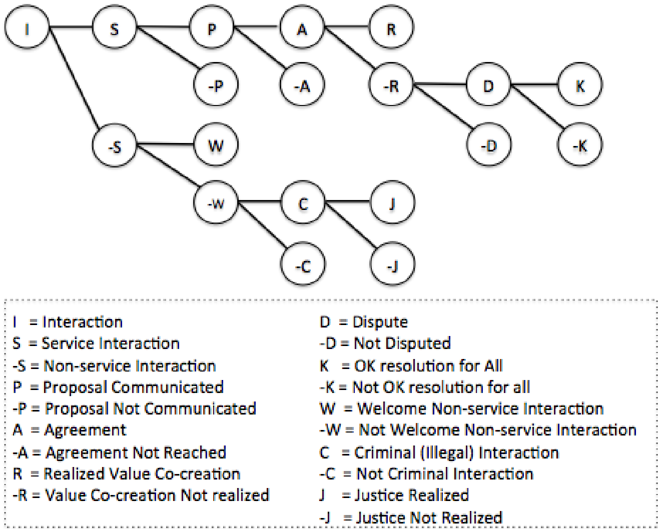

Fig. 1. The ISPAR Model of Service System Interactions

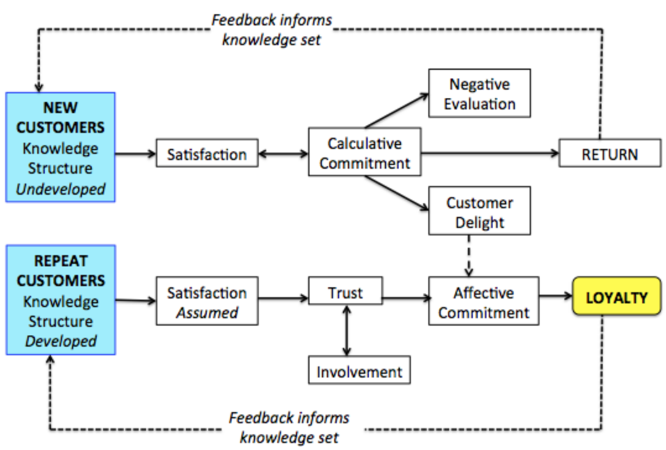

Fig. 2. Customer Engagement Process Model

creating customer experience and value is receiving increasing attention from business practitioners and academics alike [16]. While comprehensively reviewing the available literature on *engagement* to date, Brodie et al. [20] derives five fundamental propositions that define the conceptual domain of customer engagement from a relationship marketing and S-D logic perspective. The five fundamental propositions of CE derived by [20] are elaborated in Table 3.

The customer engagement process model, shown in Figure 2, depicts the formation of *loyalty* through affective commitment towards a service provider [1]. The model clearly differentiates the new customers and repeat customers. A new customer usually possess an ill developed knowledge structure about a service provider compared to a repeat customer who has a rather developed knowledge structure with previous experience. A new customer tends to evaluate different attributes of a service (from a particular service provider) when evaluating a consumption experience, which determines his or her satisfaction and intention to return. Hence, *calculative commitment* is the extent to which a new customer evaluates the attribute level outcomes of a service. A positive overall evaluation of attribute level outcomes causes *customer delight*, which would help originating an *affective commitment* in the new customer. Experience of a new customer with a service provides a feedback, which enhances the knowledge structure of that customer about the particular service provider. A repeat customer on the other hand has a well developed knowledge structure about the service of a particular service provider. Hence his or her satisfaction is assumed. The satisfaction of a repeat customer of a service provider helps developing *trust* on that service provider. The trust helps developing an emotional bond between the repeat customer and the service provider strengthening the *affective commitment* and *involvement* with the particular service provider. The affective commitment strengthens the *loyalty* of the repeat customer with the service provider while giving feedback to improve his or her knowledge structure about the service of that particular service provider.

III. A Hypothetical Use Case Scenario of Service System Interactions

In order to enhance the readability of the paper, here we present a hypothetical case from hotels industry, which helps understanding the structure of a market from a service-dominant logic perspective.

In hotels industry, the market comprises two types of entities. Those are the hotels (i.e. service providers) and the tourists (i.e. customers). According to the service system abstraction [12], each hotel and each customer of a particular tourist destination are *service systems*, which can interact with another service system such as another hotel or another customer.

The hotels at a particular destination could be categorized based on a certain set of attributes, which resembles each hotel in to a particular profile such as *a star hotel*, *a budget hotel*, *eco hotel*, *cruise*, etc. In other words, the profile of a hotel reflects its resource possession and their utilization on each attribute, in order to maintain a particular service standard. Hence, a hotel's profile is its value proposition to the prospective customers. Similarly, the tourists visiting a particular destination too have such profiles such as *back packers*, *mass tourists*, *naturalists*, etc. Such profiles are determined by evaluating a certain set of attributes that resemble a tourist. In other words, a profile reflects the level of resources that the tourist possesses along each attribute of his or her profile. Hence, the customer profile of a tourist is his or her value proposition to interact with prospective hotels.

Once a tourist decides to visit a particular destination, he or she may consider a hotel o stay at during the visit. There, the tourist will ask fellow tourists or follow Internet forums to find out the best place that is most likely to match with his profile (i.e. budget, interests, preferences, etc.). If it is a repeat visit, the tourist may already have some options in mind with a certain level of affection towards each of those options, which

TABLE III
FUNDAMENTAL PROPOSITIONS DEFINING THE CONCEPTUAL DOMAIN OF CUSTOMER ENGAGEMENT (CE)

FP ID	Description	Justification
FP1	CE reflects a psychological state, which occurs by virtue of interactive customer experiences with a *focal agent / object* within specific service relationships	• The focal agent / object a customer interacts with may be a brand, product or organization • Focal CE behaviors that have a brand- or firm-focus extend beyond transactions / purchase • Two-way interactions generating CE may occur within a broader network of customers, stakeholders, and other actors in specific service relationships
FP2	CE states occur within a *dynamic iterative process* of service relationships that co-creates value	• CE processes may range from short- to long-term, relatively stable to highly-variable processes typified by CE levels varying in complexity over time • CE occurs within specific service relationships comprising networked agents including customers, organizations and other stakeholders that co-creates value
FP3	CE plays a *central role* within a *nomological network* of service relationships	• Required relational CE antecedents include "participation" and "involvement" which may also extend to coincide, or occur concurrently, with CE • Other potential relational antecedents may include "flow" and "rapport" • CE relational consequences may include "commitment", "trust", "self-brand connections", consumers' "emotional attachment" to focal brands, and "loyalty" • The iterative (cyclical) nature of the service relationships process implies that specific CE relational consequences may extend to act as CE antecedents in subsequent CE (sub-) processes and/or cycles
FP4	CE is a *multidimensional concept* subject to a context- and / or stakeholder-specific expression of relevant cognitive, emotional, and behavioral dimensions	• The relative importance of the particular cognitive, emotional, and/or behavioral CE dimensions varies with the specific CE stakeholders involved (i.e. engagement subject, e.g. customer; engagement object, e.g. brand) and/or the set of situational conditions, thus generating distinct CE complexity levels
FP5	CE occurs within a specific set of situational conditions generating differing *CE levels*	• Specific interactions between a customer and a focal agent/object and other actors within specific focal relationships may generate different levels of cognitive, emotional and/or behavioral CE intensity, depending on specific CE stakeholder (e.g. customer, brand) and contextual contingencies driving particular CE levels

makes his decision faster and less costlier. The main concern in selecting a place to stay would be how likely the selected place would help making the visit a pleasant experience. From a service-dominant logic perspective, this is called the potential to *co-create value*. Once, a hotel is selected, a tourist would approach the selected hotel for a booking. This could be considered as the beginning of an interaction between two service systems, which may take any of the paths explained by figure 01.

The hotel may ask for a security, for example the credit card number, and if satisfied with the credibility of the customer, will agree to reserve a room for the tourist. Once the tourist arrives at the hotel and starts his or her vacation, he or she may realize value on each attribute of the hotel's offering. This realization of value at the time of use is called *value co-creation* in service-dominant logic. Notably, the realization of value depends not only on the hotel's offering but also on the profile of the tourist. For example, if the tourist has a limited budget he or she may not be able to enjoy some services offered by the hotel. Or else, if the tourist does not possess certain competences, such as the ability to swim, he or she may not able to get the better of some facilities on the hotel's offering. Thus, two tourists with different profiles will realize two different levels of value from the same offering.

However, the realized value at the end of the stay would affect the loyalty of the tourist towards that hotel as well as the desire to recommend the hotel to another tourist.

IV. THE AGENT-BASED MODEL

This section contains the details of our agent-based model. This model is based on our method to develop agent-based models based on the *service system abstraction* and *the ISPAR model of service system interactions*.

A. Structure of Agents

The agents of our artificial market model belongs to either of two main entities namely *service providers* and *customers*. Each agent has a value proposition through which they interact with the agents of the opposite entity. A service provider agent's value proposition reflects its service level, i.e. the level of competence and resources that the service provider is possessing in different attributes of the service. A customer agent's value proposition is the levels of resources in different aspects of its profile such as knowledge, demographics and psychographics. Customer agents use these resources to co-create value by interacting with the value propositions of the providers.

A value proposition could be defined as a combination of value creating attributes [21]. More precisely, service systems mobilize their resources into these attributes and develop their competences along them. For example, 'providing Internet access to guests' could be one attribute of a hotel's value proposition in the tourism market. Thus, we represent a value proposition as a combination of N such attributes. A given attribute is set to be at a particular state out of D possible states, where D could include integers as 0, 1, 2, ... For example, providing Internet access could be done by different ways such as setting up Wi-Fi zones inside hotel premises, giving access on request at a charge, giving in-room Wi-Fi access to all residents, etc. States of all N attributes thus make one particular state of the service system class and there could be D^N possible states for the given service system class. Hence, a given instance of that class could be at any of these states. For example, if we define the value proposition of hotels as N = 5 and D = 2, hotel A's state could be 10101 where as hotel B's state could be 01010. This reflects the differences of resources and competences of the two instances of the same class. In other words, if two hotels are identical in every aspect, they should bear the same state string. Similarly, two customers having identical profiles is synonymous to two instances of the customer class bearing the same state string. The individual value creating attributes are considered as contributing to the overall value perceived through the value proposition [21].

Apart from these market entity agents, there is a *controller agent*, which executes various runtime tasks such as reporting, adding-removing agents, etc.

B. Realizing Value Co-creation

According to Spohrer et al. [12], a service interaction between two service systems results in co-creation of value. We define a utility landscape for both service system entities considering their service interactions with the opposite entity. This utility landscape enables a given instance of a particular service system class to perceive (co-create) the utility (value) of a given service interaction with an instance of the opposite class.

In a service interaction *i* ($i \in I$) involving two instances *a customer* - *x* ($x \in X$) and *a service provider* - *y* ($y \in Y$), the perceived utility of *x* (= U_i^x) could be represented by Equation 1. In this representation, *X* denotes the entity of *customers* where as *Y* denotes the entity of *service providers*.

$$U_i^x = \frac{\sum_{n=0}^{N_Y - 1} u_i^n}{N_Y} \tag{1}$$

Here, N_Y denotes the number of value creating attributes of the value proposition of entity *Y* and u_i^n denotes the utility contribution of the attribute *n* of *Y*'s value proposition to the overall utility perceived by *x* in the interaction *i*. A similar equation could be written to determine the perceived value of the instance *y* in the same interaction.

Co-creation of value involves resources of both parties of a given interaction. Hence, the individual utility contribution of a given value creating attribute depends not only on its own state but also on the states of few other attributes of the same entity as well as the opposite entity. For example, the perceivable value from the attribute *Internet accessibility* at a hotel would depend not only on the type of accessibility provided but also on the structure and materials used to build its rooms (internal) as well as whether the customer possesses a laptop and whether (s)he knows how to connect it to the network (external). In order to incorporate this feature, we impose a dependency structure on each attribute, which links each attribute to other attributes of the same entity as well as the opposite entity. We base this dependency structure on the *Kauffman's NKCS architecture* [22].

In this dependency structure, we set each value creating attribute as depending on *K* number of other attributes of the same entity and *C* number of attributes of the opposite entity. According to this dependency structure, the utility contribution u_i^n of equation 1 could be elaborated as in equation 2.

$$u_i^n = f(d_i^n, (d_i^1 ... d_i^K)_Y, (d_i^1 ... d_i^C)_X) \tag{2}$$

Here, *d* ($\in D$) denotes the state of a particular attribute at the interaction *i*. According to this representation, u_i^ncould be drawn from $D^{(1+K+C)}$ different state value combinations. Thus we define a function to determine the individual utility contribution a given attribute based on combinations of state values of its own and the attributes it depends on. The function to draw the utility contribution u_i^n of equation 2 could be written as in equation 3.

$$(f^n)_Y : \{0 ... D-1\}^{1+K+C} \rightarrow R \tag{3}$$

Here, $(f^n)_Y$ is the function that determine utility contribution of attribute *n* of entity *Y* at different state value combinations of a length of (1+K+C). *D* is the number of states. R is drawn from the uniform distribution. For example, if K = 2, C = 2 and $D = \{0, 1\}$, the two state value combinations 10001 and 01110 would give $10001 \rightarrow R_1$ and $01110 \rightarrow R_1$, where $R_1, R_2 \in R$. In the system, we maintain a table containing the utility contribution of each attribute at all possible state value combinations.

C. Making a Choice: Selecting a Service Provider based on Engagement

The customer agents in our model make a choice decision based on their *loyalty* (L) towards each available service provider. The core determinant of loyalty is the *affection* (A), which is an emotional tie between a customer and a service provider. This is shown in equation 4. The whole process is developing loyalty is considered as the process of engagement. In any case if a customer agent has no positively affected service provider (s)he makes an evaluation, based on some prioritized attributes, on the expected utility with previously unvisited service providers to make a decision.

$$A \rightarrow L \tag{4}$$

Further we could represent trust as the measure of the satisfaction as shown by equation 05. Here, *delight* is also considered as a part of satisfaction. In other words, a customer could be *not satisfied*, *satisfied* or *satisfied with delight*. Even though [1] limits delight only to new customers, we consider attempts to delight the repeat customers as vital as delighting the new customers.

$$T = S \tag{5}$$

Here we consider satisfaction as the conformity of the utility of the service to the expectations of the customer. A customer agent has an *expected utility contribution* from each attribute of a service provider's value proposition. Hence, satisfaction becomes a measure of the differences between the *delivered utility* (U) and the *expectation* (E) at each attribute of the service provider's value proposition, which is shown by equation 06.

$$S = \frac{\sum_{i=1}^{N} (U_i - E_i)}{N} \tag{6}$$

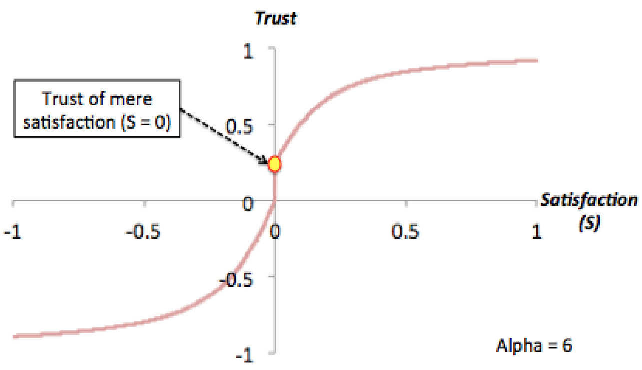

Fig. 3. Curve of the Trust Function (Equation 07) with $\alpha = 6$ and P = 0.25

Thus, we could consider that the customer is satisfied when S = 0, satisfied with delight when $S > 0$ and not satisfied when $S < 0$. In order to determine a trust quantity based on the value of the satisfaction, we define an inverse tangent function as shown in equation 07 below. There, P is a controllable parameter, which determines the trust contribution at mere satisfaction (i.e. S = 0).

$$T = \begin{cases} 2(1 - P/\pi)\tan^{-1}(\alpha S) + P & : S \geq 0 \\ 2(1/\pi)\tan^{-1}(\alpha S) & : S < 0 \end{cases} \tag{7}$$

The resulting curve from this function with $\alpha = 6$ and *P = 0.25* is depicted by figure 3. Here, the parameter α controls the steepness of the curve. After each service interaction, customer agents generate a trust quantity based on their satisfaction level with the service provider based on this curve. According to Bowden [1], *trust* acts as the major determinant of *Affection* or rather *affective commitment*, which is a holistic or aggregate judgement about a service provider that leads to a greater desire to remain with that service provider, invest in it and word-of-mouth recommendation. Hence, we consider the trust quantity resulting at each service interaction (episodic trust) to be altering the level of affective commitment of the respective customer towards the respective service provider. Based on this idea, we formulate the construct *affective commitment - A* of a given individual towards a service provider as the average trust generated through all service interactions to date between the said individual and the service provider. This formulation is shown in equation 08.

$$A_x^y = \frac{\sum_{i=1}^{Q} T_x^y}{Q} \tag{8}$$

Here, A_x^y is the affection of customer *x* towards a particular service provider *y*, T_x^y is the episodic trust generated by *x* towards *y* and Q is the number of service interactions between *x* and *y* to date.

However, in reality, peer recommendation has an impact to one's trust towards a service provider. From a S-D logic perspective, a peer recommendation could be viewed as a non-service interaction that occurs between peers. According to Spohrer et al. [12], non-service interactions act as determinants of future service interactions. Thus we alter equation 8 taking the effect of the strength of peer recommendations on one's affection towards a service provider. The modified equation is shown by equation 9. There, W_x^y denotes the strength of all recommendations that customer *x* has received from his/her peers about the service provider *y*.

$$A_x^y = \frac{\sum_{i=1}^{Q} T_x^y}{Q} + W_x^y \tag{9}$$

We consider the effect of a recommendation on an individual to be proportionate to the distance to the recommending peer. In other words, a recommendation from a peer with a close profile would be more effective than a recommendation of a peer with a more distant profile. Based on this conceptualization, we define the quantity W_x^y of equation 9 as shown by equation 10.

$$W_x^y = \frac{\sum_{j=1}^{Z} \frac{1}{b\beta}}{Z} \tag{10}$$

Here, the fraction $\frac{1}{b\beta}$ denotes a recommendation by a peer and the quantity *b* denotes the distance between the individual *x* and the recommending peer. β is a control parameter. Z denotes the total number of recommendations received by customer *x* towards the service provider *y*. Thus, the equation 09 could be re-written as in equation 11.

$$A_x^y = \frac{\sum_{i=1}^{Q} T_x^y}{Q} + \frac{\sum_{j=1}^{Z} \frac{1}{b\beta}}{Z} \tag{11}$$

As per the equation 01, a customer's loyalty towards a service provider is determined by his / her affection towards that service provider. Thus, when a customer agent is about to make a choice, he/she first evaluates his/her loyalty towards each service provider with a positive affection based on the equation 12.

$$L_x^y = \frac{A_x^y}{\sum_{i=1}^{M} A_x^i} \tag{12}$$

Here, L_x^y is the loyalty of customer *x* towards service provider *y*. M denotes the number of service providers with positive affections. Hence, one's loyalty towards a specific service provider is the share of affection owned by that particular provider in that particular customer.

Once the loyalty is computed for each service provider with positive affections, the respective customer is able to go for his/her most loyal service provider. However, in our opinion, there still is a chance that the customer may go for the next best alternative, especially when the customers loyalty to the most loyal service provider is not sufficiently large compared to that to the next most loyal service provider. Hence, the final decision of the customer agent is taken according to the process depicted by figure 4. There, E and F are the most loyal service provider and the next most loyal service provider respectively. As a result of this process, when the

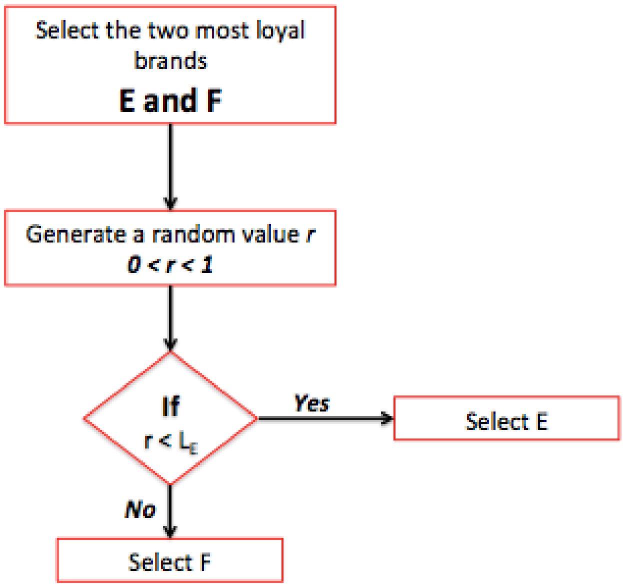

Fig. 4. Process of Making a Choice between the Most Loyal and Next Most Loyal service providers (Equation 07) with $\alpha = 6$ and P = 0.25

loyalty towards a service provider is higher, there exists a higher chance for that service provider to be selected.

D. State Variables

This section contains the details of the important state variables of the two types of agents of our model.

1) State Variables of Customers: The most important state variable of the customer entity is the *current state*. The current state of an individual customer agent is the current states of all attributes of their value proposition. In other words, the current state is synonymous to the current customer profile of that customer. For example, if the *number of attributes in the customer entity's value proposition* ($N_{customer}$) is 5 and the *number of states* is 2, a given customers current state, which has been set randomly, could be 10010. Differences in current states distinguishes customer agents from each other in terms of their customer profiles. When customer agents learn and adapt to market conditions, they dynamically change their current states by moving to neighboring states.

Another important state variable of customers is the *expectation*. This could be explained as the expected utility from a service at the time of use []. Initially, we set the expectations of individual customers randomly within a range of $0 - h$ ($0 < h < 1$), where h is controlled by a parameter (*Customers' adequate margin*). However, customer expectations usually grows with experiences, especially with delightful experiences [4]. Therefore, we set the expectations of individual customers to grow by a certain quantity given by a parameter (*Expectation growth rate*) at each successful value co-creation.

Table II contains descriptions about the other important variables of customers.

TABLE IV
OTHER IMPORTANT VARIABLES OF CUSTOMERS

Variable Name	Type	Description
Available Providers	List	The known service providers of the customer agent
Affection with Providers	List	The Affection details of each known provider
Priority Attributes	Integer Array	The most important attributes of the service providers' value proposition to the customer agent
Need Probability	Double	Probability of getting a need for the service at a given time step
My Neighbors	List	The customer agents are placed on a grid. The customer agents on the neighboring grids of a given customer becomes neighbors (peers) of that agent

TABLE V
OTHER IMPORTANT VARIABLES OF SERVICE PROVIDERS

Variable Name	Type	Description
My Check Attributes	Integer Array	The states of these attributes of customers' value proposition are checked before agreeing to serve
Interaction Number	Integer	Determines the total number of service interactions to date. This is used for reporting purpose
My Customer Relationships	List	Keeps the track of individual relationships with each customer

2) State Variables of Service Providers: .

Similar to the customer agents, the *current state* and the *expectation* are the two most important state variables of service providers. The *current state* of a service provider determines the current service level of that particular brand. In other words, it determines the levels of competences and resources the service provider possesses in different aspects of its service. If the it number of attributes in the service provider entity's value proposition ($N_{serviceprovider}$) is 5 and the *number of states* is 2, a given service provider agent's current state, which is set randomly, could be, for example, 10101. Differences in current states distinguishes service providers from each other in terms of their capabilities and possession of resources.

Similar to the expectations of customers, service providers too have an expected utility in a given service interaction. This determines the type of customers that a particular service provider is expecting for the mutual benefit of both parties. The expectations of individual service provider agents are initially set randomly in the range 0 - v (0 ¡ v ¡ 1), where *v* is an input parameter (*Providers' adequate margin*).

Table III contains the details of the other important variables of service providers.

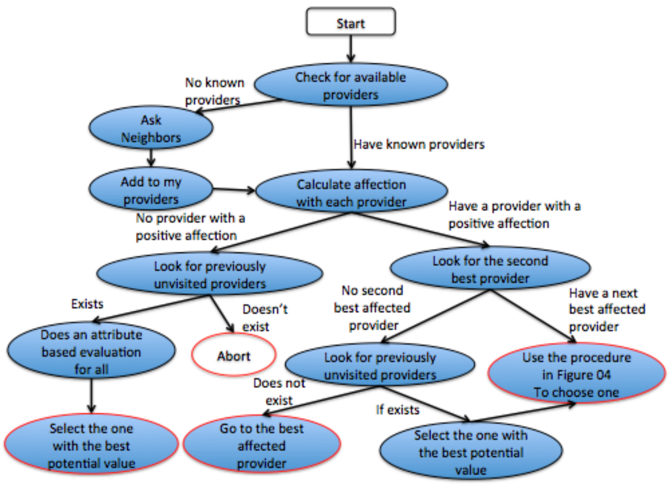

Fig. 5. Process of Selecting a Suitable Provider

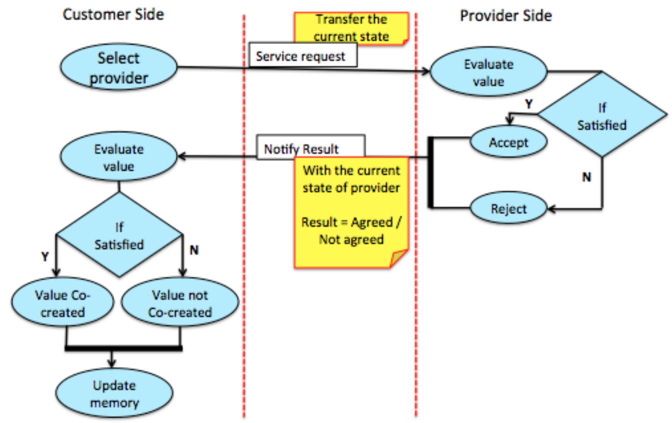

Fig. 6. Process of Interacting with the Selected Provider

E. Process Overview

This section describes the basic processes of the model.

1) Getting a Service Need: The market process in our model starts with getting a service need by individual customer agents. Getting a service need is controlled by a probabilistic value generated by the controller agent. According to this probabilistic value, an appropriate percentage of customers get the need for the service at a given time step.

2) Selecting a Suitable Provider: Selection of a suitable provider is generally based on the loyalty of customers towards each service provider. However, there exists exceptions in cases when there are no known service provider agents to the customer agent or when the customer agent have no positive affection towards any of the known service provider agents. The process of selecting a suitable service provider is illustrated in figure 05.

According to the figure 05, when a customer agent gets a service need, it checks for any known service provider agent. If any such agent does not exists, the customer agent asks its neighbors (peers) about any available providers and updates its knowledge about available service providers. The customer then calculates its affection with each of the providers in the memory based on the equation 11. In this case, if a service provider with a positive affection could not be identified, customer agent does an attribute based evaluation on its priority attributes for all previously unvisited service providers and selects the one that has the highest potential value. Otherwise it looks for the second-most affected service provider for comparison. If a second-most affected service provider could also be found, the customer uses the procedure in figure 04 to choose one of the two. Otherwise it looks for any previously unvisited service providers. If one such exists, it makes a choice between that provider and the most affected provider using the procedure in figure 04. Otherwise the agent stick to the most affected service provider.

3) Interacting with the Selected Provider: Once the customer agent selected a suitable service provider, it starts a service interaction with that provider by sending a service request. Through the service request, the service provider agent gets to know the current state of the customer agent. In case of a new customer, the provider agent does an evaluation on the check attributes to see if the customer is eligible for the service. For example, a hotel may ask for a proper identification certificate from its guests unless the guest is a regular customer of the hotel. The service provider agent then evaluates the service request by determining its value on each attribute of the customer's value proposition in that interaction based on equation 03. It next compares the value of each attribute with its expectations to determine its total satisfaction in the particular interaction. If the total satisfaction is positive, the service provider agrees to serve or rejects the offer otherwise. In case of an acceptance to serve, the customer agent on the other hand calculates its satisfaction and updates its memory based on the result. This process is typically based on the *Service Interaction* branch of the ISPAR model in figure 01 and it is further illustrated in figure 06.

4) Making a Recommendation: In case if the customer agent is delightfully satisfied with the service (i.e. satisfaction > 0), it makes a recommendation of the service to all of its neighbors. This recommendation contains the current state of the recommender, hence the peers could calculate the distance between them and the recommender in order to update their *recommendation strength* component given by equation 10 with regard to the service provider being recommended.

5) Learning and Adaptation: Whether customers and service providers learn and adapt is depending on an input parameter. In case of customers, if the parameter for learning and adaptation is set to *true*, they attempt to learn and adapt by looking for a better state among their *one-mutant neighboring states* [], which is more likely to give them a better satisfaction with a given service provider. Once a provider is selected, the respective customer agent checks with its neighbors about their previous value co-creation experiences with the same provider. If the agent could find better value co-creation experiences by its neighbors than its current expected value, it moves one step (*i.e. moving to one of the one-mutant neighboring states*) towards the current state of the nearest neighbor with a better experience. This is synonymous to the process of trying to be like someone who seems co-creating more value with the same product.

In case of service providers, if the parameter for learning and adaptation is set to *true*, service provider agents try to serve their customers better by moving to better states in their *one-mutant neighborhood*. Here, the service provider agents periodically monitors the number of service interactions *sales volume* at a given time step. If a decline in sales volume is monitored compared to the previous figure, the respective service provider agent check its potential performance at its one-mutant neighboring states in consultation with *a selected number of top customers*. If a better state that is more likely to enable its customers to co-create better value, it moves to that state. This is synonymous to the process of firms trying to improve themselves by continuously discussing with its best customers.

F. Implementation

We implement this model using the social simulation development environment *Repast*. The important parameters of the system are introduced in table 04 with a short description and the initial (default) values.

Apart from these basic parameters, we implemented an option of categorizing the *service providers* and *customers* into two distinct segments called *high end* and *low end*. In this differentiation, utility landscapes are adjusted in such a way that the *high end customers* get higher utilities with *high end providers* and the low end customers get higher utilities with *low end providers*. The reason for this discrimination is to emphasis the importance of selecting the right customers and also to cope with the reality, where such discrimination usually exists.

1) Emergence: The emerging pattern that we are mainly interested here is the formation and evolution of customers' affection towards service providers. Thus we depict the macro-level variation of average affection of customers towards each service provider.

V. Simulation Results

One of our main interests is to find out how affection towards a service provider changes with time due to the process of customer engagement. Thus, we plot affection against time in the graph in figure 7. To generate this graph, we used 10 simulation runs, each of which having only one service provider and different random seeds, and got the average affection at each time step. According to this graph, the affection towards a service provider initially goes through a hype but declines thereafter gradually with time towards a stable point. As shown in Figure 8, this general shape of the curve didn't change when the number of providers were increased to two, except that due to first mover's advantage, one provider out performed the other.

TABLE VI
Important Parameters of the System

Parameter Name	**Description**	**Default Value**
CustomerN	The number of attributes in customer entity's value proposition	10
ProviderN	The number of attributes in the service provider entity's value proposition	10
K-Value	The number of other attributes of the same entity that a given attribute depends on	2
C-Value	The number of other attributes of the opposite entity that a given attribute depends on	2
No. of Customers	The number of customer agents	1000
No. of Providers	The number of service provider agents	2
No. of States	The number of states that the attributes can be at	3
Customers' Adequate Margin	The upper margin of the initial expectations of customers	0.40
Providers' Adequate Margin	The upper margin of the initial expectations of service providers	0.40
Customer Learns	Whether the customer learns and adapts	*true*
Provider Learns	Whether the service provider learns and adapts	*true*
Expectation Growth Rate	The percentage growth of expectation at a successful value co-creation	0.05
Need Probability	The probability to getting a service need by a customer at a given time step	0.25
Alpha	The α value of equation 07	6
Beta	The β value of equation 10	50000
Trust of Conformity	Component P of equation 07	0.25
Innovation Frequency	How frequently does the service providers check their sales performance if *Provider Learns* is set to *true*	10

In fact, this result corresponds with a common observation with new offerings where lots of attention being drawn at the particular offering through reviews, discussions, recommendations, etc generated through delightful experiences of the early users. However, as customer expectations grow with firsthand experiences with the offering, the trust towards the particular offering in the population of its customers gets lowered gradually towards an equilibrium point.

A. Selecting the Right Customers

Next we increase the number of service providers to two; one high-end provider and one low-end provider. 99% of

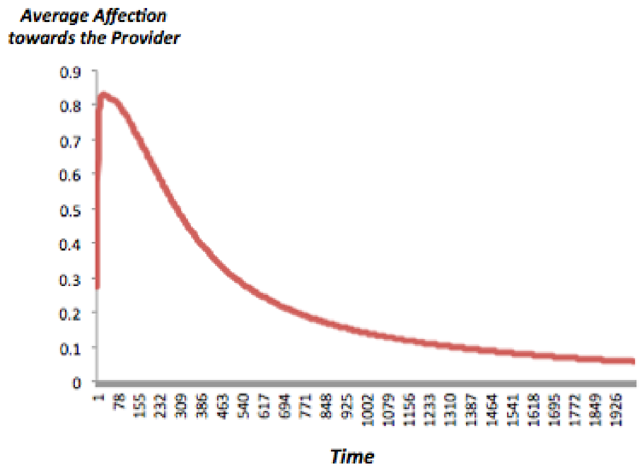

Fig. 7. Change of Average Affection Towards a Provider over Time

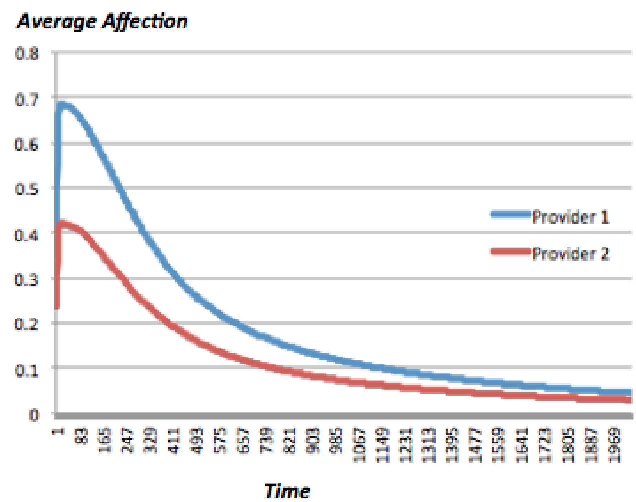

Fig. 8. Change of Average Affection Towards a Provider over Time : With Two Competing Providers

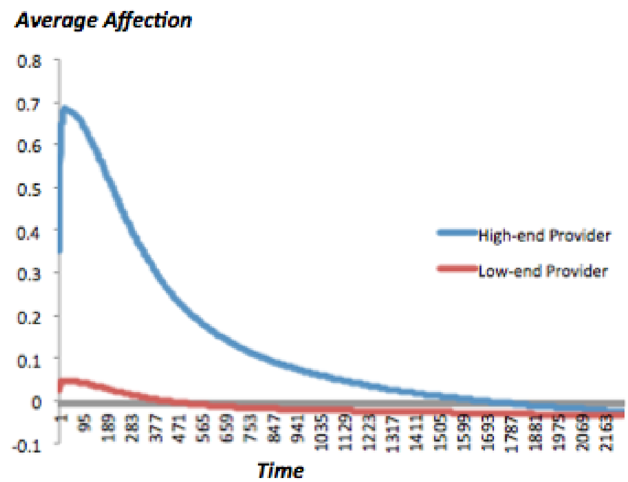

Fig. 9. Change of Average Affection Towards a Provider over Time : A high-end provider and a low-end provider in a market of mainly high-end customers

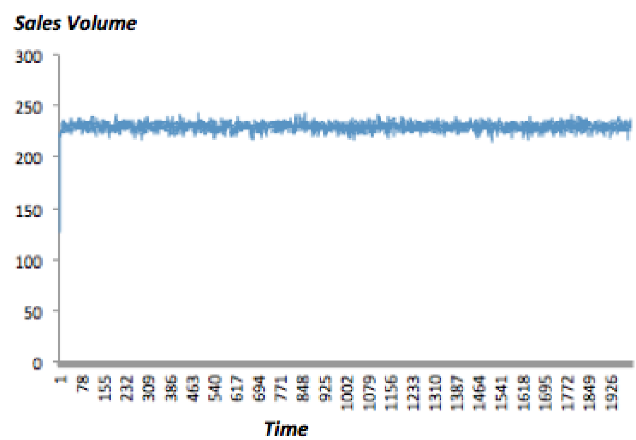

Fig. 10. Change of Sales Volume over Time in spite of Changing Affection - The case of one service provider

the customer population comprises high-end customers. As it could be precisely predicted, the high-end provider outperformed the low-end provider by a huge margin. This is shown by the graph in figure 09.

B. Impact of Affection on Sales Volume

Our next interest is to see if there is any impact on the sales volume due to the change of affection among the customers. Here we consider sales volume at a given time step as the total number of service interactions occurred during that time period. We plot the sales volume of the service provider corresponding to the figure 07 at each time step as shown by the graph in figure 10. Apparently, the change of affection shows no impact on the sales volume as it continues steadily throughout the time period concerned.

One probable reason for this pattern would be that the expectation growth rate is not adequate to make a significant impact on the sales volume despite the declining customers' affection towards the service provider. To get this clarified, we plot the same graph for six different expectation growth rates, i.e. 0.02, 0.05, 0.07, 0.10, 0.12 and 0.15, selected arbitrarily. The corresponding graph is shown in figure 11. Notably, the sales volume drops over time when expectation growth rate increases. This too complies with the general observation that the offerings get outdates soon when the customers' expectations in the given industry grows fast. For example, offerings in the *Information and Communication Industry* get obsolete much faster than those in any other industry due to fast growing customer expectations. On the other hand, this result could support the discussion when and where to delight customers [4] by suggesting that delighting customers in industries with fast growing customer expectations may negatively affect the sustainability of service providers.

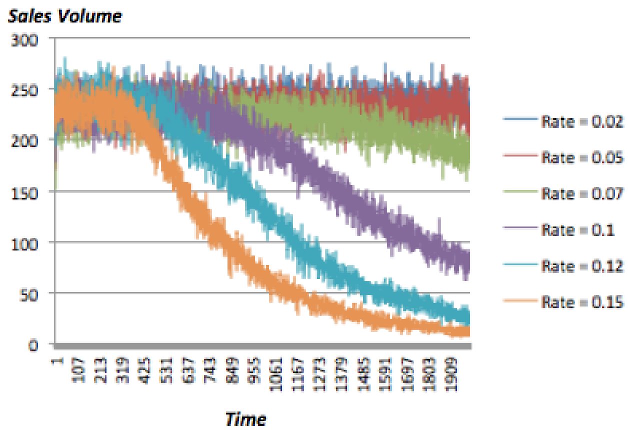

Fig. 11. Change of Sales Volume over Time in spite of Changing Affection - The case of one service provider at different expectation growth rates

VI. Conclusion

The prime objective of this research is to find new insights on the issue of customers leaving service providers despite their attempts to improve the service. In this endeavor, we take a novel approach by initiating an interdisciplinary inquiry that involves *agent-based modeling*, *customer engagement*, and *service-dominant logic*. The increasing attention received by the role of *customer engagement* from the business practitioners and academics in co-creating customer experience and value stimulated us to further inquire the phenomenon in a dynamic and interactive setup to achieve our prime objective. The dynamic and interactive nature of the market environment being concerned demanded the capabilities of *agent-based modeling and simulation*, which has a reputation in successful modeling of *complex adaptive systems*. In doing so, we first created the agent-based model as an artificial market environment of a particular service as a system of service provider and customer agents and this paper contains the logical formulation of the model together with some initial outcomes.

Our next step is to use this model as a tool to achieve our prime objective. There we intend to conduct our analysis in both micro and macro levels to identify some critical properties and sensitive parameters that lead customer agents to switch service providers. Given that the model has been formulated logically with respect to latest research in customer engagement and service-dominant logic, we believe that it would enable us to gain some interesting insights in our future work.

Acknowledgment

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Simulating the Emergence of the Organizing Structures of Work

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***Abstract*—This article is a first step toward a visualization and classification system for studying dynamic organizing structures of work. As a first step toward this research objective, this study brings together two active projects. One called "relatonics" studies work group formation and is primarily empirical and inductive. The other called "Human Interaction Dynamics (HID)" imports concepts, relationships and modeling from complexity science and is therefore primarily theoretical and deductive. The vision is to use social media, data gathering, and process simulation technologies to rigorously describe, systematically visualize, and validly model the complex dynamics of work processes of different types. This work will serve as a means to classify, study and improve the performance of work systems. We describe our progress to data and suggest further research.**

I. Introduction

THIS paper is a starting point of a process aiming at building a tool for simulation of work activities in an organisation. It does so by merging the thinking from two different projects. The first is a series of studies which are developing the concept of "relatonics" and its visualisation. The second is a project that is developing a model of human interaction dynamics (HID) on a base of complex system theory.

After briefly describing the two projects, this paper discusses how one might use the HID-model to analyse empirical data that was collected in one of the relatonics projects. This study is the first bridge between the two projects, and it seeks to link findings from both theoretical and empirical based research in a general theory that classifies the mechanisms of organizing in human complex adaptive systems. The aim of the paper is to formulate a base for a discussion on how to simulate the emergence of the organising structures of work.

II. Relatonics and Visualisation of an Organisation

Relatonics is here defined as the composite existence of relations in a workplace that are of importance in and for the performance of the core operational task [1]. A relatonic is charged with resources of significance for the core task, for example competence, information, and decision power, and thereby carries a capacity for action. A key determinant in differentiating relatonics from social networks in general, is that relatonics emerge in relation to shared work tasks, and comprises the relations that are used to perform the task. Each core task of an organisation has different relatonics. The concept of *relatonics* lifts up the individual level concept *relation* to an organisational level. It is used to focus on the actors of a decisive organisational task and the dynamics of their interactions [2]. A specific relatonic may crisscross between several intra-organisational units, as well as external partner organisations [3]. A challenge for managers is how to understand and lead such dynamic and moving structures.

The relatonics project also examines organisation images to facilitate change [4]. It is based on the assumption that people, co-workers as well as managers and other agents of change, act and make decisions according to their own conceptions [5], [6]. Such conceptions are grounded in one's understanding and are therefore largely dependent on context specific experiences and the images coupled to that understanding.

It is through interactions that the ongoing construction and reconstruction of a relatonic takes place, by means of either confirmation or change. The experiences of interactions that develop in an organization in the course of the performance of core tasks are of key importance to the relatonic in that they possess facilitating opportunities for future interaction of weight for operational tasks. Also, the opposite can apply; experiences of interaction within an organization may hinder future interactions.

Relatonics have process attributes as well as structural qualities. They are created and recreated in interaction, in interplay and action, and through conversation and co-acting. All this can be regarded as a process, since a relatonic is continuously created and recreated on the base of the current relatonic. At the same time, a relatonic can be regarded as a structure, since it is fairly stable, and exists as a multi-reciprocal experience pointing to future possibilities, even when it is not actively utilized. It may be said that the relatonic proceeds in more or less close interactive work processes, via which it both comes into being and is changed. The relatonic exists as a memory and a common experience, even when interaction temporarily comes to an end, and also as a potential for resumption of the interaction. In this way, the relatonic is durable, as a shared experience that intrinsically bears the possibility of future interaction.

Relatonics are path-dependent properties that emerge from of interactions between individuals in a specific context of tasks, available colleagues, constraints etc. Common experiences of interaction, and thereby the perceived

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potential for future interaction, exist as an intangible link between two persons, and as an intangible network within an organization. A mental map grows up along well-worn paths that lead to interaction with others [2]. It is thus possible, at least in theory, to understand how the structure of today's relatonics came to be if one has historical data about interactions and context. Consequently, it is also, in principle, possible to give prognoses for the relatonics of tomorrow for different changes in context. This software of the future would be a tool for practitioners to not only visualise the relatonics of today, but also simulate the relatonics of tomorrow. It would have 'sliders' to change the context, i.e., a new organisational structure, or a new design of the workplace. And it would be possible to see how such changes influence the relatonics.

There are at least two techniques that could be used for such a relatonics simulation tool. One way is to start with individuals and their interactions and use agent-based models (ABM). The goal of ABM is to simulate the collective behaviour of agents. Agents obey simple rules and can learn from experiences. Changes emerge iteratively at various stages. Different, simple rules of agents, their interaction with each other, and the context leads to the emergence of different collective behaviour, in this case relatonics. The other way is to start at the *system* level, with the relatonics. Human interaction dynamics (HID) is an analytical framework developed using information theory and mathematical models [7]. Structures at the collective level, like relatonics, which are called coarse-grained properties in HID, are described as categories. Drawing support from the category theory of mathematics, deductive logic can be used to predict the behaviour of coarse-grained properties

III. Human Interaction Dynamics Model

The HID approach uses a complex systems theoretical framework to study human organizing as an emergent phenomenon. To do this, it looks at three levels: relations, information and action. Each level of the HID-model consists of a duality in each of these areas [7]-[9].

Relations focuses on the socio-emotional influences that constrain and enable the *integration* of individual choice and action into the collective. For example, Hazy and Silberstang describe organizing acts that integrate individual choices into collective action calling these "micro-enactments" [10], [11].

These relational "level 1 models" focus on the nature of *relations* among individuals and things and how these come together to form the understandable and predictable coarse-grain objects, for example recognizable variables such as the position "X", that define a community and its organizational identity [12], [13] and the capabilities of organizations [14]. Integration *with* the uncertainties of individual autonomy form an inevitable duality for agents within a complex adaptive system when recognizing and predicting the outcomes of social objects within organizations.

Information is created when surprising events unfold in an organizational context. In HID "level 2 models" describe how observers (whether inside of outside an organizational boundary) recognize, interpret and use the information being created as events are observed and how this is used by individuals within the system to structure and execute complex action in the context of the changing relationships that were implied by the level 1 models that were described in the prior paragraph [15]. The level 2 models describe the information within the organizing structures and how this information flows to and among individuals through their interactions with others and the environment [16].

Treating the systems of interactions that use and create information as the unit of analysis, level 2 HID models are fundamentally about change, *dXdt*. They explore the detail of both *convergence* and *divergence* within the changing micro-states recognized by individuals as coarse-grained properties during interactions—including the rules that govern these interactions, how they are enacted, and how they change. Convergence along some dimensions *with* divergence along others form another inevitable duality when gathering and processing information in a changing environment [17], [18]. This duality is acknowledged in the context of performance and learning. It is embedded in the action level as the balance between exploitation versus exploration.

Action, the third level, identifies organizations as entities and focuses on how they relate with one another as multi-agents and do so within ecosystems. These "level 3 models" enable individuals to *act* collectively in the context of the organization's objectives [19]. In this context individuals within organizations must *explore* for new information and use both it and other information that has been stored during past events available to *exploit* collective potentials even as these potentials are likewise changing. This is done by sharing and using level 3 models about the organization and how it interacts and exchanges resources within its ecosystem. Level 3 models help the organization as a whole as it both exploits its current resources and capabilities and at the same time explores the environment and innovates to improve its internal capabilities in an effort to sustain the organization in the face of forces of change impacting those potentials, d^2X/dt^2.

In the context of level 3 models, individuals use level 2 models to predict the organization's changing properties and potentials in an effort to enable their own individual *potency* through collective action as they understand it in the context of their own interests as explicated through their level 1 models. To navigate this complexity, individual agents engage various dualities at each of these three levels in ways that empower them to act. At the same time, they learn to do so by thoughtfully and skilfully using the *constraints* that organizing places on others so they can to channel collective activity in ways that further each individual's personal agenda. They do this by leveraging effective coordinated action in service of their needs. Both potency and constraint are perceived in an efficacious balance.

IV. Empirical Data About Relatonics

The empirical material discussed in this paper is based on an on-going research and development project exploring visualisations as a tool for organisational change and development [3]. In the municipality featured in the project, as in many other Swedish municipalities, there is an on-going struggle with increased expenditure and social costs due to high youth unemployment. Youth unemployment can be described as an ill-structured problem with few given means and ends [31]. Also, when working with youth unemployment, there are several stakeholders who need to be involved and who, by law, have different responsibilities. The senior management of the municipality initiated several efforts to change how work was organised by addressing the problem of youth unemployment from a more holistic perspective. Thus, during autumn 2012, they launched an *Employment Project* (EP) to work with this task. A core part of the EP was a small project team – the EP team – working with coordination and job coaching.

The empirical material consists of relatonics analyses of the task of ‘getting young people into work’ in a small Swedish municipality. Methods for data collection are two surveys, a couple of interviews with the senior management, and meetings with key people where network images have been presented. The visualisations of relatonics was created by using the software Netdraw [20], based on a Multi-Dimensional Scaling (MDS) technique. MDS is a family of techniques that is used for information visualization to assign locations to nodes in multi-dimensional space (in the case of the drawing, a 2-dimensional space) such that nodes that are "more similar" are closer together. The algorithm used uses iterative fitting to locate the points in such a way as to put those with smallest path lengths to one another closest in the graph. This approach can often locate points very close together, and make for a graph that is hard to read. In the visualizations, we've also selected the optional "node repulsion" criterion that creates separation between objects that would otherwise be located very close to one another.

The relatonics analyses were done on the basis of a web-based survey covering three main areas, see Table 1: q1 frequency in interaction, q2 topic of interaction, and q3 experienced benefit of the interaction. q1 functions as a name-generating question, while q2 and q3 address certain qualities of the specific relations – the so-called name interpreter questions [21].

Three main steps were taken in our efforts to draw the map of relatonics concerning the task of ‘getting young people into work’: 1) A senior manager – responsible for the newly started employment project in the municipality – identified three other key individuals in the task, two of whom worked within the municipality (one team leader in the employment project and one manager at the social welfare office). The third key individual worked at the local employment office. 2) Interviews were done with all four key individuals to map their network of people for the task. The interviews resulted in a roster consisting of 62 individuals. 3) A web-based questionnaire, using the roster, was distributed to the entire network. Additionally, when answering the questionnaire the respondents had the possibility of adding new people (with whom they interacted in the task).

TABLE I.
QUESTIONS IN THE RELATONICS SURVEY

No.	Questions	Response alternatives
q1	Which persons or functions are you in contact with, one way or the other, in the work task of getting young people into work?	Daily, weekly, monthly, rarely
q2	For what reason have you been in contact with X concerning the work task of getting young people into work?	Routine tasks, problem-related task, goal-oriented planning, strategic planning
q3	How much benefit have you had of person X in the work task of getting young people into work?	Rating between 1 (not at all) and 7 (very much)

The first questionnaire Q1 was distributed in December 2012, resulting in 48 full responses, a response rate of 77%, and was followed some six months later by a second identical questionnaire Q2. For the second questionnaire, the list of names was edited due to the fact that some people had turned out not to be relevant to the network. Also, a few people were added, including people that had changed job descriptions and who now potentially could be part of the network. The second questionnaire Q2 was distributed in June 2013 to a total of 59 respondents, resulting in 41 full responses, a response rate of 70%.

Some respondents were excluded to be able to better compare the results of the two questionnaires. Only organizational units included in both Q1 and Q2 were included in the comparison (5 units with a total of 8 respondents in Q1 and 1 unit with 1 respondent in Q2). For the comparison we thus have 40 respondents in both Q1 and Q2.

V. DIFFERENT KINDS OF ANALYSES OF THE DATA

Two different kinds of analyses of the relatonics data have already been used: Qualitative interpretation and Statistical reductionism. Some results from these analyses are presented below as illustrative examples. Two more kinds of analyses are planned to be used: Categorisations of actors and Agent based models. This paper is discussing these planned analyses.

A. *Qualitative interpretation*

In the qualitative interpretation approach people in the analysed organisation was asked to reflect about visualisations of their relatonics [4]. The argument behind this approach is the assumption that people, including managers and other agents of change, act and make decisions according to their own conceptions. The aim was to explore and exemplify how work-integrated relations may be visualised, and to discuss qualities of three different types of organisation image in terms of their potential contribution to an understanding that is useful for intended change. Mintzberg and van der Heyden [22], were pioneers in drawing alternative organisation images – organigraphs – showing how companies work. They identified four basic types of organigraph based on principles for managerial work: set, chain, hub and web, through which managers are respectively thought to allocate, control, co-ordinate and energise. This work aside, little attention has, in the research literature, been paid to problematizing visual organisation images and representations when it comes to their influence on change and development. This makes it relevant to use information visualization as a means to understand what is going on in an organization in terms of work-integrated relationships where expertise flows between people.

The visualisations of the relatonics as a network have been useful for the participating organisations as a mean for reflection. Participating managers, leaders and co-workers have seen the images as relevant to ongoing work where a new network is emerging for a new shared task. The images have, in some respects, confirmed senior managers' understanding of existing problems in patterns of interaction and collaboration. They have also challenged preconceptions about such patterns, e.g., by making hidden collaboration patterns visible.

One example of this is that the leader of the labour market project team observed how central she was in the relatonic of the task of 'getting young people into work' in the beginning of the project, see Fig 1. Then she sought to involve more people in the job and succeeded to do this, see Fig 2.

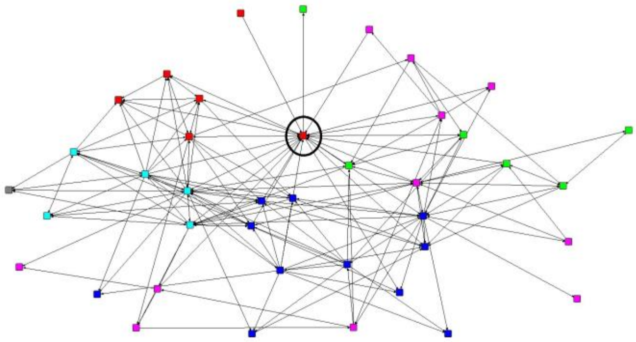

Fig. 1. The relatonic of the work task of 'getting young people into work' in December 2012 (Q1), with the team leader encircled. The small, colored squares represent people/functions (nodes). A node's color represents the organizational unit to which it belongs. The denser the work-integrated interaction, the more central the placement of the node. The lines between the nodes show that the individuals interact with one another at least once a week.

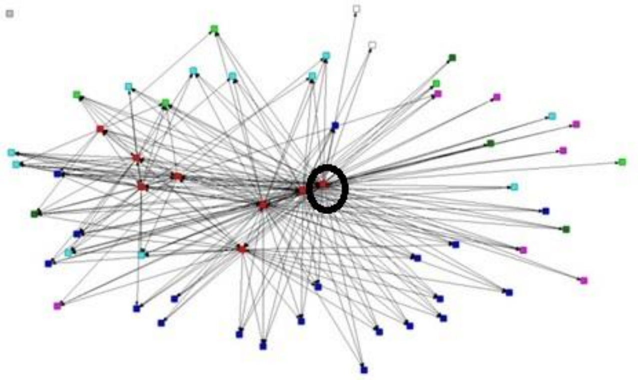

Fig 2. The same kind of picture as figure 1 half a year later, Q2 in June 2013.

Further, concepts from social network analyses such as cliques and bridges has been used to focus the on possibilities and weaknesses in the network structure [23], see Fig 3. Here, the efforts to use social network analysis as a tool for organisational development have been inspired by Cross, Gray, Cunningham, Showers, and Thomas [24].

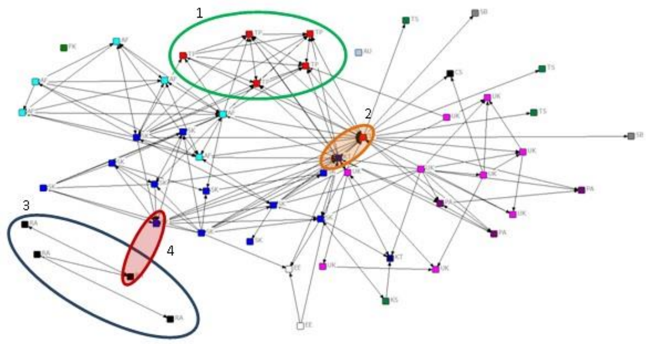

Fig. 3. The relatonic of the work task of 'getting young people into work'. The lines between the nodes show that the individuals interact with one another at least once a week. Encircled are phenomena focused in qualitative interpretations.

B. *Statistical reductionism*

In the statistical reductionism approach calculations on system level are used to summarize qualities of the relatonics. These analyses are on the system as a whole while the lower level structures of the relatonics are not included in the analyses.

Two measures have been used: Density and Centrality of the network. *Density* is the percentage of all realized talk connections among all possible. In a network with high density, many actors have direct contact with the other actors, and the flow is supposed to be high. In networks with low density, most actors have few direct contacts with others, and the flow is low. The *centrality of the network* is a measure of its overall structure. In a network with high centrality, one or few actors are in the center of the network, influencing most of the flow in the network, and the other actors are in the periphery, with little influence of the flow. Such network is of a hierarchical type. In a network with low centrality, most actors have about the same influence of the flow. Therefore, this network is more equal. We use group closeness centralization as the measure. The calculation of it is based on the sum of the differences in individual centrality between the actors of the network. Individual centrality is a measure of how central or important a person is in the network. A person with high centrality, a broker, has direct contact with more of the others than a person with low centrality. Thus, he or she is able to influence the flow to a greater extent. We use Actor Closeness Centrality (ACC) to measure this. ACC is the inverse sum of the distances from the actor to all other actors. The centrality of the network is measured in percent, where 100 % is the highest possible centrality. The software UCINET 6 [25] was used for data management and analyses.

The results from our study for the relatonics of "*Interact at least once a week in the task of 'getting young people into work'*" is showed as an example. For Q1 the density is 17% and the centrality 42% (December 2012). For Q2, half a year later, the density is 21% and the centrality 26%.

C. Categorizations of actors

The categorizations of actors approach is inspired by Backström, Hagström and Göransson [26]. They made classifications of actors are into a spectra of different categories: managers or non-managers respectively high, middle or low integration into to organizational culture. Analysis are made to see if these categories had systematically different positions in the pattern of interaction for different kinds of workgroups.

The HID-model includes six poles, a duality for each of the three levels. A first suggested operationalization of these poles when analysing the empirical data from the relatonics project are:

- *Integration* in the Employment project means that you are part of the relatonics of this work task.
- *Autonomy* from the project means that you are not part of it.
- *Convergent* information is operationalized as when you have strong ties in the network of talk about plans and goals of this task.
- *Divergent* information is that you have weak or no ties of this kind.
- *Exploit* and *Explore* will be decided using the interviews with senior managers about the action of the organization when it comes to this work task.

In the project we have data about the relatonics of the task of getting young people into work both before and after the Employment project. In the analyses we will try to understand mechanisms behind the emergence of relatonics. Some first hypotheses to be tested are:

H1. More people will be integrated into the task after the project.

H2. Since interaction about a subject triggers more interaction about the same subject, the frequency and density of interaction will increase.

H3. People included in the relatonics before the project will be more central in the relatonics after the project than newcomers.

Some first research questions to try to answer:

RQ1. If more people have been integrated into the task, is there a connection to this and the actions, is there for example a more of exploiting the resources?

RQ2. We have different data concerning the quality of the interaction, for example concerning the subject of the interaction and the perceived usefulness of it. Which qualities are most important for the emergence of the relatonics?

D. Agent based models

Agent-based models (ABM) [27] are unfamiliar for most of the authors of this paper. Attending to this conference is a starting point in learning how to use ABM to analyze empirical data about emerging phenomena. Simulation of organizational behaviors of a firm is a traditional approach in social simulation literature, see for example [28]. Our effort is a bit different in that it uses the human interaction dynamics as a base for the simulation. Further, we assume that a few order and control parameters [29] decides the general tendency of individual behavior in an organization [8]. The vision is to be able to simulate the emergence of relatonics in for example NetLogo using the six poles in the HID-model as global model parameters and sliders [30].

VI. Conclusion

One ambition of the municipal senior management included in the relatonic project was to organise the task of getting young people into work through boundary-crossing – not only working across unit boundaries in the municipality itself, but across to units in other organisations, especially the local employment office. However, the existing organisational structure and the image that represents it – the organisational chart – were described by leaders and managers as problematic, because of the influence both on how the work task was understood and on how resources were allocated. An additional problem that was identified by our research team was that the work task was defined and labelled differently within each unit, and was managed as if it were part of only a single unit, thus resulting in sub-optimisation and a lack of coordination. This made collaboration in the task more difficult.

Images of relatonics provide novel and richer pictures of organisation, and, for some of the interviewees, give a strong feeling of recognition and amazement. Network images do afford opportunities to understand the possibilities of intervening, for example, through appointing people to shared tasks, which means that there are possibilities to facilitate the emergence of changed structure. There are empirical indications of the value of relatonics visualisations in modern organisations.

Complexity models of leadership and influence have the potential to classify visualizations of these structures. For example, Hazy [16]-[18], [32] describes the emergence of networks of influence based upon individual influence and leadership [17] and highlights the potential that emergent work structures might support organizational learning in a manner analogous to neural network learning models [33]. The assertion that work structures create network effects has also been explored in simulations related to boundary spanning [34]-[37].

This paper describes an ongoing project that is intended to add the dynamic visualization of work process to the analysis toolkit in support of organizational effectiveness. It is our hope that advances in complexity science bring with them additional analytical approaches and technologies as aids for the human project. We all, it seems, want to believe that "there must be a better way to do things." In the end, we feel, it is this age-old expression of hopeful frustration that drives human progress.

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Effective population and phenotype-genotype decoupling in cultural evolution

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Although the attempt of sociobiology to provide a unified account of human biological and cultural evolution foundered on the sheer plasticity of human behaviour, subsequent attempts to rescue the relevance of evolutionary biology for the study of cultural phenomena have proved fruitful. A—perhaps the—major driver of this success has been the development of dual inheritance models (Boyd and Richerson 1985) that explicitly acknowledge the operation of both genetic and non-genetic inheritance in human sociocultural evolution. The development of such models has come about through, on the one hand, a willingness to apply Darwinian "population thinking" to social and cultural phenomena and, on the other, the recognition that biological genetic evolution is but one specific example of a more general 'algorithm' applicable to several domain beyond biology (Hull, 1982; Dennett, 1995).

Nevertheless, there remains considerable debate about whether cultural change is an evolutionary process operating on the same kinds of functional entities (replicators, interactors and lineages), or whether it is simply an analogous process. A common refrain in the debate about the status of cultural change as an evolutionary process, voiced by biologists and social scientists (Gould, 1987), is that if cultural change is evolutionary then it is Lamarckian rather that Darwinian. None of the protagonists believe that cultural evolution is literally Lamarckian in the sense that acquired cultural characteristics might somehow become encoded in genetic material. Rather, the question arises out of uncertainty surrounding what is genotypic and what is phenotypic in purely cultural evolution (e.g. Lake 1998). Indeed, in the case of the evolution of material culture, objects are often conceived as phenotypic expressions of genotypic ideas, but there may well be circumstances in which they actually function as cultural genotypes or even conflate both functions (Lake 1998).

Although the genotype-phenotype distinction in material culture is philosophically interesting, the question we address in this paper is essentially pragmatic: does the uncertainty surrounding the physical permanence of material culture actually matter for the application of models derived from evolutionary biology? We seek to explore potential implications of this phenomena for the application of one particular model that has been widely adopted for the study of cultural evolution:the neutral allele theory (Kimura, 1983). Originally developed in population genetics, its flexible and broad mathematical basis can serve as a null model for a variety of applications, including circumstances where the frequency of cultural variants change as a function of innovation rate and unbiased copying processes. The latter implies that variants are replicated without any particular selective pressure, and random events associated with sampling errors can lead to the spread or loss of knowledge.

Archaeological applications of this null hypothesis produced a variety of results. Some exhibit empirical patterns predicted by the neutral model (e.g. Bentley et al. 2004), while others suggest the effect of systematic social choices or biases (e.g. Shennan and Wilkinson 2001). Premo (2014) has however demonstrated that techniques developed to identify neutrality are not necessarily capable of identifying unbiased cultural transmission in samples collected from time-averaged archaeological assemblages.

In this paper we argue that there is potentially another problem with using the standard biological neutral model to detect the emergence of systematic preferences in the evolution of material culture, i.e the possibility that the effective population of cultural models is the number of artefacts in circulation rather than the number of people producing them. In addition, considering the differential durability of material culture, it is also possible that this number includes artefacts created by previous generations of producers. The first issue was noted by Shennan and Wilkinson (2001). As we are aware there have been explorations of the concept of memory in language evolution (Bentley et al. 2011), but there are no formal studies concerning the consequences of the persistence of material culture on the application of the neutral model.

In order to investigate this problem we develop a simulation model where standard unbiased cultural transmission has been modified to incorporate a ‘production’ and a ‘persistence’ bias. Rather than formalising knowledge transfer as an individual-to-individual process, we build a model where individuals update their ‘genotype’ by copying from objects produced by other agents. This slight change in the model introduces two new mechanisms: the expression of the phenotype might be affected by stochastic events (‘production bias’), and objects might persist in the physical world for a given amount of time, potentially outliving their creator/genotype (‘persistence bias’). We generate a series of artificial archaeological records to examine whether these two biases modify the result of tests commonly used to detect neutrality in cultural datasets (Slatkin’s Exact test and Ewens-Watterson homozygosity test). Preliminary results suggest that this is the case, with the frequency of cultural variants showing significantly greater diversity than expected according to the standard neutral model. Our result thus indicates that in the presence of production and persistence bias there is a higher chance of incorrectly rejecting the null hypothesis of random copying/neutral cultural transmission.

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Modeling Human Stability and Change in Organizations

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***Abstract*—This extended abstract describes current work in progress on so-called micro-foundations of organizational routines. These are individual-level human processes assumed responsible for the emergence of routines. Recent agent-based models in organization science focus on psychological mechanisms operationalizing the stability of human behavior. As similar concepts exist in creativity research, the aim of this project is to facilitate a dialogue between organization scientists and creativity researchers in order gain insight on these processes. The latter will subsequently be implemented in agent-based models of generic as well as applied routines to test and compare models of these micro-foundations.**

I. Introduction

Considered "the building blocks of organizations" [2, p. 3], organizational routines are elementary processes by which employees accomplish their work. Routines can be described as encompassing two parts, their representation and their enactment [26]. A routine's representation refers to its "abstract or generalized pattern" [29, p. 796], sometimes called its *ostensive* part [29]. It can be envisioned as people's accounts of how something is or should be done. Such accounts can be conceived as internalized representations, as in individuals' mental models [37], and they can be indicated by externalized collective representations such as written standards [9]. A routine's enactment refers to "actual performances by specific people at specific times in specific places" [30, p. 286], sometimes called its *performative* part [29]. The interplay between the representation and enactment of a routine is constitutive and generative to a certain extent depending on the context. For example, a hospital may have a rule stating staff meetings are to be held at every change of shifts. Given the rule is indisputable, this collective representation of the routine "staff meeting" will not change based on its enactments even if some unofficial variations in start and end times occur. On the other hand, a small start-up may, as an initial act of professionalism, decide to hold staff meetings every Monday morning at 9 o'clock sharp. After a while, the staff realizes it needs to hold meetings more often and spontaneously whenever it needs them. So by enacting their representation of a staff meeting, over time they change its representation in terms of frequency and purpose.

Although researchers agree that routines represent an organization's basic behavioral unit, understanding their explicit role in forming organizational behavior is still a matter of scientific debate [7]. Recently, *micro-foundations* are in tight focus [6], [21], [33], i.e., human mechanisms thought to influence the stability and change of routines. The underlying idea is that if one wants to manage or modify organizational routines, e.g., to enhance an organization's resilience, one needs to start by understanding and changing the behavior of the humans carrying them out. However, routines are difficult to empirically investigate, as their operationalization and measurement have many degrees of freedom [28], [30]. Moreover, reaching empirical consistency is an obstacle, because the "same" routine can vary starkly depending on the organization, observer-dependence, and gaps in what employees do and report they do [16]. Furthermore, there is disagreement regarding which constructs or mechanisms significantly describe and drive the micro-foundations of routines, e.g., human memory (procedural, declarative, transactive; [24]), cognitive frameworks [3], individual habits [26].

Recently, organization scientists have started to use agent-based modeling to conceive more formal models of routines [4], [12], [19], [24], [25], [31]. As agent-based models can be used to show how simple rules of micro-level interaction can lead to macro-level phenomena [13], the method corresponds well to the interplay between a routine's representations and enactments. Nevertheless, many agent-based models to date focus on teams or managers as the lowest system level. They thereby disregard the essential role the actual actors of routines play in generating these emerging processes [19], [20].

Stability and change of individual behavior is a concept inherent in creativity research in psychology [10], [17], [27], [32], [35], [39]. Creativity researchers have established diverse models describing how humans differ in the stability of their behavior and how variability in behavior can be modeled [5], [8], [18], [23], [34], [36]. They address personality, cognitive, behavioral and social aspects of human creativity, i.e., behavioral stability and change. Moreover, work designing agent-based models of human creativity in a social context has been successfully completed [15], [16]. Models of individual creativity are not present whatsoever in current models of micro-foundations of organizational routines, although the latter implies the construction of individual and social mechanisms for behavioral stability and change within a larger social context. Although both sciences – that of organizational routines and that of creativity research – attempt to model human behavior as something varying in stability, they do so from very different perspectives. Furthermore, modeling human behavior is not just about which model to choose, but how to connect several interdependent models to one complex view of human behavior. By transferring concepts from creativity research to organization science, a current gap in work on organizational routines will be addressed in this project. Agent-based modeling will function as a methodological bridge between both disciplines, allowing for an original approach to understanding the micro-foundations of organizational routines.

II. Research Goals and Questions

Table I summarizes the research goals and questions in this project.

III. Method

The three research goals stated in Table I will be operationalized as three separate subprojects. The questions corresponding to each research goal will be addressed by the methods described per subproject in the following.

A. *Subproject 1*

Exploring individual and social mechanisms creativity researchers and organizational scientists assume to be responsible for behavioral stability and change will be achieved with the Delphi method [11]. This is technique used to structure group communication on developing solutions to complex problems. The group usually consists of experts from different domains, each able to contribute specific knowledge to solving the problem. In its original form, it is carried out as disparate rounds of questionnaires. A facilitator analyzes the questionnaires before each new round starts to give experts feedback on others' solutions and group tendencies to solving the problem. In each new round, experts can change their answers. Participants remain fully anonymous, and their expertise is seen as potential to optimize solutions. The Delphi method will be implemented to professionally consult selected creativity researchers and organization scientists on the following issues: mechanisms (micro-foundations) of human stability and change (e.g., habits, cognitive frameworks, memory, social influence), ideas on what may currently be lacking to define such mechanisms, how different mechanisms can be connected, how individual creativity can be linked to organizational routines. The goal of this subproject is to conceive a framework to describe how both disciplines construct behavioral stability and change particularly with respect to the formation of routines.

B. *Subproject 2*

The results from Subproject 1 serve as precursory quality assurance for this subproject. Only mechanisms considered having the greatest impact on behavioral stability and change, according to the experts in Subproject 1, will be chosen for modeling. The method of agent-based modeling will be used to design and test agent prototypes in a generic model of organizational routines. The agent prototypes will be constructed in NetLogo [38], a modeling environment

Table I.
Research goals and questions

No.	Goals / Questions
1	**Explore** individual and social mechanisms for behavioral stability and change
1.1	Which constructs do creativity researchers & organization scientists use to describe/explain behavioral stability and change on individual and social levels? In which *targets*, i.e., real-world task scenarios, are the constructs applied?
1.2	What similarities & differences exist between the constructs used by these scientists? Can a mutual framework be derived to describe how behavioral stability and change is constructed in both disciplines?
2	**Model** individual and social mechanisms for behavioral stability and change
2.1	Which constructs determined in Goal 1 are most suitable for modeling individual and social mechanisms particularly in organizational routines?
2.2	What would these constructs look like operationalized as programmed prototypes (agents)?
2.3	How would these agents' behavior/performance compare on a generic routine (task)?
3	**Apply** individual and social mechanisms for behavioral stability and change
3.1	Which targets are suitable for testing the agents' behavior within a more complex organizational environment?
3.2	How do the agents' behavior/performance compare on these tasks?
3.3	How can the validity and feasibility of using these agents for modeling organizational routines be evaluated? What value do they contribute to modeling routines?

suitable for this subproject's goals and for demonstration to non-modeling audiences. The generic model of organizational routines will be designed after recent computer models [24], [25], [31]. In these models, an organizational routine is operationalized as repeating sequences of *n* disparate actions (enactments) and an *n*n* matrix saving the conditional probabilities between all possible actions (representation). Specifically, previous enactments affect upcoming ones in terms of "action pairs" ", i.e., the next action to be taken in a sequence depends on the conditional probabilities between the current action and all other possible actions. To agents on the micro-level, the routine is a first-order Markov process. These models, however, only use one type of agent. The performance of the agent prototypes in this setting will be characterized by output measures describing qualities such as the recognizability, repetition, formation, adaptation and stability (change) of their collective behavior [16]. Currently, these qualities are commonly used to describe routines [1], but they are not linked to specific or standardized measures. An auxiliary goal of this subproject is to define specific ways to measure these attributes. This will allow a concrete and quantitative comparison of their behavior, therewith facilitating the assessment of how similar the proposed mechanisms for behavioral stability and change are.

C. Subproject 3

In this subproject, companies our research team already collaborates with will be asked to "donate" example routines to retest the agent prototypes in more realistic and applied scenarios. The same agents and output measures will be used as in Subproject 2. The overall goal at the end of this subproject is to evaluate the insight gained with all three subprojects and to compose a comprehensive framework on which micro-foundations (individual and social mechanisms for behavioral stability and change) are constitutive for describing, explaining and implementing organizational change in terms of routines.

IV. Conclusion

This project started in April, 2014, and its current focus is Subproject 1. The sampling procedure as well as the interview questions are momentarily being developed for the Delphi technique. Moreover, initial preparations are being made for Subprojects 2 & 3. A preliminary prototype agent-based model is being built, and informal discussions about exemplary routines from practice are being conducted with collaboration partners.

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Bounded Confidence, Radical Groups, and Charismatic Leaders

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***Abstract*—By few simple extensions it is possible to model radical groups, charismatic leaders and processes of radicalization in the bounded confidence framework. In the resulting model we get a lot of surprising (non-)monotonicities. In certain regions of the parameter space more radicals or more 'charismaticity' may lead to less radicalisation.**

I. Introduction

There are some stylized facts about charismatic leaders, radical groups and processes of radicalisation. Among them we presumably find the following three: *First*, a radical group has compared to 'normal' agents a comparatively stable in-group consensus on an extreme opinion. *Second*, a charismatic leader counts for 'normal' agents that are under his/her influence much more than other 'normal' agents. *Third*, in a process of radicalisation people tend to get less and less open-minded. The three facts inspire an applied and modified version of the well known bounded confidence model as introduced by Hegselmann and Krause in [1]. The modified version is still an extremely simple conceptual model. Under some assumptions the whole parameter space can be analysed. The model shows some surprising results and mechanism that inspire new possible explanations, new perspectives for empirical studies, and new ideas for prevention policies.

II. Basics of the Bounded Confidence Model (BC-model)

The basic assumptions of the BC-model are:

- There is a set of n individuals; $i, j \in I$.
- Time is discrete; $t = 0, 1, 2, \ldots$.
- Each individual starts with a certain opinion, given by a real number; $x_i(t_0) \in [0, 1]$.
- The profile of all opinions at time t is $X(t) = x_1(t), \ldots, x_i(t), x_j(t), \ldots, x_n(t)$.
- Each individual i takes into account only 'reasonable' others. Reasonable are those individuals j whose opinions are not too far away, i.e. for which $|x_i(t) - x_j(t)| \leq \epsilon$, where ϵ is the *confidence level* that determines the size of the *confidence interval*.
- The set of all others that i takes into account at time t is:

$$I\big(i, X(t)\big) = \{j \,|\, |x_i(t) - x_j(t)| \leq \epsilon\} \tag{1}$$

- The individuals update their opinions. The next period's opinion of individual i is the average opinion of all those which i takes seriously:

$$x_i(t+1) = \frac{1}{\#\big(I\big(i, Xt)\big)\big)} \sum_{j \in I\left(i, X(t)\right)} x_j(t) \tag{2}$$

III. Modifications of the BC-model

For the modified BC-model we now assume that there are *two* groups of agents: The first group, the *normals*, have opinions from the interval $[0, 1]$, they all have a positive $\epsilon^{normals} > 0$, and they update according to equation (2). The second group, the *radicals*, have all the opinion R, with R again from the unit interval, but more or less close to the upper bound, e.g. $R = 0.9$. The radicals' confidence level $\epsilon^{radicals}$ is constantly and homogeneously 0. Consequently, they update according to

$$x_i^{radicals}(t+1) = x_i^{radicals}(t) = R \tag{3}$$

Figure 1 shows single runs with the same uniform start distribution for 50 normal agents with an $\epsilon^{normals} = 0.2$. In the left figure there are no radicals. Light grey vertical lines between *neighboring* opinions indicate that their distance is not greater than $\epsilon^{normals}$. In the figure in the centre a group of 5 radicals is added. Their opinion is $R = 0.9$. The black horizontal line is their trajectory. Dark grey vertical lines indicate the chain of direct or indirect (i.e. via a chain of others) influence of radicals on normals. In period 4 that chain breaks. The dark grey area indicates that part of the opinion space in which all normals, given the size of their confidence interval, are under the direct influence of the radicals. (The right figure will be explained below.)

Charismatic leaders can be covered by *reinterpretation*: We consider a radical group with m members as *one* person that counts m-times for all normal agents that have the charismatic leader within their confidence interval. Thereby, the radicals' group size m turns into a kind of *degree of charismaticity*. Assuming that R is the same in all cases, the conceptual model covers it all: a radical group, a charismatic leader, or any combination of both.

To include that in a process of radicalisation normals get *less and less open-minded*, requires a simple, but substantial modification of the original BC-model: We apply the BC

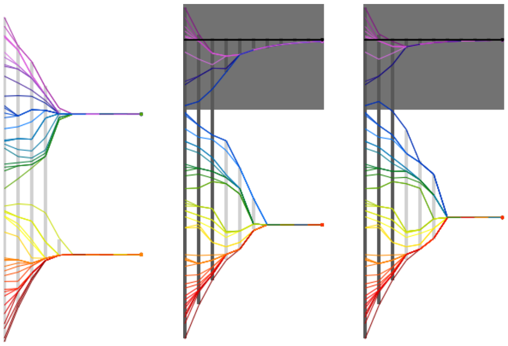

Fig. 1. 50 normals, the same start distribution of normals in all pictures, $\epsilon = 0.2, R = 0.9$. *Left*: no radicals. *Centre*: 5 radicals, no confidence dynamics. *Right*: 5 radicals, with confidence dynamics.

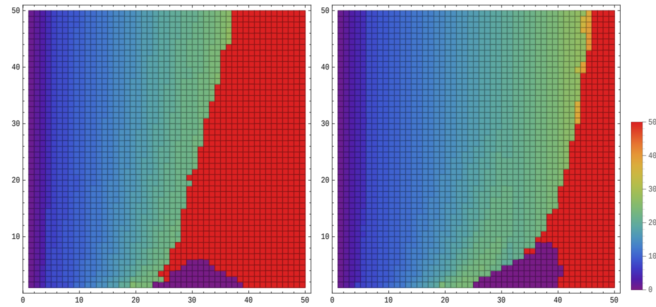

Fig. 2. x-axis: the confidence level increases in 50 steps of size 0.01 from 0.01 to 0.5. y-axis: the number of radicals increases from 1 to 50. Colours indicate the number of normals that end up at the radical position which is here assumed to be $R = 0.9$. The total number of normals is always 50. *Left*: without a confidence dynamics. *Right*: with a confidence dynamics.

mechanism, i.e. averaging over elements within one's confidence interval, on *both*, opinions *and* the confidence levels. That modification has no effect, if ϵ is the same for all agents. However, in our context radicals have an $\epsilon^{radicals} = 0$, while normals start with an $\epsilon^{normals} > 0$. As a consequence, the confidence level of normals will shrink if they are directly or indirectly influenced by radicals. Figure 1 right shows such a dynamics for the same start distribution as in figure 1 centre. Note that under this *confidence dynamics* (as we will call it in the following) one normal less ends up at the radical position.

A bit more formally: A confidence dynamics makes the confidence level $\epsilon^{normals}$ an individualised and time dependent $\epsilon_i^{normals}(t)$ and the set of agents j that i takes seriously changes from (1) to

$$I\big(i, X(t), \epsilon_i(t)\big) = \{j \big| |x_i(t) - x_j(t)| \leq \epsilon_i(t)\}. \qquad (4)$$

Under a confidence dynamics normals, then, update according to *two* equations:

$$x_i^{normals}(t+1) = \frac{1}{\#\Big(I\big(i, X(t), \epsilon_i(t)\big)\Big)} \sum_{j \in I\big(i, X(t), \epsilon_i(t)\big)} x_j(t), \qquad (5)$$

and, additionally, with regard to the confidence level by

$$\epsilon_i^{normals}(t+1) = \frac{1}{\#\Big(I\big(i, X(t), \epsilon_i(t)\big)\Big)} \sum_{j \in I\big(i, X(t), \epsilon_i(t)\big)} \epsilon_j(t). \qquad (6)$$

The radicals stick to their confidence level 0 and 'update' accordingly:

$$\epsilon_i^{radicals}(t+1) = \epsilon_i^{radicals}(t) = 0. \qquad (7)$$

(2) together with (3) defines a system *without* a confidence dynamics. (3) together with (5) to (7) is the corresponding systems *with* a confidence dynamics of normals.[1]

[1]Note that in the model the radicals or a charismatic leader, respectively, are simply *given*. Baurmann, Betz and Cramm present in [2] a model in which charismatic opinion leaders can *evolve*.

IV. First Results

There are many interesting questions about final results, e.g. the number or frequency of normals that finally end up at the radical position R, the mean and median of the normals' opinions, or – as one of several possible distance measures – something like a root mean square deviation of the normals' opinions with regard to R. It is very natural to think that final results crucially depend upon the number of radicals (or the degree of charismaticity, respectively) compared to the number of normals, the confidence level at $t = 0$, and the radical Position R. All the questions mentioned above, can be answered by systematic simulations that cover the whole parameter space—admittedly, under some simplifying assumptions.

A first step in this direction is documented in *figure* 2. The figures show, indicated by color, the number of normals that finally end up at the radical position R, which in this example is assumed to be $R = 0.9$. To the left are the results without, to the right the results with a confidence dynamics. The x-axis gives the value of the normals' confidence level at $t = 0$. It is the same for all normals. In 50 steps of size 0.01 the confidence level $\epsilon^{normals}$ increases from 0.01 to 0.5. The y-axis gives the number of radicals (or the degree of charismaticity, respectively). In 50 steps that number increases from 1 to 50. As to the normals we always assume 50 agents with opinions all over the opinion space. For each step combination x, y we run simulations until the dynamics is (almost) stable. Then we count the number of normals that (almost) ended up at the radical position R. *Figure* 2 shows, indicated by colors, the number of normals that finally end up at the radical position.

There are at least *three lessons* that we can take away from *figure* 2:

1) With or without a confidence dynamics, for a certain range of confidence levels an *increasing* number of radicals leads to *less* radicalisation in the sense that less normals end up at the radical position R. Thus, for a certain range of confidence levels radicalisation is mildly though clearly *monotonically decreasing* with respect to the number of radicals.

2) In another range of confidence levels, again with or without a confidence dynamics, it holds: With only a few radicals *no* normal ends up with the radical position R. Above a certain number of radicals suddenly *all* normals end up with the radical position. But if we further increase the number of radicals, then, suddenly, we get again *less* radicalisation. Thus, in that range of confidence levels radicalisation is *not monotonic* with respect to the number of radicals.
3) For any number of radicals, *with* a confidence dynamics the sudden transition to a state in which all normals end up radical occurs, compared with the dynamics without a confidence dynamics, only for much bigger confidence levels. In general: The confidence dynamics lets the confidence level of at least some normals shrink. But that leads to *comparatively less* radicalisation.

Obviously, in our model works a complicated and sometimes counteracting interplay of increasing number of radicals and/or an increasing size of the confidence level. As a consequence we get some *counterintuitive (non-)monotonicities*. All the effects can be explained by an analysis of single runs.

V. Next Steps

The simulations documented in *figure* 2 show, indicated by color, the number of normals that finally end up at the radical opinion, which was assumed to be $R = 0.9$. To get a complete overview we will run simulations for $R = 1.0, 0.99, \ldots, 0.5$. That will be done for both, without and with a confidence dynamics. The results will be visualised by two animations of 51 pictures of the type used in *figure* 2. There is much more that can be analysed and visualised in the same style: for instance, the mean or the median of the normals' opinions, the final cluster structure and their distances to the radical position.

However, there are two major *caveats* with regard to the preliminary results: *First*, it has to be checked, whether or not the results crucially depend upon the ratio *or* the absolute numbers of normals and radicals. And, *second*, a kind of confession: The results in *figure* 2 are *not* based on repeated runs with random start distributions for each x, y-combination. They are based on just *one* run for each combination. In *all* runs the same very special, but in a certain sense 'typical' start distribution of n normals is used: An opinion profile is an *ordered* profile iff for all $i \leq (n-1)$ it holds that $x_i(0) \leq x_{i+1}(0)$. In all runs of *figure* 2 we use an ordered start profile in which the i^{th} normal opinion is $i/(n+1)$. In such an ordered and equidistant start profile the i^{th} opinion is exactly there where it will be at the average over infinitely repeated uniform *random* distributions. On the one side, that distribution is therefore very 'typical'. On the other side, the regular structure of the profile may make us blind for important effects that are caused by the typical density fluctuations of single random distributions. Whether or not the use of our start distribution is a problem or a solution of many problems has still to be checked.

Acknowledgment

The model was developed 2013 during my time as a senior fellow at the Alfried Krupp Wissenschaftskolleg in Greifswald. The model is the direct result of intensive discussions with Gregor Betz, Michael Baurmann and Rainer Cramm, which at that time were working there on their own model of radicalization processes (cf. [2]). I profited a lot from our discussions and the stimulating intellectual atmosphere in the Alfried Krupp Wissenschaftskolleg in Greifswald. In 2014 I'm visiting international fellow of the department of sociology at Surrey University. Corinna Elsenbroich, Jen Badham, and Peter Johnson (all of them members of CRESS, the Centre for Research in Social Simulation, based in the sociology department) helped me a lot to analyze the model, to fix bugs, and to develop ideas for future modifications of the model. Many thanks to all of them.

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Network models of minority opinion spreading

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Abstract—**Despite there are different models in literature that analyze the dynamic of opinion formation, less attention has been paid to explain how the structure of social networks and their contextual circumstances can influence the course of minority public opinions. This work is aimed to ask three basic questions: (1) how can affect the structure of social networks to minority opinion spreading, (2) how committed agents can influence in this process, and (3) how mass media action, as a contextual factor, can vary different agents' opinions and network composition. Agent-based modeling is used to perform a network model of preferential attachment that is used to explore how phenomena of minority opinion spreading can evolve under different simulated scenarios. This study shows that the success of minority opinions depends on the network structure and composition, and thus external factors such as mass media action that can mediate the strength of these internal determinants. In spite of people tend to remain silent when they feel that their opinions are in the minority pole, our findings suggest that prevailing majority opinion may be promptly replaced by formerly minority opinion if core agents in the network structure and/or external sources support this view.**

I. Introduction

THE shaping of public opinion through process of social interaction has been subject of significant interest in social sciences. At present, this topic has gained especial relevance due to the proliferation of online social media such as Twitter, Facebook or Youtube, and rising social movements related with the use of these platforms (e.g. Arab revolts, May 15th, Occupy Wall Street, etc.). Despite there are different models in literature that analyze the dynamic of opinion formation [1]-[11], less attention has been paid to explain how the structure of social networks and their contextual circumstances might affect the course of public opinions.

Previous studies demonstrate that physical factors such as network connectivity represents a crucial determinant of social contagion [12]. In terms of complex contagions, the diffusion of opinions needs two basic prerequisites: (1) a single contact between nodes; and (2) certain predisposition to acquire new information, either to (consciously or unconsciously) fill a gap of knowledge or reinforce previous beliefs. While the diffusion of information across social network, understood as a "simple communication process", only requires connectivity between nodes, the processes of opinion spreading requires multiple reinforcing ties to survive [12]. In real life, the success of a specific opinion depends on the connectivity between nodes and, obviously, on the social legitimacy of groups and their ideas in different normative contexts. In other words, the processes of opinion spreading are related to the consensus between social groups [13]-[15]. What opinions were socially allowed, what were prohibited or critiqued, what were successful or which failed in their attempt to spread depends on networks structure and a community consensus between majority and minority groups, where the latter are generally silenced [16].

In the field of political science and mass communication studies, the spiral of silence theory – propounded by Elisabeth Noelle-Neumann (1974) – tries to explain why minority opinions remain silent when society threatens individuals with fear of isolation [17]. Spiral of silence theory explains the opinion dynamics in terms of the assumption of dual climate of opinion: (1) individuals' interactions with mass media (i.e. indirect observation of reality through the eye of the media); and (2) reference social groups (i.e. direct or firsthand observation of reality). In this theory individuals are assumed to be active agents that are able to monitor the dual climate of opinion (mass media and public opinion), and intuitively compute the prevalence of opinions, to avoid being punished by the society for holding the minority opinion (and possibly controversial) [17]-[18]. Spiral of silence theory points out that individuals will fall silent if they consider their opinions are different from the dominating ideas of the mass media.

Thus the reinforcement of this dynamic leads to the progressive emergence of the spiral of silence phenomenon. Since this point of view, agents' individual reluctance to express their opinion, simply based on intuitive perceptions of what everyone else thinks, has important implications to explain the emergence of complex social dynamics at the macro level. Nevertheless, there are many debates and criticisms surrounding this theory. Different studies have

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found inconsistent results and methodological problems to articulate the aggregate-level (i.e. contextual variables) and individual-level (i.e. individual predictors related with agents' social behavior) [19]-[21].

Taking into account these previous findings from social sciences and computational physics, this work is aimed to study the process of minority opinion spreading under different possible scenarios, and giving response to three basic questions: (1) how can affect the structure of social networks to minority opinion spreading ('network physical structure' effect), (2) how committed agents can influence in this process ('opinion loyalty' effect), and (3) how mass media action, as a contextual factor, might vary agents' opinions and network composition ('media opinion' effect).

II. METHOD

Agent-based modeling (ABM) is used to perform a network model of preferential attachment that is used to explore how phenomena of minority opinion spreading can evolve under different simulated scenarios. The algorithm used in this simulation generates networks that are constructed through the process of "preferential attachment" in which agents, step by step, prefer to join to other agents who have many neighbors. This procedure leads to the emergence of clusters highly connected, while most agents in the network have very few connections.

This model simulates a scenario with two opinions (A-B) and four possible models of minority opinion spreading:

A. Random model

In this model, agents choose randomly one of their neighbors and adopt the respective neighbor's opinion. This is a model of "easy consensus", because agents have no previous knowledge and no preference. For example, this model could be possible in the case of conformity between communities that might choose between different unknown alternatives, and when the selection of alternatives have no important consequences.

B. Learning-based model

Agents listen their neighbors' opinions, adding arguments for the selection (i.e. weighting listened opinion), and update their probability of using one opinion (A) or the contrary (B). Agents' opinions might change over time: if (1) their neighbors have arguments to change their opinion and (2) they are not supposed to be committed with previous opinion.

C. Threshold model

Agents adopt one opinion if a certain percentage of their neighbors are already using this opinion. In this scenario, agents' opinion change depending on the proportion of neighbors that support the minority/majority opinion. That is, individual will modify his initial opinion (A) only if there are a fraction of neighbors holding other opinion (B). In this case, the process of opinion spreading is mainly affected by others' opinions. In this model, agents retain the new opinion one they have changed (i.e. cannot go back to the previous opinion).

D. Media effects model

Finally, agents adopt one opinion if a certain percentage of their neighbors and (observed) mass media are already using this opinion. In this model, agents' opinion change depending on the proportion of neighbors that support the minority/majority opinion, but also on the proportion of mass media sources in their context with opinion A or B. Therefore, individuals will change their initial opinions only if there are a fraction of neighbors and (listened) media sources holding other opinion.

In addition, other parameters such as average node degree and agents' commitment (i.e. loyal agents towards minority/majority opinion that do not change their initial state) (Fig. 1) have been introduced in the model to introduce more complexity and practicality in the initial conditions. Committed agents maintain their minority opinion when they listen majority opinion.

III. RESULTS

This study shows that the success of minority opinions does not only depends on the network structure and composition, but especially on external factors such as mass media information or agents' commitment that can mediate the strength of these structural determinants. In spite of people tend to remain silent when they feel that their opinions are in the minority pole, our findings suggest that prevailing majority opinion (A) may be replaced by formerly minority opinion (B) depending on different conditions.

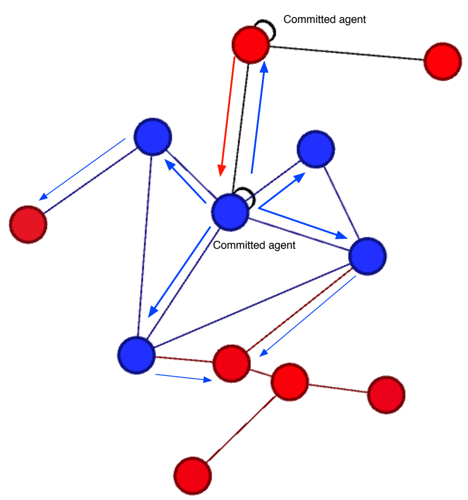

Fig. 1 Influence in committed agents

Table 1 shows that minority opinions (B, 10%) are more probable to win the majority (A, 90%) IF: (1) a certain proportion of loyal or committed agents in the network structure support the minority opinion (10% committed); (2) there exist a high degree of connectivity between neighbors (i.e. nodes lives in a small-world); and/ or (3) when external sources (i.e. mass media information) give a higher external support to minority group.

Committed have been found critical in the model of *individual random contagion*. Despite is highly probable that minority opinion (10% agents with opinion B) loses the game, this probability might be reversed if a minimum proportion of agents are loyal to opinion B. In addition, a higher connectivity between nodes increases exponentially the speed of opinion contagion in both situations (i.e. minority opinion wins or loses).

The *learning-based model* reduces highly the probability of success for minority opinion since this model is based on a summative criterion of listened opinions. In other words, we could say that majority group has a higher advantage to express and also be listened in the simulated world.

The minority opinion contagion based on the *threshold model* generally wins when the average-node-degree is high. In this model, agents embrace one opinion if a certain proportion of their neighbors are already using this opinion, so when the agents live in a small-world is highly probable they find other neighbors holding minority opinions. In this scenario, minority opinion can easily become the majority. On the other hand, the inclusion of committed agents seems to reinforce this tendency. That is, the opinion loyalty slightly increases the possibilities to locate additional B opinions that are susceptible to change A opinions.

Figure 2 shows twelve possible initializations in the threshold and media effect models: (a) average-node-degree 1 without committed agents; (b) average-node-degree 5 without committed agents; (c) average-node-degree 10 without committed agents; (d) average-node-degree 1 with 10% committed agents for B; (e) average-node-degree 5 with 10% committed agents for B; and (f) average-node-degree 10 with 10% committed agents for B. Despite the presence of a minimum proportion (10% of agent holding minority opinion B) of committed agents does not produce important variations in the initial results, this effect might increase if the connectivity between nodes increases in the model.

Finally, the inclusion of media effect increases the general complexity of the initial model. In this case, agents listen both at neighbors and external media information (in case they are near to these sources) that randomly appear in the lattice. Media sources are defined in the model as motionless cellular automata that are situated in a second layer (i.e. as an environmental characteristic in the simulation). Media sources are more or less visible for the agents in the simulation depending on the agents' interest in listening to new information. The initial model with media effects included in the world 100 media sources and agents with visibility equal 2 (VSBT = 2 patches). That is, agents are supposed to observe only adjacent media sources.

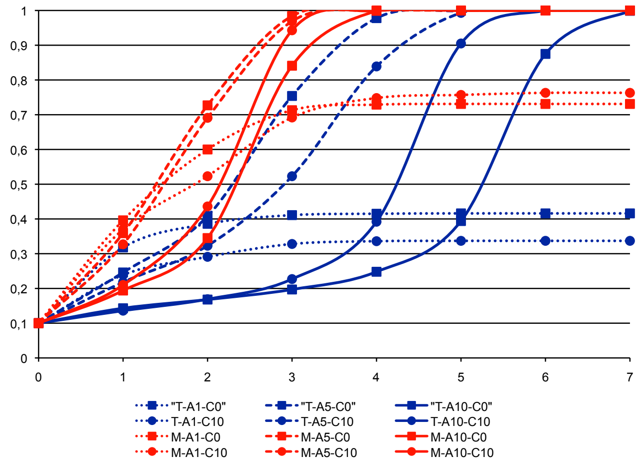

Fig. 2 Average node degree and committed agents (10% B) effects (Threshold and Media Effect Models)

The inclusion of media effects (30% for B) increases significantly the bias towards minority opinions, and varies the structural effect of the network and the position of (committed or non-committed) agents. These combined models demonstrate that the initial relevance of the network structure might be drastically reduced or even reinforced

TABLE I.
MODEL, INICIALIZATION CONDITIONS AND MAIN RESULTS

AB Models	Initialization conditions	Average-node-degree (AND)	Commited-agents	Threshold, (% neighb.)	Media effects (% bias B)	Time for A wins with AND 1-10	Time for B wins with AND 1-10
Random	1000 nodes; 10% opinion B, 90% A	1-5-10	No	No	No	495-126-100	B loses
	1000 nodes; 10% opinion B, 90% A	1-5-10	10% of Bs	No	No	A loses	971-395-159
Learning-based	1000 nodes; 10% opinion B, 90% A	1-5-10	No	No	No	395-126-98	B loses
	1000 nodes; 10% opinion B, 90% A	1-5-10	10% of Bs	No	No	620-159-118	B loses
Threshold	1000 nodes; 10% opinion B, 90% A	1-5-10	No	30%	No	4-loses-loses	3[33%]-5-7
	1000 nodes; 10% opinion B, 90% A	1-5-10	10% of Bs	30%	No	3-loses-loses	3[37%]-4-5
Media effect	Equal conditions + 100 media sour.	1-5-10	No	30%	100 media, 30% (vsbt=2)	2[14%]-loses-loses	4-3-2
	Equal conditions + 100 media sour.	1-5-10	10% of Bs	30%	100 media, 30% (vsbt=2)	2[11%]-loses-loses	3-2-2

with the presence of other communication channels.

Figure 3 compares results for the threshold and the media effects models. This figure demonstrates that external (media) information might produce important changes in the outcome models, independently of the presence of committed agents and the degree of connectivity between agents.

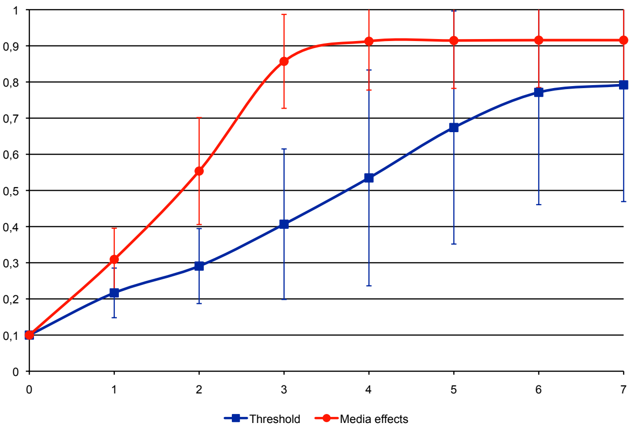

Fig. 3 Models with confidence interval (threshold and media effect)

IV. CONCLUSSION

The present work shows how different network models that are theoretically based on different opinion types might produce extremely different results. Random contagion models could be based on conformity mechanism due to the lack of initial information and predisposition towards certain opinion, while learning or threshold models implies social choice based on different known alternatives and also on neighbors' opinions and expectations for what should be considered the appropriate public behavior. The inclusion of media effects introduce external information in the world and produce a simulation that could be initially more realistic, and also more complex to predict (especially because this effect can modify the impact of global connectivity).

Of course, we know mass media can modify our opinion, attitudes, and social behavior, especially under certain contextual circumstances when social agents have no first-hand information to choose their alternatives [22]-[23]. In these cases where agents do not obtain information from their network and they have to look for additional data in the media, as a result media effects could become stronger in this situation. Clearly, outcomes are hardly predictable when agents receive information both from two channels (i.e. social networks and media), however, we could adjust our prediction if certain communication channel present more relevance in the results under specific contexts.

The results of the present model for the study of minority opinion spreading might be relevant to understand the communication process involved in formation of public opinion, social contagion dynamics, and the emergence of collective behavior in complex social systems. The model also may apply to study of rumor propagation through social networks and opinion silencing processes.

This is a basic model with two competing opinions that has been performed to study the fundamental conditions for minority opinion propagation in small-world and free-scale networks, but future models should include additional opinions, and also could include inoculation effects (i.e. resistance to persuasion) that could make it difficult the process of social contagion.

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Aqueduct construction in the late-antique east: an agent-based modeling and geoarchaeological approach to building evidence for the Water Supply of Constantinople.

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INTRODUCTION

The result of recent research (Snyder, 2013 – PhD thesis) on construction materials and workforce has shown that the Water Supply of Constantinople was one of the largest construction projects undertaken in the ancient world, requiring as much stone as the Great Pyramid of Giza and five times more manpower than of the Baths of Caracalla in Rome. However, with lacking archaeological and textual evidence, many vital questions remain about macro-level outcomes of this massive undertaking and the organisation of the labourers involved. This project provides the unique opportunity to explore one of the most under-appreciated aspects of modern classical scholarship: the spectrum of large-scale construction from the role of the individual to the function of the empire in the late antiquity.

The construction process in the eastern Roman provinces is an important topic that has seen little inclusion into modern scholarship, especially compared to Imperial Rome and the west. Often, this is based on the perpetuated and antiquated idea that the decline and fall of Rome signalled the end of an administrative ability to produce long-lasting monumental architecture. This research project will address this knowledge gap by investigating details of the large-scale building operations that led to these important infrastructural successes in the hinterland of Constantinople and beyond, many of which are under threat from modern development projects. In order to accomplish this, an original interdisciplinary approach will be taken that includes the application of new methods such as social simulation and geospatial analysis.

AIMS AND METHODOLOGY

Agent-based modelling (ABM) is an emerging technique for analysing social behaviour and organization in an archaeological context. Important studies include Kohler's (1995) "Agent-based modelling of Anasazi village formation in the northern American Southwest", Graham's (2006) "Networks, Agent-Based Models and the Antonine Itineraries: Implications for Roman Archaeology", and Maas and Ruths' (2012) "Road Connectivity and the Structure of Ancient Empires: A Case Study from Late Antiquity". Applying GIS and ABM to the study of construction processes of the Water Supply of Constantinople will allow for the systematic exploration of assumptions made due to the lack of physical and textual evidence.

How many people could build at the same time? What role did the terrain play in the location of the construction site? Would composite building materials be prepared closer to the raw material source or the construction site? What would have been the most efficient combination of workmen compared to the available stream of material resources? This innovative computer-based simulation will provide a means of experimenting with 'what-if' scenarios based on important variables such as topography, bedrock geology, workforce interaction, and climate to answer these questions. Applying agent-based modelling to this project will allow us to approach a quantitative subject of manpower and required construction materials with new and unique qualitative results— something that was previously impossible.

- PART I: QUARRIES, PRODUCTION SITES, AND SUPPLY NETWORKS

With no evidence of quarries, little has been said with confidence about the specific regional sources of stone (facing, core rubble, water channel masonry) and sand (mortar aggregate) materials for the Water Supply of Constantinople. Through previous research, it has been shown that vast amounts of these materials were needed and consequently, a massive workforce for their extraction and implementation.

- **Aim**: Identify likely areas of stone and sand sources used in the building of the water supply and long wall. By identifying any geographical relationship between building sites and these raw material sources, a system of supply networks will be built using GIS and tested through ABM analysis (discussed in part II).
- **Methods**: Detailed geological bedrock data for the Thracian Peninsula will be used to identify possible areas of raw material procurement in proximity to the water supply and long wall. This information will be integrated with data from the Anastasian Wall Project to build a terrain model which will be the basis for this project such as developing scenarios for material transportation by least-cost path GIS analysis as well as for the agent-based computer simulations in Part II of this project.

- PART II: WORKFORCE ORGANISATION AND BUILDING LOGISTICS

Again, with almost no information available from the textual or archaeological record, little is known about the size of the workforce, how the work was organized, or the time it took to construct them. Janet DeLaine (1997) developed methodology to explore large-scale construction scheduling and organization using analogous studies of historical construction prior to mechanization in her work on the Baths of Caracalla. This work has been very important for our understanding of monumental construction in Roman Italy but the methods cannot be directly transferred, due in part to the scant evidence for construction organization in the east.

- **Aim**: Explore scheduling and worksite organization in order to build timeframes of construction as well as identify aspects of the workforce that built the Water Supply of Constantinople and the Anastasian Wall.
- **Methods**: Using the terrain model of Thrace from Part I as the cornerstone, agent-based modelling (NetLogo) will be applied to test scenarios of construction logistics. These 'what-if?' scenarios, derived from analogous information from earlier large-scale construction projects in the Roman west (i.e. Eifel Aqueduct, Hadrian's Wall, Baths of Caracalla), can "generate answers 'organically'" (Graham, 2006: 60) with limited archaeological and textual evidence (Maas and Ruths, 2012). Additionally, the transportation network from Part I will be simulated to test and compare the usefulness of GIS analytical techniques.

This paper will discuss the historical framework, the project to date, and the preliminary design of this new project phase. This is part of a larger project on the archaeology and engineering of the Water Supply of Constantinople to be undertaken at the University of Edinburgh starting in the fall of 2014 under the direction of Prof. James Crow.

Title
Simulating social influence dynamics from observational data: the case of secessionist flags in Barcelona's balconies.

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Abstract

Different models of social influence have explored the dynamics of social contagion, imitation, and diffusion of different types of behaviour. However, empirical data on social influence processes have usually relied on surveys, virtual networks analysis or laboratory experiments, while few behavioural data indicating large social influence dynamics have been obtained from direct observation in 'natural' social contexts. This paper is based on a research project that provides precisely that kind of evidence in the case of the public expression of political preferences in the city of Barcelona during the years 2013-2014.

Since september 2012 a widespread social and political movement in Catalonia claims to organize a referendum on political independence from Spain. Secessionists have successfully called for several massive demonstrations in Barcelona, and have achieved the political support of the Catalan government for their claims. In this context, and since then, Catalan pro-independence flags have proliferated in Barcelona's balconies and windows. The act of hanging a pro-independence flag in your flat's balcony or window has become a very usual way of publicly expressing support for 'the process' (a term secessionists use to name the political and social road to independence).

The visual observation of flags in Barcelona's façades is therefore a chance to obtain direct and objective data on a social behaviour which has a simple binary structure (the options are to hang a flag or not to do it) and a very clear meaning (to express political preferences about 'the process'). It is also possible to analyze the distribution of flags in the visual space of the city in order to detect mechanisms of imitation or contagion. In fact, a preliminary observation of the main streets and avenues of the city confirms that

flags seem to appear together in clusters, and that the relationship between the frequency of flags and variables such as voting behaviour or income level is not obvious. In a pilot study during January 2013, we observed the distribution of flags in seven block's façades of one of Barcelona's main avenues, where big buildings with a large number of households are the norm, and a high number of flags were hanged. By calculating discrete probability distributions (DPD) of flags as a function of the observation window, we confirmed that observed distributions differ systematically from random distributions.

In order to confirm that a social influence mechanism is operating in the flags distribution, we have observed (during July 2013) the complete distribution of flags in a representative sample of 276 electoral districts in the city of Barcelona (almost one third of the total extension of the city); the sample includes 213,667 households in which 293,144 voters are registered. In a first stage of the project, we have studied the density of flags and how it correlates with the level of pro-independence vote in the 2012 election for the Catalan Parliament; it is then possible to observe that the hanging of a flag is to some measure inhibited in those electoral districts where there is not a clearly majoritarian pro-independence vote, while it is fostered in those where such a majority clearly exists. We then use a simple simulation model to reproduce the main trends of the distribution of flags in the space of the city buildings' façades. The model assigns agents a given probability of hanging a flag depending on their voting behaviour and calibrates this relationship using the sample data. Then the model introduces a simple social contagion mechanism by which the probability of hanging a flag raises when your neighbours do so. Comparing both types of simulation, we show that there is evidence of a non negligible effect of social influence among neighbours which explains the observed patterns better than the level of pro-independence vote alone.

In a second stage of the project, we selected a sub-sample of sixteen spatial areas (each one composed of six contiguous blocks' façades) in different electoral districts with different frequencies of flags. We then observed on the field the evolution and position of flags from 4 to 18 September 2013 (note that September 11th is Catalonia's National Holiday, and it is usual to hang a Catalan flag in the balcony that day); this observation allows to provide empirical evidence on the dynamics by which flags 'appear' before September 11th and 'disappear' afterwards, departing from a given pre-existing level of flags. A second simulation model is built in order to assess whether the specific spatial distribution of flags in the selected areas, as well as its temporal evolution, systematically differs from the level of clustering that would be expectable by chance. Again, the model provides evidence that successive hangings of flags are not independent events and that there is some influence mechanism that favors the clustering of flags.

Knowledge transfer dynamics: how to model knowledge in the first place?

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Abstract

In this paper, we study both processes of direct and indirect knowledge transfer, from a modelling perspective, using agent-based models. In fact, there are several ways to model knowledge. We choose to study three different representations, and try to determine which one allows to better capture the dynamics of knowledge diffusion within a social network. Results show that when knowledge is modelled as a binary vector, and not cumulated, this enables us to observe some heterogeneity in agents' learning and interactions, in both types of knowledge transfer.

Key words: knowledge modelling, knowledge transfer, social networks.

Introduction

Upstream of any innovation activity, individuals implied in the process of innovation must be able to interact and exchange knowledge under satisfying conditions. In this context, Foray and Zimmermann (2001) talk about the "good properties" of knowledge distribution. They write on this matter « *only fast and widened knowledge circulation makes it possible to profit from the single potential of a great number of qualified individuals*" (ibid, p.7). The speed with which knowledge is transmitted between various individuals thus makes it possible for them to coordinate in an easier way. Besides, the distribution of knowledge within a network offers a "guaranty of quality" (ibid.) of the produced knowledge, as it is checked by a certain number of individuals, who had to deal with. Hence, the sharing of knowledge between several individuals is a complex process that seems relevant to study.

The process of knowledge transfer is often studied in the context of a social network (Cowan and Jonard, 1999; Cowan and Jonard, 2006; Morone and Taylor, 2004a; etc). as it allows repeated interactions between various individuals. Besides, the frequency of interactions can constitute a key element in the transfer of certain knowledge, especially tacit knowledge (Nonaka and Takeuchi, 1995).

In this perspective, agent-based modelling (ABM) can be considered as a suitable tool to study the problems of knowledge transfer within social networks (see for example works of Cowan and Jonard, 1999; Morone and Taylor, 2004a; Cataldo *et al.*, 2001). Indeed, they enable to study dynamic phenomena and to capture complexity within a model (Phan, 2003; Gilbert *et al.*, 2001). Moreover, they enable to test different scenarios of simulations. But before studying knowledge transfer, one seeks to know how to model knowledge in the first place, in a way that enables us to study knowledge transfer within a social network. As Walliser states, knowledge « is frequently incorporated into agents and cannot be encoded in an explicit way" (Walliser, 2004, p. 194).

According to Cowan and Jonard (1999), models presenting knowledge as a scalar cannot apprehend the process of knowledge diffusion, while models presenting knowledge ad a vector can. In addition, the representation of knowledge as a stockpile was highly criticized in the literature (Morone and Taylor, 2003). *"… Cognition follows combinatory rules and not additive rules"* (*ibid*., p 9), and does not allow to capture the way that knowledge is diffused between various individuals, as a knowledge vector would (Cowan and Jonard, 1999). Indeed, knowledge is not accumulated, but rather is articulated with knowledge already held by an individual. This argument finds its origin in the distinction made between the economy of knowledge and the economy of information (Ancori *et al.*, 2000). Thus, the question that we raise here is *how knowledge should be modelled in order to capture the dynamics of knowledge diffusion within a social network?*

To answer this question, we will go through the existing literature around knowledge, and try to identify different kinds of knowledge and how they can be transferred. This will allow us to build agent-based models featuring three different representations of knowledge, where we will observe the dynamics of knowledge transfer. The last section of this paper will present the results, discussion and concluding remarks.

1. Information, knowledge and transferability

1.1.Knowledge vs. Information: convergence or complementarity?

It is not possible anymore to consider knowledge as partitions of information held by individuals, the only difference between different knowledge being the composition of these partitions (Lazaric and Lorenz, 2000). In fact, the definition of knowledge held by an individual is rather an issue of articulation and treatment of information. They state: "*The idea is that knowing something requires active interpretation of information, and this knowing may be highly unevenly distributed despite the fact that access to information is symmetric or equal*".

Hence, knowledge appears much more complex than information. If it is not interpreted to be used in a particular context, information does not have a value as such (Cohendet *et al*, 2006). If, on the other hand, it is interpreted and contextualized, then it is transformed into knowledge. Knowledge is then built from information that is processed and interpreted in a given context. An existing knowledge can also be supplemented by new knowledge. Knowledge "is nourished" by information (Créplet, 2001).

The difference between knowledge and information can be tempered as Andriessen *et al* (2004) do it. Indeed, one can represent these two concepts like two ends of the same continuum with various zones of gray. For example, a list of names cannot represent anything more but information, while data on the manner of solving a problem can represent knowledge.

Zacklad (2004) offers a definition of it which joined this argument and which we adopt in what follows. He defines knowledge as "*a potential of action given to an individual or collective actor in the context of a situation within which he pursues a project* ».

According to this definition, knowledge transfer is different from information transfer. Complexity inherent to the concept of knowledge also implies a certain complexity in its diffusion. In fact, the transfer depends on processes determining the definition of knowledge. Thus, transferring knowledge depends on the cognitive capacities of the individuals involved in the transfer (comprehension and interpretation), as on the context in which this process is. These two parameters relate to the epistemological approach of knowledge.

1.2.An epistemological approach of knowledge

This dimension, which originates with the work of Polanyi (1958), is largely used in the literature and classifies knowledge as tacit or implicit knowledge, and explicit knowledge.

1.2.1. Explicit knowledge

Explicit knowledge is a knowledge which can be transmitted without taking the risk that it loses whole or part of its meaning. That is ensured through a process of codification, because explicit knowledge is a codifiable or codified knowledge. As stated by Foray (2000), explicit knowledge is placed on a knowledge store, it is not linked to a specific person.

Explicit knowledge can be handled like information (Cowan and Foray, 1997). We draw the reader's attention not to confuse these two concepts, which are certainly closely dependent, but that we consider as completely distinct. Explicit knowledge and information do share an important characteristic which is the facility of circulation, but as we specified previously knowledge is *built from* information. The latter must still be interpreted by the actors to become knowledge. Information as such has only little value; what makes it valuable is the interpretation that individuals make of it in a particular context.

Explicit knowledge is often transcribed in a codebook (Cowan *et al.*, 2000). The process of codifying knowledge brings some fundamental changes in the economic aspect of the creation and the diffusion of knowledge. The principal change lies in the costs of access to knowledge. Knowledge codification can indeed generate important fixed costs, relating to the various stages of the process of codification. However, once this process is done, the transmission of this codified knowledge can be done at lower cost (Cowan and Foray, 1997). Knowledge is stored on a knowledge store which facilitate their access and which preserve the integrity of its meaning. It can be consulted an infinite number of times, without deteriorating its quality or its quantity.

Moreover, knowledge codification brings changes relating to the economic activities and the process of innovation in particular. It allows the externalization of the processes of knowledge creation. Certain knowledge can be bought, instead of being produced within the firm (*ibid*.).

1.2.2. Tacit knowledge

To define this concept, we will relate to the work of Cowan *et al.* (2000), which offers a synthesis of work treating of the tacit character of knowledge. The tacit term was popularized by work of Polanyi (1958), which considered tacit knowledge as a component of human knowledge distinct from but complementary to explicit knowledge in the conscious cognitive processes.

Polanyi illustrated this concept in reference to the fact that the individual is conscious of certain objects, without its attention being necessarily focused on these objects. This did not make them less important, because they constituted the context which made possible the focusing of the individual's attention (Cowan *et al.*, 2000). Andriessen *et al.* (2004) define tacit knowledge as often implicit and unconsciously articulated. Following this, the concept of "tacit knowledge" was largely applied to personal knowledge that was **not easily transmitted** between individuals.

In the literature, the two concepts of explicit and tacit knowledge are often opposite. One could then try to define tacit knowledge, while basing oneself on the definition of explicit knowledge. Explicit knowledge being defined like a codified knowledge, a tacit knowledge could be defined as non codified knowledge or non codifiable (Witt *et al,* 2007). It is expressed through action and defies any verbal expression (*ibid*), and can be classified in the category of non codifiable and non articulable knowledge. It is a knowledge which can be acquired only by action, and falls under the "learning by doing" or the behavioral learning processes (Leroy, 1998). Hence, this kind of knowledge translates "know-how".

Let us now see how these types of knowledge can be transferred.

2. Knowledge transferability

The major differences between tacit and explicit knowledge involve important differences in the way of transferring them from an individual to another. Witt *et al* (2007) present two types of knowledge transfer which we decide to adopt here.

2.1. Direct knowledge transfer

Direct knowledge transfer is done thanks to means of communication used between two individuals, such as verbal communication, which require face-to-face contact. Witt *et al* (ibid) talk about knowledge transfer in terms of communication between individuals. *"Knowledge is communicated directly only in oral or visual transmissions requiring face-to-face contact between transmitter and recipient – the communication technology that humans are naturally endowed with*" (*ibid,* p. 3).

We choose to extend this definition to all the means of communication which enable two individuals to communicate instantaneously and without intermediary. Thus, we include there all the technological means available which fulfill these functions. For instance, we can think of means like telephone, videoconferences, etc.

We supplement the definition offered by Witt *et al* (2007) and we define direct knowledge transfer as any knowledge transfer which allows two individuals to communicate without intermediary.

2.2. Indirect knowledge transfer

In a similar way, indirect knowledge transfer is a transfer which is done thanks to means of indirect communication. Knowledge must initially be explicited by the transmitter then transmitted or stored by means of an artificial medium which will allow the recipient to consult it later on, an unlimited number of times. "*Indirect knowledge transmission relies on optical, acoustic, or electronic signals. Examples of communication by means of intermediate knowledge storage are written documents and visual and acoustic displays*" (*ibid*., 2007, p. 3).

This type of transfer thus supposes a preliminary codification of non-codified and codifiable knowledge. It enables the recipient to consult knowledge as many times as he wishes to, without time constraint. These authors consider this type of transfer more interesting in terms of knowledge transfer than the direct transfer, because once knowledge is codified and sent to the recipient, it is stored on a knowledge store that is accessible by the recipient, who can consult it instantaneously or later on. "*Indirect communication making use of technical media enables a more powerful knowledge transfer than direct communication*" (*ibid*). This for the following reasons:

This type of transfer is not restricted to only two individuals; knowledge can have several recipients, and thus be diffused more widely, unconstrained, provided that all the recipients understand the code used to codify it;

Codified knowledge is transmitted independently of the physical presence of the individual who holds it. The technological medium can be improved by the various individuals implied in the transfer process. To this definition of the process of indirect transfer, we can bring the following examples: knowledge posted on an electronic forum, knowledge codified and transcribed on paper or electronic documents, etc.

2.3.How knowledge can be transferred?

According to the definition of the two types of transfer previously mentioned, it seems that what determines the type of transfer to use is not the explicit/tacit character of knowledge. In fact, this very widespread classification in the literature is not very relevant in making such a decision. Indeed, what determines that knowledge has to be transferred in a direct or indirect way is its codifiable/non codifiable character. Hence, we propose an alternative classification based on this condition.

At this stage, we think that it is necessary to bring some details, as for the codified character of knowledge. If it is codified, it can as well be transmitted via oral communication as through a written knowledge store for example. In some cases, it is easier to transmit codifiable knowledge in an indirect way. For example, to solve a mathematical problem, it is easier to transmit the solution by writing down the mathematical demonstration, than by transferring it in an oral way. Thus, it would be more interesting to codify this knowledge in order to transcribe it, *and* it can be stored easily. This represents a considerable advantage if knowledge is intended for several individuals.

On the other hand, a non codified and non codifiable knowledge cannot be transmitted by means of a written knowledge store. If one takes the example of the knowledge which enables to ride bicycle, it cannot be transcribed or transmitted by means of any support. It is a tacit knowledge, which is not articulable and which can be expressed only in the action of the individual who holds it. Thus, to transmit such knowledge, “the transmitter” must *show* to the “recipient” what to do. This is know-how. For this type of knowledge, the only type of possible transfer is the process of direct transfer.

Let us summarize in what follows the types of transfers corresponding to the various kinds of knowledge, classified according to their codifiable character.

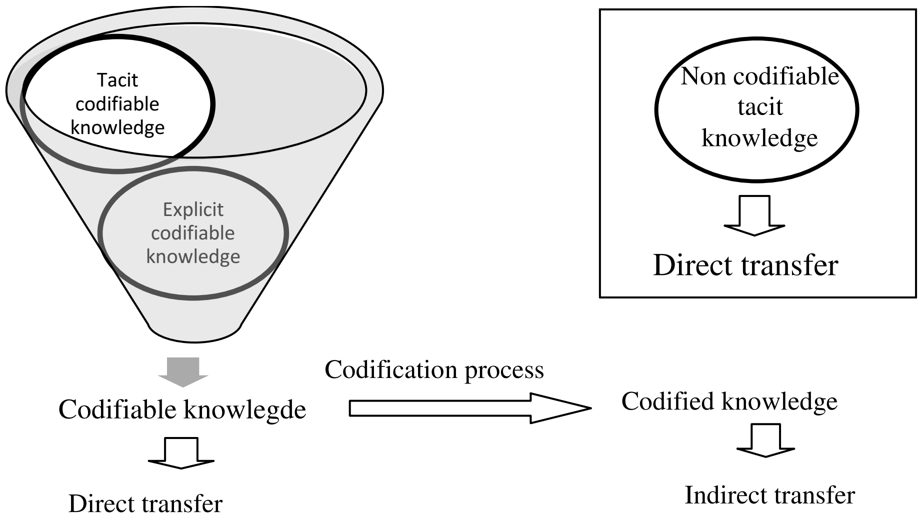

Fig. 1 An alternative classification of knowledge

3. Agent-based models

We will use ABM to study knowledge diffusion within a social network. We will model both direct and indirect knowledge transfer within a population composed of a pool of experts and new comers who seek to acquire knowledge. Both models will feature 3 representation of knowledge, and we will try to observe the dynamics of knowledge diffusion for each representation. This is described in what follows.

3.1.Definition the agents' and the population's features

We have a population composed of 110 agents[1]: a pool of 10 experts and 100 new comers. The goal of each new comer is to acquire knowledge, by asking questions. Each agent is characterized by the following features:

3.1.1. An initial endowment in knowledge:

For each model, we propose to test three different representations of knowledge; two of them present the cognitive endowment of an individual as a stockpile of various knowledge, while the third is a binary vector.

a. *Knowledge as a binary vector*:

Each agent in endowed with a knowledge vector, composed of 100 types of knowledge[2]. An endowment of 0 in a knowledge *k* means that an agent doesn't have that particular knowledge; whereas, an endowment of 1 means that he does.

Knowledge →	1	2	…	99	100
Knowledge endowments →	1	0	…	1	1

Fig. 2 Example 1: This agent has knowledge 1, 99, and 100, but doesn't have knowledge 2.

We draw the attention of the reader to the fact that this vector consists of binary values only. There is no accumulation of knowledge here. It is different from the one used by Cowan and Jonard (1999) as they cumulate knowledge.

b. *Knowledge as a stockpile*

➢ *One knowledge with 100 degrees of expertise*

Here, agents only have one type of knowledge. However, they have different degrees of expertise in this knowledge, ranging from 0 to 100. This knowledge can be illustrated in the following way:

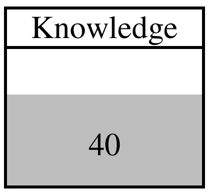

Fig. 3 An agent has a degree of expertise of 40

[1] We studied the effect of the size of the population on the learning of agents. Results show that the size of the population has no effect on the results of the simulations.

[2] We deliberately chose these values because they enable us to keep certain coherence in terms of knowledge to be acquired for an agent. In each of the three representations, an agent has to acquire 100 elements (knowledge or degrees of expertise).

➢ *10 different knowledge with 10 degrees of expertise*

An agent can have 10 different types of knowledge with different degrees of expertise ranging from 0 to 10 in each one of them.

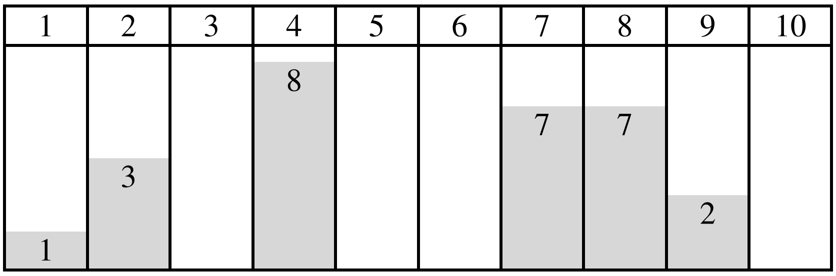

Fig. 4 Knowledge and degrees of expertise of an agent

3.1.2. An agent's competence

It is defined according to the representation of knowledge used:

For knowledge as a binary vector, we define an agent's competence by the number of knowledge he possesses. Technically, an agent's competence is the sum of ones in his knowledge vector. This definition follows the work of Cataldo *et al* (2001). In their model, these authors model each agent's knowledge as a mask composed of 0 and 1 for different types of knowledge. They state: *"The increasing number of pieces of information of a particular type, the more experienced the individual will be in that area. In addition, experience is represented in the number of ones that the knowledge mask has".*

With regard to the situation where the agents have only one type of knowledge with 100 degrees of expertise, the competence of an agent is simply equal to its degree of expertise.

Lastly, when agents have 10 different types of knowledge with 10 degrees of expertise, the competence of an agent will be equal to the sum of its degrees of expertise in the various knowledge it possesses. For example, the competence of the agent whose knowledge is illustrated in Fig. 4 will be equal to 28.

3.1.3. Rules of interaction: The selection of an knowledge-provider

The choice a knowledge-provider will depend on the type of simulations which we use.

- In simulation with direct knowledge transfer: agents always choose the most competent agent in the population.
- In simulation with indirect knowledge transfer: agents don't choose a particular agent, but post a question on a forum. It is a mode of communication that is often used in knowledge intensive communities (see for instance the work of (Guechtouli *et al*, 2013); Marquois-Ogez (2006), Conein and Delsalle (2005)). Here, individuals do not interact in a direct way, with a targeted individual.

3.1.4. Other features:

Availability: defined by the number of questions that an agent is able to answer per time-step.

Tolerance threshold: defined as follows:

- In direct knowledge transfer: it is defined as the number of unanswered questions that an agent is willing to accept from another agent, before deciding not to ask this agent anymore.
- In indirect knowledge transfer: it is it is defined as the number of unanswered questions that an agent is willing to accept before deciding not to ask questions anymore and leaving the network.

In terms of answering questions and providing knowledge, we consider that the population of agents is divided in two parts: priority knowledge-providers (pkp) and secondary knowledge-providers (skp). *Pkp* have a competence equal to 100, whereas *skp* have a competence greater than or equal to a competence threshold (CompMin) defined as the minimal competence required in order to be able to answer questions. This threshold is set to 75[3].

Agents with competence lower than 100 will be called knowledge-seekers.

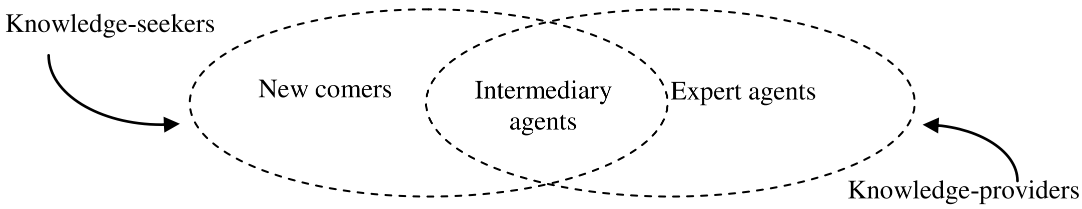

Fig. 5 Agents and their functions

3.1.5. Definition of interactions:

Each agent interacts once per time step. According to the way in which knowledge is modelled, the question asked differs.

If knowledge is modeled as a binary vector, the question raised by agent *a* will concern a knowledge chosen randomly among all those which it does not have.

If knowledge is represented as a stockpile, then the question asked will relate to the smallest degree of expertise which the agent does not have. In order to better understand this, let us take the examples presented in the figures Fig. 3 and Fig.4.

If an agent has only one type of knowledge with 100 degrees of expertise, as it is illustrated in Fig.3, its next question will relate to a degree of expertise equal to 41.

Whereas if an agent has 10 knowledge with 10 degrees of expertise for each one of them as presented for instance in Fig. 4, then the question will relate to a knowledge chosen randomly among the 10 knowledge of the agent. As for the degree of expertise, it corresponds to the smallest degree that an agent lacks in the selected knowledge. For example, if the question is about knowledge 4, then the degree of expertise required will be 9.

3.1.6. The process of response of a knowledge-provider

Once he receives a question, a knowledge-provider provides an answer if he is available and if he can answer the question. For that he carries out two tests:

Test of availability:

[3]We led simulations for several values for CompMin and 75 is the value where the largest number of agents is able to increase their individual competencies.

If the number of questions that the knowledge-provider received is lower than the value of his availability, the he is available and carries out the second test.

If not, he ignores the question.

Test of competence:

This test is different according to whether knowledge is represented as a binary vector or as a stockpile.

For knowledge as a binary vector: the test of competence is summarized in what follows:

- If the knowledge-provider has the requested knowledge, he answers the question.
- If not, he ignores it.

For knowledge in the form of a stockpile: (one knowledge with 100 degrees of expertise or 10 knowledge with 10 degrees of expertise), here the question asked by each knowledge-seeker corresponds to a degree of expertise concerning a given knowledge. The test of competence is as follows:

- If the degree of expertise required is lower than or equal to the degree of expertise of the knowledge-provider that receives the question, then this agent can answer the question;
- If it is higher than the degree of expertise of the knowledge-provider in the requested knowledge, then it cannot answer the question and ignores it.

A knowledge-provider carries out the two tests of availability and competence to answer (or not) each question he receives.

Each knowledge-seeker asks a question per time step, as long as its competence is lower than the maximum competence.

3.1.7. Learning process

Each time an agent gets an answer to a question; it raises its knowledge of that particular subject to 1, and won't ask questions about this knowledge anymore. Following example 1 (cf. Fig. 2), an agent increases her knowledge of subject 2, as shown below.

Subjects →	1	2	…	99	100
Knowledge vector →	1	**1**	…	1	1

Fig. 6. An agent learns and acquires knowledge about subject 2

For the two other representations of knowledge, the process of learning is as follows: each time an agent receives an answer concerning a particular knowledge, his degree of expertise in this knowledge increases with 1 point.

4. Results of simulations:

4.1.Simulations with direct knowledge transfer

The objective of these simulations is to see how a different representation of knowledge can influence the process of knowledge transfer. This is why the results obtained following these simulations will be presented in the form of a comparison between the three representations of knowledge.

We chose to observe only one indicator, which summarizes well the way in which knowledge is transferred. This indicator is agents' coordination for optimal learning, that is the matching values of availability and tolerance threshold that are necessary for all agents to become experts.

The parameters which we varied are the following:

- Knowledge-providers' availability between 1 and 10 questions per time step;
- Knowledge-seekers' tolerance threshold between 1 and 10 unanswered questions per agent;

Results are as follows:

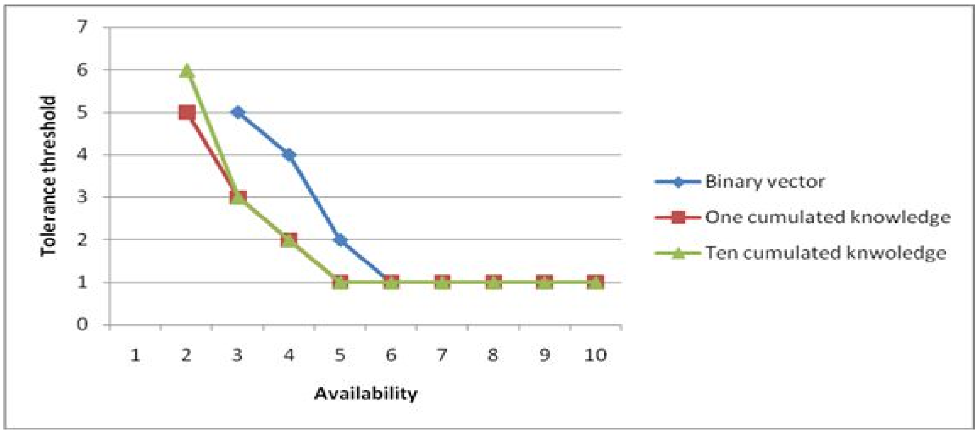

Fig. 7 Agents' coordination for optimal learning in direct knowledge transfer

We can notice, from the results presented in Fig. 7, that agents' coordination is much easier in simulations with one and ten knowledge that in simulations where knowledge is modelled as a vector. Optimal learning is in fact observed for all the values of availability, even if knowledge-seekers are not tolerant. Whereas when knowledge is represented as a binary vector, it is necessary to wait for availability equal to 3 questions per time step and a tolerance threshold equal to 5 to observe optimal learning.

4.1.1. Discussion of the results:

By modelling knowledge as a vector, there is no particular bond between the different types of knowledge that compose this vector. Knowledge is not ordered according to any degree of difficulty; they are thus not cumulated. An agent may have knowledge located at the beginning of the vector and not possess some other located a little further on the vector.

That is not the case when one speaks about knowledge as a stockpile. If a question relating to a degree of expertise *n* is asked to an agent which has a degree of expertise *m* equal to or higher than *n*, then this agent can obligatorily answer this question. The only element which conditions its answer is its availability. This is illustrated in the following figures:

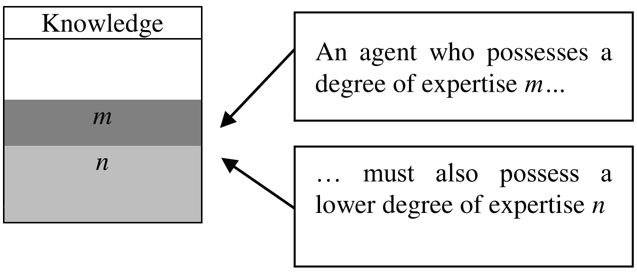

Fig. 8 Knowledge as a stockpile

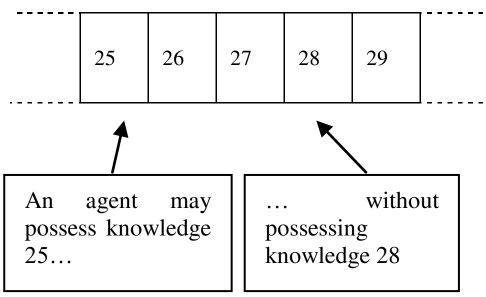

Fig. 9 Knowledge as a binary vector 10

Thus, if we compare the three types of knowledge modelling, all things being equal, an agent gets more answers when knowledge is cumulated (cf. two preceding figures). It is this difference which induces great changes in terms of agents' coordination.

4.2.Simulations with indirect knowledge transfer

In indirect transfer of knowledge, results show a clear difference between the three representations of knowledge. Here, all the agents become experts for all the values of availability and tolerance when knowledge is treated as a stockpile (one or ten knowledge with various degrees of expertise). This result is only due to this way of modeling knowledge. When one models knowledge in the form of degrees of expertise, agents receive more quickly answers to their questions. These answers being stored on a forum, all the agents have access to knowledge before deciding to leave the social network.

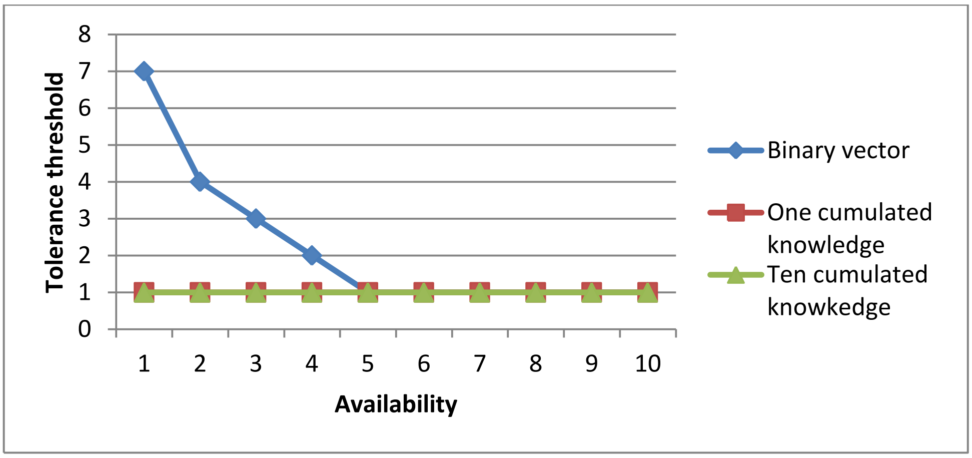

Fig. 10 Agents' coordination for optimal learning in indirect transfer: three structures of knowledge

4.2.1. Discussion of the results

The results observed in Fig. 10 show that there is a difference in terms of transfer in knowledge, if it is modelled as a binary vector or as a stockpile. In these simulations, it seems that, thanks to the mechanism described in the Fig. 8 and Fig. 9, agents receive answers sufficiently quickly so they do not have to leave the network.

In fact, given the mechanism of interaction describes previously, all knowledge-seekers ask the same question at the beginning. The interactions occurring on a forum, all the individuals receive the answer given by one of the knowledge-providers. All the knowledge-seekers then increase their individual competences on the first time step. The same procedure is repeated with the following time steps. Consequently, they all systematically obtain answers to their questions. They never leave the network.

We had chosen this mechanism of interaction to maintain a plausible character for the interactions within asocial network. A new comer cannot ask a question requiring a high degree of expertise without having a certain expertise first. The process of learning is done gradually by asking questions requiring a higher degree of expertise as the individual competence of the agent increases. However, it proves that this modeling of knowledge as a stockpile does not enable us to have a real heterogeneity in the interactions. Thus, this representation of knowledge does not enable us to capture the way in which knowledge is diffused.

5. Concluding remarks:

In this work, we aimed to study the processes of knowledge transfer within social networks, and more precisely, we wished to know which representation of knowledge would enable us to better capture the dynamics of knowledge diffusion.

In order to do so, we chose to use agent-based modelling, this methodology seeming particularly adapted to our purpose. Simulations which we carried out related to two types of transfer: indirect and direct transfer of knowledge. We tested two types of representations of knowledge: knowledge as a stockpile, and as a binary vector.

Our results show that the transfer of knowledge is facilitated when knowledge has a cumulated form that when it is represented by a binary vector. This result concerns both types of knowledge transfer studied in this paper. That is due to the fact that, when knowledge is represented as a stockpile, various knowledge which an individual possesses are connected to each other. They are ordered (cf. Fig. 8), and an individual cannot have a knowledge requiring a certain degree of expertise without having some other requiring a lower degree of expertise. However, since knowledge is ordered following an order which requires ascending degrees of expertise, this representation of knowledge does not enable to observe a great heterogeneity in the interactions, and does not allow to capture the way in which knowledge is diffused within a social network.

On the opposite, when knowledge is modelled as a binary vector, i.e. when knowledge is not cumulated, simulations enables us to observe some heterogeneity in agents' learning and interactions. This modelling of knowledge thus allows for a better capturing of knowledge transfer dynamics within a social network.

In our future research, we would like to extend the work presented in this paper to the process of knowledge creation. Following the models developed by Cowan et *al.*(2006) and Cowan *et al*. (2007), we could observe how knowledge creation dynamics can be captured according to the chosen knowledge representation.

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Social Simulation of Commercial and Financial Behaviour for Fraud Detection Research

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***Abstract*—We present a social simulation model that covers three main financial services: Banks, Retail Stores, and Payments systems. Our aim is to address the problem of a lack of public data sets for fraud detection research in each of these domains, and provide a variety of fraud scenarios such as money laundering, sales fraud (based on refunds and discounts), and credit card fraud. Currently, there is a general lack of public research concerning fraud detection in the financial domains in general and these three in particular. One reason for this is the secrecy and sensitivity of the customers data that is needed to perform research. We present *PaySim, RetSim, and BankSim* as three case studies of social simulations for financial transactions using agent-based modelling. These simulators enable us to generate synthetic transaction data of normal behaviour of customers, and also known fraudulent behaviour. This synthetic data can be used to further advance fraud detection research, without leaking sensitive information about the underlying data. Using statistics and social network analysis (SNA) on real data we can calibrate the relations between staff and customers, and generate realistic synthetic data sets. The generated data represents real world scenarios that are found in the original data with the added benefit that this data can be shared with other researchers for testing similar detection methods without concerns for privacy and other restrictions present when using the original data.**

I. Introduction

Modelling the social financial behaviour of individuals is not a simple task. The social behaviour of individuals include many complex transactions. These interactions are driven by many factors and are constrained by the context surrounding them. In this paper we cover an important topic concerning the human financial interactions in the financial transactions domain. Unfortunately, whenever money is involved, there is been a risk of fraud.

Fraud is an important problem in a number of different situations. The economic impact can be substantial. The detection of fraud is therefore a worthwhile endeavour. However, in order to investigate, develop, test and improve fraud detection techniques there is a need for detailed information about the domain and its peculiarities.

All these needs can be satisfied if we had access to publicly available data of financial transactions so that different approaches could be compared and contrasted. Unfortunately for several reasons, including confidentiality, protection of privacy, the law, internal policies and regulations, it is hard if not impossible for an outside researcher to get access to such a data. Hence, research has historically been hampered by a lack of publicly available relevant data sets. Our aim with this work is to address that situation.

This paper is an effort to deal with the lack of public available financial data, with the idea that if we can not get access to public financial records due the restrictions mentioned before, then one good alternative is to use a simulator to generate financial data. However simulating a financial environment and generating data brings new challenges, specifically those related to characteristics of the generated data such as quality, privacy, realistic and usefulness.

We present three different case studies in the area of the social simulation of financial transactions for fraud detection research. The first consists of a new payment system that uses mobile phones to ease the payments, called *PaySim* [1]. Our access to base level data was poor at the time of that research being performed. Thus, we experienced difficulties to build an accurate model. This lead our research to our second case study called *RetSim* [2]. *RetSim* is a simulation tool that generates realistic scenarios of a retail store based on transactional data from one of the biggest shoe retailers in Scandinavia. The last case study is called *BankSim*, which is our first approach towards the simulation of bank transactions; payments and transfers between different people and merchants. *BankSim* is based on the public available aggregated transactions shared by a bank in Spain, with the main objective of promoting applications for Big Data uses of their services.

The main goal of developing these simulators is that it enables us to produce and share realistic fraud data with the research community, without exposing potentially sensitive and private information about the actual source.

Simulation also have other benefits: it can produce more data much faster and with less cost than for instance, collecting data, and one can try different scenarios of fraud, detection algorithms, and personnel and security policy approaches, in an actual store, for example, the introduction of new supervisors, security cameras, auditing routines, etc. The latter also risks incurring e.g. unhappiness among the staff, due to trying e.g. an ill advised policy, which leads to even greater expense and problems.

The main contribution of our approach is a method to generate anonymous synthetic data of a "typical" financial chain, that can then be used as part of the necessary input data for the research, development and testing of fraud detection techniques, both research prototypes and commercially available systems. Also, the data set generated could be the basis for research in other fields, such as marketing, demand prediction, logistics and demand/supply research.

The rest of this paper is organised as follows: Section II presents related work on simulation and fraud detection for the financial domain. Section III describes the methodology used for our research. Section IV presents *PaySim*. Section V presents *RetSim*. Section VI presents *BankSim*. We present a description of the model, evaluation and results for the simulators and finish with a discussion in section VII and conclusions, including future work in section VIII.

II. Background and Related Work

Simulations in financial domains have traditionally been built to predict markets changes, stocks prices and more specifically in the domain of retail stores for finding answers to logistics problems such as inventory management, supply management, staff scheduling and for customer queue reductions [3]. Our work uses similar techniques of financial modelling but has a different focus, which is the generation of synthetic data sets for fraud detection research.

Some of the benefits of using a synthetic data set for testing machine learning algorithms have been previously addressed by us [4]. We argue that: data that represent realistic scenarios can be made readily available; the privacy of the customer is not impacted; disclosure of results is not affected by policies or legal issues; the generated data set can be made available for other researchers to reproduce experiments; and different scenarios can be modelled by changing the parameters controlled by the researcher.

There has been work in the area of privacy preserving methods for data mining [5]. However, since the main problem in our experience usually is to get access to the data in the first place, our approach is to try and generate data that can then be shared without problems from a privacy perspective. The actual analysis method then does not need to be privacy preserving.

Social Network Analysis is a topic that is currently being combined with Social Simulation [6]. Both topics support each other in the representation of interactions and behaviour of agents in the specific context of social networks. However, there is no work in the field of customer/salesman interaction that we are aware of.

Money laundering threatens the economic and social development of countries. Due to the high amount of transactions and the variety of money laundering tricks and techniques, it is difficult for the authorities to detect money laundering and prosecute the wrongdoers. Thus, it is not only the ever increasing amount of transactions, but the ever changing characteristics of the methods used to launder money that are constantly being modified by the fraudsters which makes this problem interesting to study.

In Sweden and other countries, most companies in the financial sector are required by law to implement money laundering detection. The cost of implementing such controls for AML is quite high, mainly because of the amount of manual labour required. In Sweden alone the cost is estimated to be around 400 million SEK annually [7]. The most recent notorious case of money laundering is the HSBC Bank case [8], where the lack of AML controls lead to large amounts of money being laundered and injected into the U.S. financial system from countries under strict control, such as Mexico and Iran.

The most common method today used for preventing illegal financial transactions consists on flagging different clients according to perceived risk and restricting their transactions using thresholds [9]. Transactions that exceed these thresholds require extra scrutiny whereby the client needs to declare the precedence of the funds. These thresholds are usually set by law without distinction made between different economic sectors or actors. This of course leads to fraudsters adapting their behaviour in order to avoid this kind of controls, by e.g. making many smaller transactions that fall just below the threshold. Hence, these and other similar methods have proven insufficient [7].

New promising research in the field of data mining based methods have also been used to detect fraud [10]. This leads to the observation that machine learning algorithms can identify novel methods of fraud by detecting those transactions that are different (anomalous) in comparison to the benign transactions. Supervised learning algorithms have been used on synthetic data to prove the performance of outliers detection in different domains [11].

Several machine learning techniques have been used for the detection of fraud, and more specifically money laundering [12]. The application of machine learning to the problem is advantageous in many situations [13], [14]. However, to our knowledge, there are not a sufficient number of studies on this topic with public financial data to determine whether one detection method is better than another. Our simulators aim to close this gap and allow these researchers and organisations interested in fraud detection research to test, compare and develop new methods.

III. Methodology

We developed three different case studies on financial transactions. The first consists of a payment system that uses mobile phones to easy the payments *PaySim*, introduced in [1]. The second is *RetSim*, a simulation tool that generates realistic scenarios based on transactional data from one of the biggest shoe retail stores in Scandinavia. [2], [15]. The last, is *BankSim*, a simulator built on a sample of aggregated transactional data that one Spanish bank made available for a contest to encourage the development of applications in the *big data* field and specifically based on their data set. All simulators use the same Multi-Agent Based Simulation toolkit, called MASON, which is implemented in Java [16].

PaySim was based only on the schema of the database and the described behaviour of the customers for the simulated system. At the time of development, the system was in a testing phase, which made it impossible for us to obtain realistic data to calibrate the behaviour of the agents. However, we used the generated data to illustrate the possibilities and usefulness of the model by first generating a synthetic data set and second by performing an example of fraud detection using labelled data and machine learning techniques to classify the injected malicious behaviour.

PaySim is still waiting for real data from our partner in order to move forward with the calibration of the simulation and experimentation on diverse fraud scenarios. This situation made us focus our attention on our second case study RetSim.

RetSim started with the contribution of real data from a new partner, one of the largest Nordic shoe retailers. This data contains several hundred million records of diverse transactional data from all their stores from a few years ago, and also covering several years. This data is recent enough to reflect current conditions, but old enough to not pose a serious risk from a competitor analysis standpoint.

To better understand the problem domain, specifically the normal operation of a store (which is the domain from where we have access to data), we began by performing a data analysis of the historical data provided by the retailer. We were interested in finding necessary and sufficient attributes to enable us to simulate a realistic scenario in which we could reason about and detect interesting cases of fraud. This information was useful to build a social network interaction between customers and salesmen.

Fraud analysis has traditionally been strongly associated with network analysis. This is because of the possibility of several actors participating in a specific fraud in order to confuse the investigators and dilute the evidence, hence describing a network of actors, companies, ownership etc. By doing this we aim to model the micro behaviour of the different agents that captures the observed macro behaviour and gives rise to a total picture of the store. We generated a social network from the relation between customers and salesmen. We measured and use its properties to simulate a similar network with the aim of preserving interesting properties from the original social network such as topology, average in-degree and out-degree distribution of the salesmen and customers that are relevant to fraud detection.

We have no known instances of fraud in the real data (as certified by the data owner). So we had to inject malicious behaviour, by programming agents that behave according to some known or hypothesised retail fraud case presented before: *Refunds* and *Discounts*.

IV. PaySim, a Mobile Money Payment Simulator

Mobile Money Payment Simulation case study is based on a real company that has developed a mobile money implementation that provides mobile phone users with the ability to transfer money between themselves using the phone as a sort of electronic wallet. The task at hand is to develop an approach that detects suspicious activities that are indicative of money laundering.

Unfortunately, this service has only been running in a demo phase. This situation prevent us to collect any data that can be used for analysis of possible detection methods of illegal money transfers.

We modelled and implemented a Multi-Agent Based Simulator that uses the schema of the real mobile money service, but can generate synthetic data based on unknown scenarios that we based on our guess of what could be possible when the real system starts operating.

The simulation contains one agent that represent the clients of the service. The agents are represented by the class *Client* which extends to two child classes (*ClientSimA and Fraudster*). The inherit model allows an agent to rewrite specific behaviour of a client but implement its own specific behaviour. We created different types of agents and instantiate them together in the class *Clients* to represent the normal behaviour of clients and fraudsters.

Each clients has four possible actions in each step of the simulation. They can either make a *deposit*, a *withdrawal*, a *transfer* or simply “decide” not to do anything. The autonomy of the agent is implemented by a probabilistic transition function that computes the type of operation and the action that an agent will perform in each step. This transition function depends on the attributes of the client such as *Age* and the amount is calculated according to the balance and the limits previously defined for each client profile. To reflect what a realistic scenario could look like, we used the thresholds imposed by the original money laundering system.

For each simulation we can modify the parameters and the probabilities of occurrence for the transitions in order to improve the quality of the simulation. It is difficult to find the right probabilities that model a realistic scenario. Our implementation is based on pseudo random transitions. The given probabilities are based on 3 different configurations for the percentage of account balance in comparison to the maximum limit allowed by the client profile (Lower than 15%, higher than 80% and *medium balance* which is between *low* and *high*). The agent has a higher probability of making a deposit when the balance is low. When the balance is high the agent has a higher probability of making a withdrawal or a transfer, rather than a deposit.

A. Description of Scenarios

Our chosen scenario is an hypothetical situation where 200 clients from 4 different cities perform several transactions with partners inside or outside their city. We decided to have around 10% of the clients behaving as malicious agents (fraudsters). In a real scenario it is more common to find a lower percentage of fraudsters. The idea behind a higher proportion of fraudsters is to prevent the class imbalance problem during the training of the detector. All of the fraudsters were connected in a network where the 3 roles of the money laundering chain were represented (injection, layering and integration).

The social network between the clients was built restricting the network to a maximum of five contacts per client inside the city, and two outside the city. The fraudsters can also interact with normal clients of the system.

All the transactions are stored in a log file. The simulation was run five times for 1000 steps. Each step represents a time unit that we assume is the transaction rate of the clients (1/3 per day). The files generated were merged and ultimately used as input for the machine learning algorithms presented in sect. IV-B.

B. Results

In total we simulated 486977 transactions over 5 simulations, each one with 200 agents performing 1000 steps. A total of 6006 transactions were generated by 107 malicious agents and labelled as *suspicious*. Each of the malicious agents was designed with a specific goal in mind, chosen from the money laundering cycle that involves the three stages: placement (40), layering (33), and integration (34). The data generated by the simulation represent a realistic situation of the class imbalance problem, where one of the classes is very large in comparison to the other one. In this case only 1.23% of the total data is suspicious. For the experiment we ran different supervised algorithms that were selected for the purpose of classifying the class labelled as suspicious transactions.

The results can be seen in Table I and II. We can see that *JRip* produces the best accuracy in TP (True Positive) rate and FP (False Positives) rate in comparison with the other algorithms. The MC (Misclassified) number of instances is a bit higher than for the other algorithms e.g J48graft or Random-Forest.

TABLE I
RESULTS FOR THE CLASS *money laundering* (SUSPICIOUS)

Algorithm	TP	FP	MC
Naive-Bayes	0.988	0.479	8543
Decision-Table	0.999	0.029	200
Jrip	0.999	0.012	115
Random-Forest	0.999	0.009	66
Random-Tree	0.999	0.015	173
J48graft	0.999	0.014	118

TABLE II
CONFUSION MATRIX

Algorithm	JRip		Random-Forest		J48graft	
class*	a	b	a	b	a	b
a	5934	72	5954	52	5922	84
b	43	480928	14	480957	34	480937

* a=Normal b=Suspicious

C. Evaluation of the model

We start the evaluation of our model with the verification and validation of the generated simulation data [17]. The verification ensures that the simulation correspond to the described model presented in the chosen scenarios. We can easily check the constraints in the generated data such as positive balance numbers, account age, consistency between the transfers, deposits and withdrawals with the changes in account balances. Validation of the model is a bit more complex, since we need to ascertain whether the model is an accurate representation of a real world situation. Since we do not have real world data at this time, we need to rely on a description of the desired scenario and the opinion of experts in the field to validate that the basic statistics and the overall process of the simulation design correspond to a real world scenario. The complexity of the agents also matter here, the simpler the agents the easier is to validate the model.

Calibrating the model to a realistic scenario was rather hard in this simulation. From this difficulty we learnt a lot about the importance of accessing and sharing real data for fraud detection. Hopefully soon we will be able to get our hands on real data from this system that will help to improve the accuracy of the simulator.

V. RETSIM, A RETAIL STORE SIMULATOR

Since we have access to several years worth of transaction data from one of the largest Scandinavian retail shoe chains, we developed *RetSim*, a **Ret**ail shoe store **Sim**ulation, built on the concept of Multi Agent Based Simulation (MABS). RetSim is intended to be used for developing and investigating fraud scenarios at a shoe retail store, while keeping business sensitive and private personal information about customers consumption secret from competitors and others.

The defence against fraud is an important topic that has seen some study. In the retail store the cost of fraud are of course ultimately transferred to the consumer, and finally impacts the overall economy. Our aim with the research leading to RetSim is to learn the relevant parameters that governs the behaviour in and of a retail store to simulate *normal* behaviour, which is our focus in this paper. However we also touch upon the simulation of malicious behaviour and detection. As fraud in the retail setting is usually perpetrated by the staff we have focused on that. Examples of such fraud is e.g: *Sales cancellations* The salesman cancels the purchase of some items on the receipt and doesn't tell the customer, pocketing the difference. *Refunds* The salesman creates fraudulent refund slips and keeps the cash refund. *Coupon reductions/discounts* The salesman registers a discount on the sale and doesn't tell the customer, pocketing the difference. In many of these cases the fraud is simplified if the customer is an accomplice.

A. Model

The design of *RetSim* was based on the ODD model introduced by Grimm et.al. [18]. ODD contains 3 main parts: *Overview*, *Design Concepts* and *Details*.

We aim to produce a simulation that resembles a real retail store. Our main purpose is to generate a synthetic data set of business transactions that can be used for the development and testing of different fraud detection techniques. It is important due to the difficulty of finding a sufficient amount of diverse cases of fraud in a real data set. However this is not the case in a simulated environment, where fraud can be injected following known patterns of fraud.

There are three agents in this simulation: *Manager*, *Sales clerk* and *Customer*.

Manager This agent decides the price, check inventory and order new items.

Sales clerk Is in charge of promoting the items and issues the receipt after each sale. A sales clerk can be in state busy when the clerk is serving its maximum amount of customers.

Customer The behaviour is determined by the goal of purchasing one or several items. A customer is in an active *need-help* state, when no sales clerk is assisting the customer with its shopping.

1) Process overview and scheduling: During a normal step of the simulation, a customer enters the simulation, and a sales clerk sense nearby customers in the *need-help* state and offers help. There are two different outcomes: Either a transaction takes place, with probability p, or no transaction takes place with, trivially, probability $1 - p$.

The time granularity of the simulation is each step representing a day of sales. So a normal week has seven steps and a month will consist of around 30 steps. We do not make any explicit distinction between specific days of the week. Instead we handle differences between days by using a different distribution of the customers per day.

2) Design Concepts: The *basic principle* of this model is the concept of a commercial transactions. We can observe an *emergent* social network from the relation between the customers and the sales clerks. Each of the customers have the *objective* of purchasing articles from the store. The sales clerks *objective* is to aid the customers and produce the receipt necessary for the generation of the data set. Managers play a special role in the simulation. They serve as the schedulers for the next step of the simulation. Given the specific step of the simulation the manager generate a supply of customers for the next day and activate or deactivate specific sales clerks in the store. In our virtual environment the *interaction* between agents is always between sales clerk and customer. Purchase articles from another customer or selling articles to a sales clerk is not permitted.

Customers and sales clerks can scout the store in any radial direction from their current position and search or offer help, respectively.

The agents do not perform any specific learning activities. Their behaviour is given by probabilistic Markov models where the probabilities are extracted from the real data set.

3) Details: The simulation starts with a number of sales clerks that serve the customers, an initial number of customers and one manager that does the scheduling.

The in-degree distribution is used as an indication of how good a sales clerk can be. Each sales clerk is assigned an in-degree value in each step of the simulation when the sales clerk searches for customers in need of assistance. The bigger their in-degree the more customers they can help.

RetSim has different inputs needed in order to run a simulation. The input data concerns the distributions of probabilities for scheduling the sales clerks, the items that can be purchased and different statistic measures for the customers. A CSV file which contains an identifier, description, price, quantity sold and total sales specify these inputs. For setting the parameters, including the name of the CSV-file, we use a parameter file that is loaded as the simulation starts or the can also be set manually in the GUI.

Figure 1 shows the different use cases of the agents. This model represent the different actions that an agent can take inside the system.

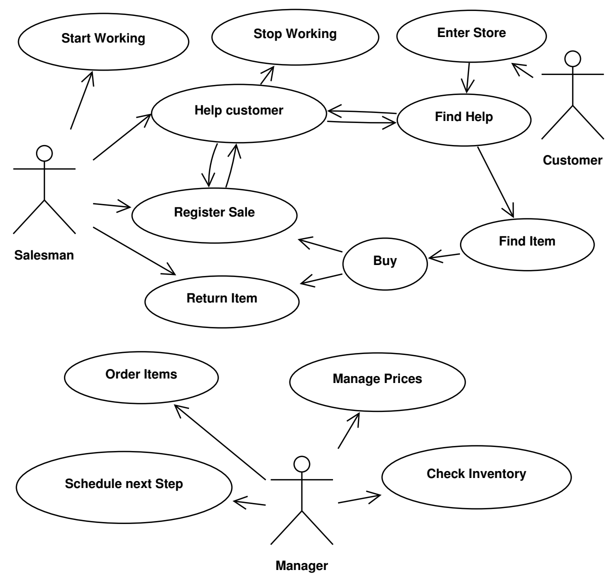

Fig. 1. RetSim Use Case Diagram

Manager scheduler: This agent is in charge of scheduling the next step of the simulation. There is only one manager per store. This agent creates the new customers that are going to arrive to the store according to a distribution function extracted from the original data set. The manager also allocate the sales clerks that are going to be active during the this step of the simulation.

Customer finder: Is performed by the sales clerk and it starts with the agent searching nearby for a customer that is not being helped by an other sales clerk. Once the contact is established a sale is likely to occur with a certain probability.

Sales clerk finder: Customers that are still in need for help can also look for nearby sales clerks. This again could lead to a sale.

Network generation: Every time a transaction is performed between a customer and a sales clerk, an edge is created in the network composed of the customers and the sales clerks in attendance. The weight of the edge represent the sales price. The network grows by the inclusion of new customers or sales clerks.

Item selection for purchasing: Items are classified into 5 different categories according to their quantity or units sold. From the original data we extracted the probabilities of each of the categories and quantities. A customer can also purchase more than one item.

Item return after purchasing: A customer can also decide to return a purchased item with a certain probability p.

Log of receipt transactions: Each time an item is purchased a receipt is created. A receipt contains the information about the customer, sales clerk, item(s), quantities, sales price, date and discount if any.

B. *Validation and Verification*

We start the evaluation of our model with the verification and validation of the simulator and the generated data [17]. Verification ensures that the simulation corresponds to the described model presented by the chosen scenarios. In our model, we have included several characteristics from a real store, and successfully generated a distribution of sales that involved the interaction of salesmen and customers.

The validation of the model answers the question: *Is the model a realistic model of the real problem we are addressing*? After the calibration of the model using the original data set, we can see that the descriptive statistics of both top simulations are close to the descriptive statistics of the real data. For the purpose of this presentation we performed visual, statistical tests and evaluated the network topology and parameters to verify that our simulation is sufficiently similar in behaviour to the original data to perform fraud detection testing.

Figure 2 shows an overlap of our sample store with different simulation runs by RetSim. Visually the distributions look similar. However there are several differences in the small shapes.

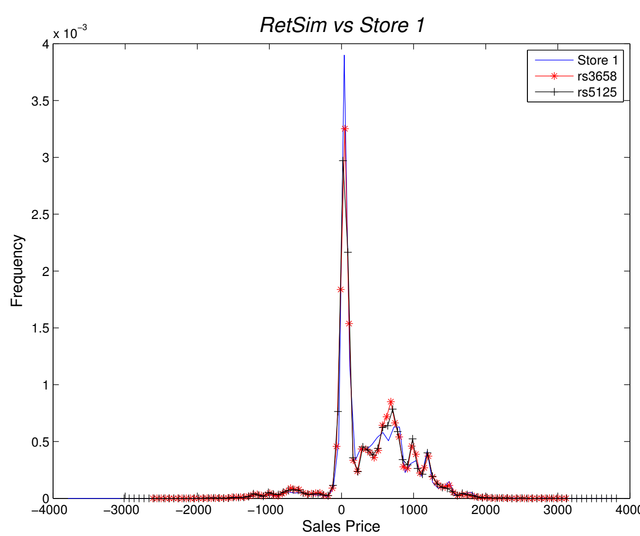

Fig. 2. Comparison of distribution of simulated vs real data

In figure 3 we can see a box plot comparison of store one with the RetSim runs. We can visually identify that the five statistical measures provided by the box plot are similar without being identical.

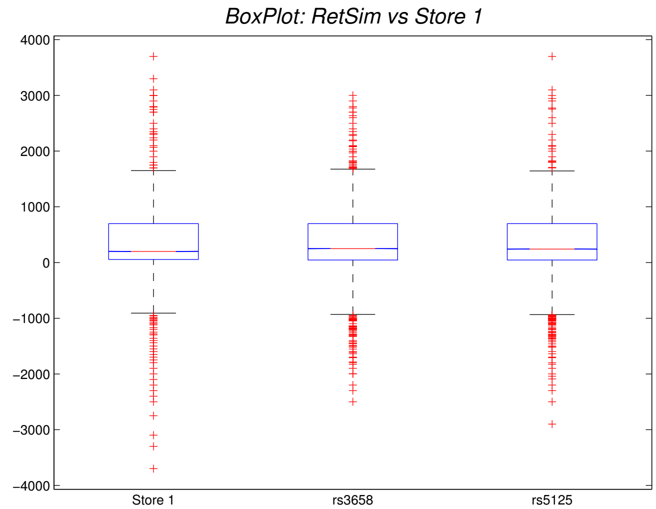

Fig. 3. Box plot of simulated vs real data

Since we are running a simulation, we argue that the differences are not significant for our purpose, which is to use this distribution to simulate the normal behaviour of a store, and later combine this with injected anomalies and known patterns of fraud.

C. *Fraud Scenarios in a Retail Store*

In this section we describe how three examples of retail fraud can be implemented in RetSim. These fraud scenarios are based on selected cases from the Grant Thornton report [19]. As can be seen in section V-A, the different scenarios can be implemented in almost the same way. Furthermore, a fraudulent sales clerk will probably use several different methods of fraud, which means that RetSim needs to be able to model combinations of all fraud scenarios implemented. Although the implementation of these scenarios are out of the scope of this paper, we include a description and explain how to implement them in RetSim.

1) Refunds: This scenario includes cases where the sales clerks creates fraudulent refund slips, keeping the cash refund for themselves. In terms of the object model used in RetSim, the refund scenario can be implemented by the following setting: Estimate the average number of refunds per sale and the corresponding standard deviation. Use these statistics for simulating refunds in the RetSim model. Fraudulent sales clerks will perform normal refunds, as well as fraudulent once. The volume of fraudulent refunds can be modelled using a sales clerk specific parameter. The "red flag" for detection will in this case be a high number of refunds for a sales clerk.

To model the first scenario we need information about the relevant parameters describing the normal behaviour: figure 4 shows the percentage of total value of refunds divided by the total sales for each salesman, for the simulation *rs5125*. The figure shows the values for both the normal behaviour, and two simulations with injected *return fraud*. The first fraud simulation (-+-) shows a conservative fraud behaviour agent where the agent will not attempt to commit fraud if the sales value is more than 800 units in the fictitious currency, and the frequency with which it commits this fraud is 5% of all sales. The total profit obtained by all fraudulent agents in a year is 161630 units in this scenario.

The second fraud simulation (-.-) shows an aggressive fraud agent behaviour where the threshold to commit fraud is 600 units and the frequency is 10% of sales. The total profit obtained by all agents is 400451 units per year.

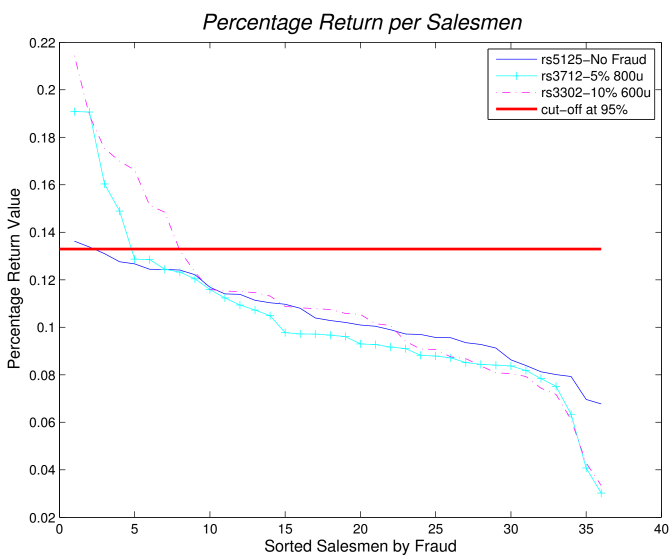

Fig. 4. Return Value Over Sales Total per Salesman

2) Coupon reductions/discounts: This scenario includes cases where the sales clerk registers a discount on the sale without telling the customer, i.e., the customer pays the full sales price, and the sales clerk pockets the difference. In terms of the object model used in RetSim the coupon reduction/discounts scenario can be implemented by the following setting: Estimate the average number of cancellations per sale and the corresponding standard deviation. Use these statistics for simulating discounts in the RetSim model. Sales clerks who perform fraud will make normal discounts, as well as fraudulent ones. The volume of fraudulent discounts can be modelled using a sales clerk specific parameter. The "red flag" for detection will in this case be a high number of discounts for a sales clerk with a low number of average sales.

Figure 5 shows the percentage of the total value of discounts over the total sales before discount for each salesman for the simulation *rs5125*. The figure shows the values for both normal behaviour together with two simulations with injected discount fraud. The first fraud simulation (-+-) shows a conservative fraud agent behaviour where the threshold to commit fraud is 800 units and the frequency is 5% of sales. The total profit per year, for by all agents is 18423 units.

The second fraud simulation (-.-) shows an aggressive agent with a fraud threshold of 600 units and the frequency 10% of the sales. The total profit obtained by all agents is 80600 units per year.

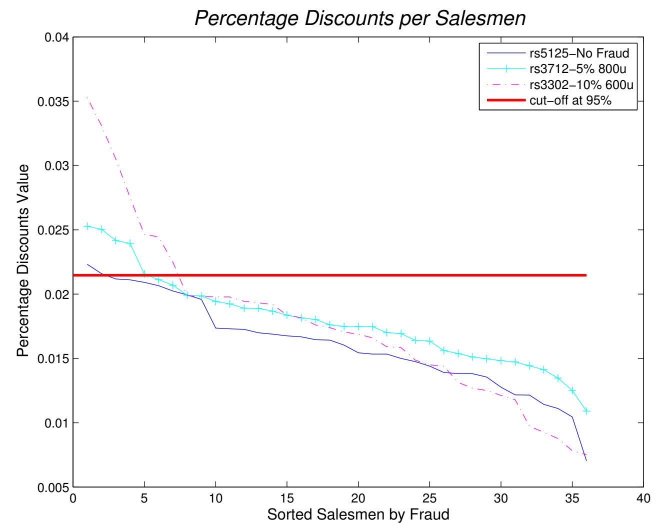

Fig. 5. Discount Value Over Sales Total before Discount per Salesman

D. Results

We extracted statistical information that comprises the sales from one store during one year. The *store one* sample contains 147037 records of transactions. The retailer runs a fidelity program that allows customers to register their purchases. This means that the majority of receipts belong to unidentified customers. However for all these records we can identify the item(s), sales price and the salesman.

Fraud analysis has traditionally been strongly associated with network analysis. This is because of the possibility of several actors participating in a specific fraud in order to confuse the investigators and dilute the evidence, hence describing a network of actors, companies, ownership etc. By doing this we aim to model the micro behaviour of the different agents that captures the observed macro behaviour and gives rise to a total picture of the store. We use the properties of the original social network generated from the customers and simulated a similar network with the aim of keeping the social network properties or the original such as topology, average in-degree and out-degree distribution of the salesmen and customers.

From the network analysis there is a lot of data we can use for our model. One of data point is that the 90.26% of the members have been helped by only one salesman, as described by the out-degree distribution.

We have no known instances of fraud in the real data (as certified by the data owner). So we will have to inject malicious behaviour, by programming agents that behave according to some known or hypothesised retail fraud case presented before: Refunds and Discounts.

In terms of the object model used in RetSim the refund scenario can be implemented by the following setting: Estimate the average number of refunds per sale and the corresponding standard deviation. Use these statistics for simulating refunds in the RetSim model. Fraudulent salesmen will perform normal refunds, as well as fraudulent once. The volume of fraudulent refunds can be modelled using a salesman specific parameter. The "red flag" for detection will in this case be a high number of refunds for a salesman.

Similar to refund scenario, RetSim generates malicious coupon reduction/discounts and the analysis can also be performed in similar way as with refund fraud.

VI. BankSim, a bank transactions simulator

Initial studies started on *BankSim* with the purpose of creating a MABS that can be used for studying fraud prevention pertaining to online financial services. The motivation for this is that authorities like the Federal Financial Institutions Examination Council (FFIEC) in the US and the European Central Bank (ECB) in Europe have stepped up their expected minimum security requirements for financial institutions[20][21], including requirements for risk management of online banking. Thus, access to proper risk management tools is becoming increasingly important, including tools for simulating and being prepared for emerging threats. However we had no access to this type of financial data until we participated in a contest presented by the BBVA bank in Spain. his contest had the aim of promoting the development of applications for the so called "big data challenge" using their aggregated financial information provided by a web service.

A. Data Analysis

The data exposed to the public in the Bank web service contained information on credit card payments during 6 months (November 2012 until April 2013) for the cities of Madrid and Barcelona.

The data was segregated by zip code, gender, and age, and was aggregated by week and month. The web service implemented by the bank provided rich statistical information useful to build an agent model that contains all the consumption patters specified in the data.

The payments were categorised in 14 different categories that allowed the differentiation between e.g. transactions made at a restaurant or in a car dealership. We could also identify consumptions patterns by gender and age, that allowed us to build different kind of agents and implement their consumption pattern according to their given initial characteristics.

A social network is also possible to implement due to the possibility to see the zip code origin of the card used for the payment. Therefore we could identify and build a social network of different agents making payments in different zones of origin.

B. Model

The preliminary design of *BankSim* was again based on the ODD model introduced by [18].

We aim to produce a simulation that resembles real bank transactions between customers and merchants. Our main purpose is to generate a synthetic data set of payment transactions that can be used for the development and testing of different fraud detection techniques. Our model so far only covers bank payments and withdrawals, but we aim to extend it to bank deposits as soon as we can get access to statistical information or real data to properly validate the outcome.

There are two agents in this simulation are: *Merchants* and *Customers*.

Merchant Is in charge of selling one of the categories of available products to the customers.

Customer The behaviour is determined by the goal of purchasing one or several items from the different categories. A customer searches for merchants in its surroundings and execute payments after obtaining the goods.

1) Process overview and scheduling: During a normal step of the simulation a customer can select a category to start a purchase. After selecting the desired category, it enters the simulation environment and sense any nearby merchants that matches the selected category. There are two different outcomes: Either a transaction takes place, with probability p, or no transaction takes place (with probability $1 - p$).

The web service provides detailed information about the time granularity of the transactions. This allows the simulator to set its time granularity between hours or days. So a normal week can either have seven steps or 24×7, if hour granularity is chosen. We do not make any explicit distinction between specific days of the week, information about each day of the week is provided by the web service of the bank.

2) Design Concepts: The *basic principle* of this model is the concept of a commercial transactions. We can observe an *emergent* social network from the relation between the customers and merchants of the same or different zip codes. Each of the customers have the *objective* of purchasing articles or services from the merchants. In our virtual environment the *interaction* between agents is always between merchants and customer. However we aim to extend the model later to allow customer/customer interaction (transfers).

The agents do not perform any specific learning activities. Their behaviour is given by probabilistic Markov models where the probabilities are extracted from the provided data set and specified per hour or day.

C. Evaluation and Results

Similar to the *RetSim* case, we start the evaluation of our model with the verification and validation of simulator and the generated data [17]. Verification ensures that the simulation corresponds to the described model presented by the chosen scenarios. In our model, we have included several characteristics from a real scenario where the interaction between merchants and customers is given by the commercial transaction. We successfully generated a data set of payments that involved the interaction of our agents under our virtual environment.

The validation of the model answers the question: *Is the model a realistic model of the real problem we are addressing*? We calibrate the model using the original data set values.

But since *BankSim* is currently in a development phase, the evaluation and results of this simulator are not yet available. Similar to what we previously did with *RetSim*, we aim to perform visual, statistical tests and evaluated the network topology and parameters to deduce whether our simulation is sufficiently similar to perform fraud detection testing.

VII. Discussion

We started with a rather trivial but meaningful simulation of a payment system (*PaySim*). The original goal of finding money laundering in financial transaction is an ambitious goal which lead us to the building of two more simulators *RetSim* and *BankSim*.

RetSim was our first attempt to simulate commercial transactions based on real data. The benefit of a deep data analysis allowed the simulator to accurately generate synthetic transactional logs of the store. Our evaluation showed that we obtained a data set that resembled the original data set. This without disclosing personal and private information of the customers. We succeed on using this simulator to seek answers about simple threshold detection and its effectiveness. In a real data set the cost of the fraud is most of the time unknown, and it is estimated by using a control mechanism such as inventory control and video surveillance of the store. This does not represent a problem for *RetSim* since we flag each transaction with the type of fraud committed.

RetSim has many improvements over *PaySim*. First, it uses the benefit of real data to calibrate and evaluate the model, second it uses the ODD methodology to describe and model the whole process and specify the agents. It finally uses its output to analyse a realistic fraud scenario and answer questions regarding fraud detection methods.

One piece was missing in the financial chain, and it was a bank simulator. We started to develop *BankSim*. *BankSim* is still in early development but we hope to follow the path of *RetSim* and prove its usefulness on developing and testing fraud detection methods.

All simulators share common log formats for compatibility with other software used to analyse the transactional logs. This is an important characteristic in this framework that will enable us in a future to make available standard data sets to the research community and the public in general.

Every time we build a simulator for financial transactions we aim to make it compatible with the previous simulators and also to avoid previous pitfalls in the design, model and implementation. *PaySim* for instance, required real data to calibrate the model. *RetSim* uses less detailed aggregated information as we are currently using on *BankSim*.

Modelling social financial behaviour of customers have its challenges. This paper present the way we addressed the problem of social simulation for financial transactions. One approach we considered was to implement social economical patterns of consumptions to build up an agent with preferences and choices. However, our goal here is to replace a data set that currently represent an detailed instance of a real world social situation. Using an statistical approach was a straight forward direction for simulation the "normal" behaviour of agents. However, the behavioural patterns known by fraudsters and criminals, allow the implementation a different model that makes the fraudster an agent that aims to maximise its profit and uses specifics patterns of action that aims to disguise the crime. This social behaviour was implemented in our simulators using known criminal behavioural patterns parameterised to fit different fraud scenarios.

We injected the most common known fraud behaviours, but we are aware that there are many other fraud behaviours that can have a significant economical impact on the criminal activities. We have only touched the surface of what is possible with the scenarios we have implemented.

VIII. Conclusions

This paper addressed the problem of a lack of public available data sets for fraud detection research. We experienced this difficulty and discovered that many other researchers in this field share this experience. The three simulators presented in this paper allow researchers to generate synthetic data sets that are useful for experiments in fraud detection.

In summary, we presented three case studies that implement a Multi-Agent Based Simulation model to address the problem of social simulation of financial transactions for fraud detection research. Our agent model with its programmed micro behaviour, produces a similar type of overall interaction network that we can observe in the original data, and furthermore, this interaction network give rise to the same macro behaviour for the whole store as for the real store as well. All three simulators use the same Multi-Agent Based Simulation toolkit called MASON[16] which is implemented in Java.

PaySim is our first attempt and a good example of the use of a synthetic data set representing a simulated scenario in the mobile money domain. We tested some machine learning algorithms to try to detect fraud using labelled data. While doing this we also avoided any possible issue related to privacy and identity protection of the customers of the service.

We also presented *RetSim*, and argued that it is ready to be used as a generator of synthetic data sets of commercial activity of a retail store. Data sets generated by *RetSim* can be used to implement fraud detection scenarios and malicious behaviour scenarios such as a salesmen returning stolen shoes or abusing discounts. We used the *RetSim* simulator to investigate these two fraud scenarios. Our simulator give us the benefit over real data that we can quantify and measure the amount of loses committed by our malicious agents.

We used the *RetSim* simulator to investigate two fraud scenarios to see if threshold based detection could keep the risk of fraud at a predetermined set level. While our results are preliminary, they seem to indicate that this is so. This is interesting in that it could act to explain why we have not observed more use of more advanced methods in industry even though research into more advanced techniques has been common for quite some time now. Another consequence could well be that given that simple threshold based detection is sufficient there is little economic room for other more advanced fraud detection methods that are more costly to implement.

We are currently in a preliminary phase of development with regards to *BankSim*. Our work with this simulator is just beginning with the hope to present interesting results in a future paper. We aim to rebuild our payment simulator based on real data. We have successfully achieved a realistic simulation for a retail store which we would like to extend to different kinds of retail stores. And finally we are negotiating with a Bank in Scandinavia to be able to extend the scope of *BankSim* and be able to access real data sets to model and develop deposits and enrich the *BankSim* simulator.

One of the biggest challenges for is to integrate all three simulators into one single Multi-Simulator that shares a common reference to the customers and can keep track of the transactions of a single agent across all simulators. Money Laundering exist somewhere in a complex chain that starts with *placement* of illegal funds into the legal financial systems, then a number of *layering* operations to hide the true origins and finally an *integration* stage that involves formal and legal economic activities. Our approach will focus on the integration of these different domain simulators as the key to research in the area of money laundering.

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Use of an agent-based model to explore urban transitions in commuter cycling

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***Abstract*— Encouraging a cycling culture while reducing car usage can lead to substantial health and environmental benefits. In this exploratory work, we use an agent-based model of commuter cycling focusing on the emergence of social norms due to interactions between agents and their environment (including their social networks). The overall goal is to develop an understanding of change and continuity in cycle commuting, and how this is shaped by dynamic relationships between social expectations and individual attributes. Initial characteristics of agents and the distribution of cycling in the population come from the Census and secondary quantitative data. The theoretical basis of our work comes from qualitative studies on cycling and from 'Theories of Practice', which see practices as enrolling individuals, depending on whether they have the material and cultural resources required to participate. Thus, rather than treating humans as rational individuals who, for example, follow the precepts of utility maximization, we explore how changes in norms surrounding cycling practices (such as social expectations around clothing and accessories) shape uptake, and how uptake then affects social norms relating to cycling., We test policies for increasing cycling usage based on provision of cycling stuff and improvements to the environment.**

I. Introduction

In this project we have developed an agent based model (ABM) to help understand how the transition to high cycle commuting cultures could be achieved. Mass cycling has the potential to achieve substantial health and environmental benefits [1]. For this we have drawn on largely qualitative research on cycling in England and been informed theoretically by insights from theories of practice. Theories of practice offer a distinctive perspective on agent behaviour [2]–[4]. Within transport, agents have typically been modelled as utility maximizing actors with static preferences for transport modes. Other approaches, focusing on potential for behaviour change, seek to identify psychological states associated with shifts from intention to action.

This paper's alternative approach is drawn from sociology. Priority here is given to the lived occurrence of the behaviour and the different elements that constitute it in different environments. Social norms are seen as interacting with individual characteristics. Core concepts – meanings, abilities (skills) and stuff (materials) – come from practice theories. All three concepts are defined as having both a social and an individual dimension.

In our case, the social dimension refers to shared perceptions about the cycling context, in relation to meanings, abilities, and stuff needed. For example, where cycling is perceived as very dangerous, it may also be widely believed that only very able and fit people, possessing large amounts of cycling equipment, can cycle. Conversely, where cycling is seen as a safe, everyday activity not requiring specialist clothing, it may also be seen as something that many people of varying abilities may wish to be associated with. Beliefs within cycling contexts will vary along a distribution, but, we believe, they can still be characterised and contrasted. In this version of the model we simplified complex relationships by (a) omitting 'abilities', so focusing only on stuff and meanings and (b) concentrating on what evidence suggests to be the most important meaning in the UK: danger.

The individual dimension refers to (i) the extent to which an agent wishes to be (dis-) associated with specific meanings (in the case of danger this can be seen as the level of tolerance for danger) and (ii) the level of cycling-related stuff owned by the agent. Individual danger tolerance is simplified as only changing with age while stuff is dynamic: changing as people gain or lose cycling-related stuff. The social dimensions of meaning will shift in relation to the changing individual characteristics of people who cycle (agents update their knowledge of the cultural context based on what they see others doing). This approach foregrounds the relationships between social norms surrounding cycling and the individual characteristics or preferences corresponding to those norms. It enables us to examine how both social norms and individual attributes might shift, and the relation of this to changes in cycling practices.

II. Model Description

Purpose: The purpose of this model is to understand the practice of commuter cycling and test interventions which may lead to transitions. Cycling practices are conceptualized as the outcome of social norms and expectations, individual attributes, and social interactions and observations.

Initializing: The number of agents is fixed in the simulation and does not change with time, although individual agents leave (retire) and are replaced. Demographic characteristics and initial distributions of predispositions towards cycling are informed by the Census and other secondary data sources. The cycling context is set at initialisation from one of the three cultures: low, emerging and established. All three cultures represent various contexts (cities and within them workplaces and neighborhoods) in the UK based on the population, perception and infrastructure for cyclists. These are based on our previous work [5], and are defined by the levels and types of cycling practices that are dominant, which affects the extent to which such practices are exclusive or inclusive, and who is included or excluded. The social network covering households, workplaces, neighbourhood, commute zone is initialized on a random basis, but the topology of the network is made as a power-law outlook for degree distribution. This network is dynamic in nature to mimic real life.

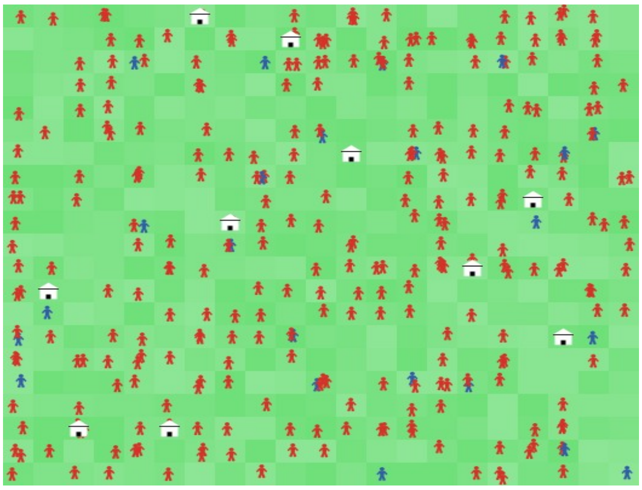

Figure 1 - Model Environment

The social networks (composed of family, friends, neighbours and work colleagues) and people observed while commuting affect understanding of cycling practices and the requisites for and barriers to participating in the practice. Each agent represents an individual in our model, with heterogeneous characteristics and orientation towards local cycling practices. There are three categories of links between people: core ties, strong ties and weak ties. Literature on social networks suggests that number of ties when plotted on a log-log scale against the number of people, is linear. In other words, the number of ties follows a power-law degree distribution [6]. For each agent, there are five core social links which are biased toward one's neighbours and work colleagues. On top of that, for weak and strong ties, we use the *Social Circle* algorithm [7] to develop a scale-free social network – a few people have a lot of links, while the majority have a fewer links. We constrained the overall network to have a higher clustering coefficient compared with a random network with the same density. Table 1 shows the overall initialization process.

Figure 1 shows the main environment of the ABM. The colour of the individual agents represents their cycling status (red for non-cyclist and blue for cyclist). The workplace agents are represented by small houses, and the colour of the patch represents the quality of the cycling environment

Set the dimension of the square grid (20×20)
Divide the agents into two types: A (people) and B (workplace)
Assign fixed number (usually 30) of agents A in each workplace B.
Divide cycling cultures into three types: low-cycling culture, emerging cycling culture, and established cycling culture.
Based on the culture, define the initial percentage of cyclists (2 for low; 8 for medium; and 30 for high cycling culture)
Set (3-5) social links for each agent – known as core links. On top of that, develop strong and weak ties based on power-law outlook.
Initialize meaning (personal danger & cycling danger), stuff (needed, owned, and used) according to their initial distribution.

Table 1- Overall Initiation Process

Culture specific danger variables:

Figure 2 shows for each of the three cultures the initial distribution of personal danger based on the findings of qualitative studies [5], [8]. The red curve represents low cycling culture where the majority of the people have a much higher association of cycling with danger. In high cycling culture it is completely opposite – there is a very low association with danger, whereas in the emerging cycling context, the cycling danger is symmetrically distributed.

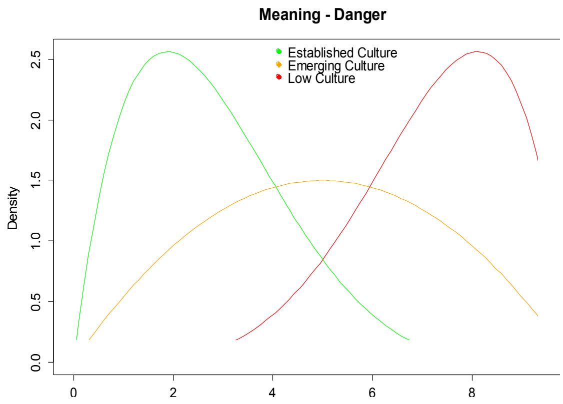

Figure 2 - Cycling Danger in Different Cultures. The X axis shows the strength each culture gives to cycling danger. It ranges from 0 to 10, where low value represents low, and high value represents high strength. The Y-axis shows the population density.

We have also incorporated incidents into our model which represent any kind of negative experience while cycling. These include, for example, abuse from motorists or pedestrians and near misses [9] but do not cover much rarer serious injuries. The risk of incidents is assumed to be related to the quality of the environment.

Model Run: After initialization, each agent, depending on his/her social network and cycling history, either has or has not the resources to engage in a local cycling practice. Each time step covers a week). At each time step, changes in the observable characteristics of the agents, such as their cycling stuff, are recorded. Changes in the nature and composition of cycling practices in areas of the abstract geography defined by a matrix of square grids are determined.

Influence:

It is assumed that each agent is influenced by four sets of agents:

1. Those living in the agent's home zone
2. Those working in the agent's workplace zone
3. Those in the agent's social network
4. Those who traverse the agent's commuting zone

The four types of network differentially enable two types of social influence: social observation (SO), and social interaction (SI). The first three sets of agents have both types of influence (SO, SI) whereas as the fourth set agents has only the second type (SO). SO describes when an agent observes other agents cycling (for example, in the local neighbourhood) whereas SI describes when an agent has a social interaction related to cycling with another agent (for example, a work colleague). The probability of a social interaction is influences by the strength of social ties.

Dynamics:

Stuff Needed: Based on observing and interacting with others, each agent may change their perception of the stuff they think is required for cycling (e.g. helmets, bike locks). We have chosen to focus on safety equipment as this is most associated with the danger meaning.

Stuff Owned: Each agent may change the cycling stuff they own, unilaterally, or through social interactions (by borrowing or donating). Stuff is assumed to be randomly and slowly lost over time.

Stuff Observed: Each cyclist observes other cyclists which s/he sees in her/his commute path, and then adjusts their perception of stuff (needed) accordingly.

Meanings: Taken from the qualitative literature, we identified seven meanings potentially associated with cycling; (1) danger, (2) fitness/health, (3) poverty, (4) affluence, (5) environmentalism, (6) fashion, and (7) "suitable for my demographics". In this model, however, we have focused on the meaning of danger as this meaning is widespread and strongly shapes currents patterns on cycling in England [10]. The degree to which cycling is associated with danger is updated dynamically based on observations of, and interactions with, other agents.

We assumed a linear relationship of cycling danger with stuff-owned. The more safety stuff someone owns, the more likely they will associate cycling with danger. At every simulation step, the stuff owned will (fractionally) move cycling danger towards this linear relationship.

Enrolment into cycling is influenced by (a) whether the stuff possessed by the agent equal or exceed the stuff s/he thinks s/he needs, (b) whether s/he wishes to be associated with those meanings s/he associates with cycling, and (c) their cycling experience in the past year.

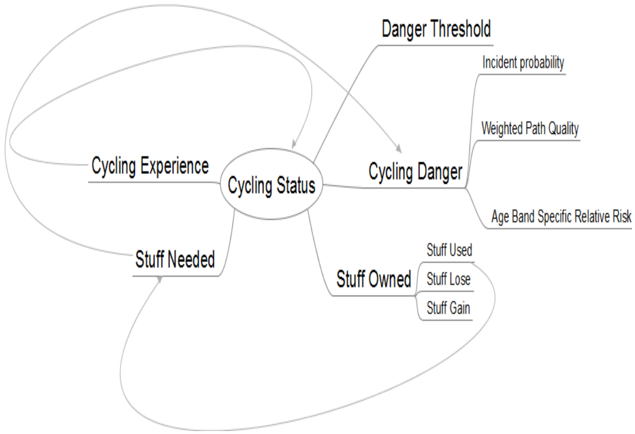

Figure 3 - Overall Mechanism

Figure 3 displays how attributes about stuff and danger towards cycling, would help determine the cycling status of a commuter. Overall enrolment in cycling practice depends on: cycling experience (experience of the past year), stuff needed, stuff used, cycling danger, cycling danger threshold. If an agent has sufficient stuff, and also his/her cycling danger is greater than his/her danger threshold, then s/he becomes a cyclist. Figure 3 also specifies how an incident affects cycling danger. Incidents occur probabilistically based on the environment a cyclist is exposed to in his/her path and their age specific relative risk. If an incident happens, it negatively changes the perception of cycling danger. This change in perception is also propagated through the social network. Unlike other attributes in this figure, the stuff needed is an observational variable based on the other cyclists one observes in his/her commute path. Based on the principle of homophily, people are more influenced by people of their own gender, age and socio-economic status.

We have implemented two potential strategies to increase cycling, (i) improvement in the cycling infrastructure, and (ii) workplace policies to provide safety stuff to employees.

III. Results

We have drawn results from our model focussing on two aspects. The first aspect is the changing trend of the proportion of cyclists over time. Figure 4 shows a sample of 10 stochastic trajectories of cycling trend in low cycling culture over a simulation period of 10 years (with the same fixed settings). We have not set a random seed with a fixed value in the random number generator to exhibit the different trajectories. The overall average remains approximately the same as the initial population of cyclists (2% versus 2.1%).

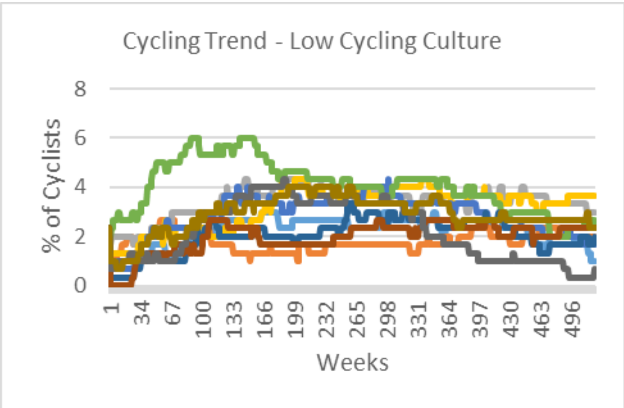

Figure 4 - Cycling Trend for Low Cycling Culture

Similar results have been drawn for emerging and established cycling cultures in Figure 5 and Figure 6 respectively. As in the case of low cycling culture, each result comprises 10 trajectories. In the emerging culture, the percentage of cycling increases in the first year and then remains stable for the next two years. After that it starts declining – and ends at 7.8%. However, in the established culture, the cycling rate remains stable for the whole simulation period. In this case, the overall average percentage reduces from 30% to 27.9%.

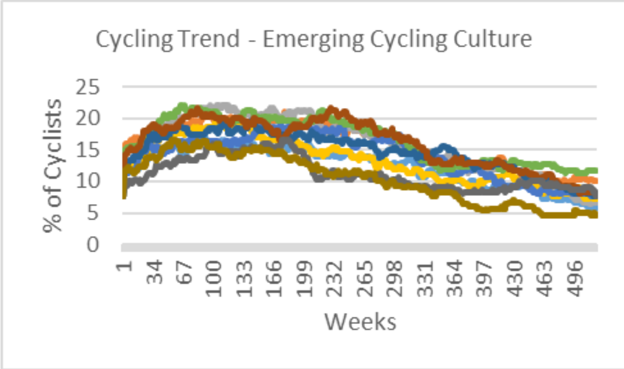

Figure 5 - Cycling Trend for Emerging Cycling Culture

The second aspect we focussed on is the evolution of cycling practices over time. We investigated practices by examining whether meanings and stuff cluster and if so whether these clusters relate to demographic and workplace characteristics. For illustrative purposes, we show the results of one of the cycling cultures – the low cycling culture. Figure 7 shows that nine clusters have been identified based on the initial group classification. The stuff owned goes hand in hand with cycling danger; both are low or both are high.

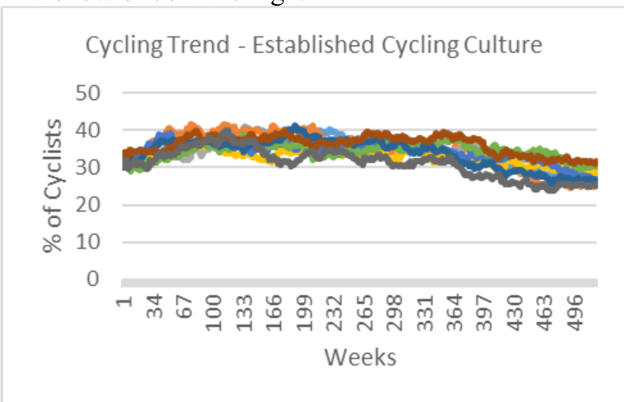

Figure 6 - Cycling Trend for Established Cycling Culture

Figure 8 shows the changes of practices at the end of the simulation period (after 10 years). The number of clusters has been reduced to five. With the perception of danger associated with culture increasing over time, the stuff owned has also increased. Several diverse cycling practices have emerged. In the figure below, for instance, the red boxes represent one cycling practice which revolves around low to medium levels of stuff owned with that of medium level of association with cycling danger.

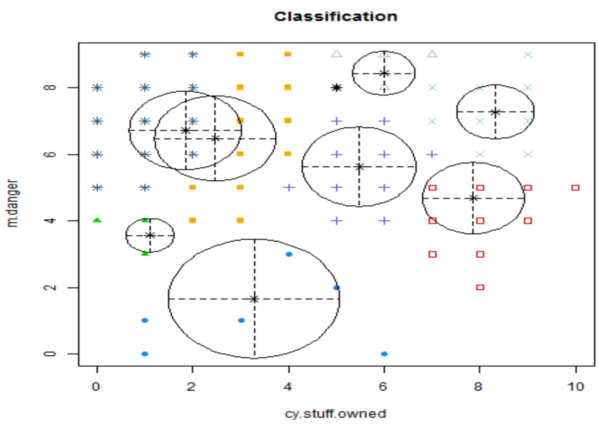

Figure 7- Cycling Practices clustered by Stuff Owned and Cycling Danger at Week 0. The X-axis shows how much cycling stuff people own (low value represents low stuff, whereas high value shows more stuff). The y-axis show cycling danger (low value represents lower cycling danger)

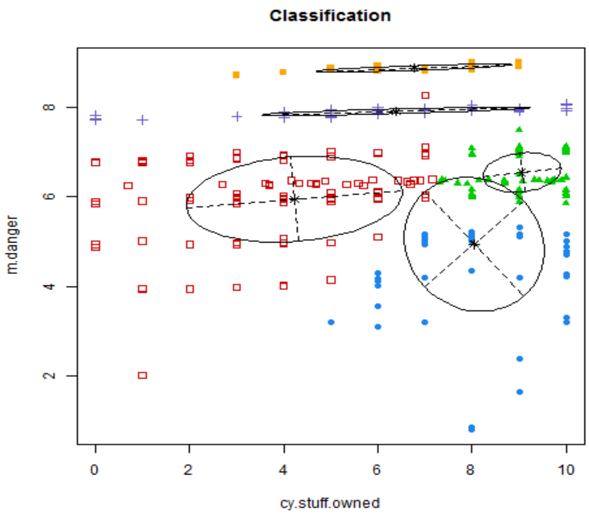

Figure 8 - Cycling Practices at the end (year 10)

IV. Conclusion and Future Work

In this paper we have presented a model of uptake of cycling to work which is inspired by the theories of practices. The enrolment in the cycling practices is an outcome based on both individualistic perceptions (meanings) and assets (stuff), as well as social interaction and observations (of both environment and other people). We have employed cluster analysis to identify various cycling practices and their evolution over time, based on meaning and stuff. Ongoing analyses of three qualitative datasets will help us determine the goodness-of-fit of these clusters. We will investigate how the clusters evolve over time and whether they exhibit sudden transitions which represent discontinuities or phase shifts from one type of behaviour to another. In addition, we will investigate how to quantify the uncertainty in the clusters resulting from propagating upstream uncertainties (e.g. uncertainties in the behaviour rules).

Model outputs are in turn being analysed qualitatively, with analysis both of sample cluster characteristics in each context and of sample individual trajectories from all clusters and contexts. This will then be compared with research findings about such cycling cultures, to establish the plausibility of the individuals and clusters being simulated. Similarly, narrative analysis of model outputs relating to our intervention scenarios will be studied for plausibility in relation to evidence around the two types of intervention being modelled.

Acknowledgment

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An Agent-Based Simulation of the Emergence of Partnership Systems in Early Renaissance Florence

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Abstract— The emergence of the partnership system in Early Renaissance Florence is often noted as a pivotal moment in the formation of capitalism. However, this social invention was not developed as a completely redefined system, but was the gradual process of adapting guild partnerships to domestic and international business. The purpose for this paper is to describe a simplistic agent-based model, where individuals form partnerships based on paradigms common in the medieval Florentine economy, as well as the results of the simulations. The final result is the emergence of entirely different partnership network structures, consistent with the structures seen in the early 15th century, as well as a rise in individual capital which led to the success of this system replicating itself across the European landscape.

I. Introduction

THE Florentine economy of the early 14th century, while diverse and dynamic by European standards, did not operate significantly differently from other places in Europe at that time. However, by the beginning of the 15th century, and decidedly by 1434, the new economic model of patronage, business alliances and international partnerships not only formed the backbone of the Florentine economy, but was being exported throughout the Italian peninsula and across Western Europe.

It is tempting to imagine these "new men of business" as revolutionaries, determined to redefine the way of doing commerce and international trade. However, this is often at odds with the relatively conservative mindset of the bankers who established this system. If anything, they were counter-revolutionaries, determined to bring order and hierarchy back to Florence after the proto-Marxist Ciompi Revolt of 1378. How, then, can we consolidate these two competing views?

A hypothesis put forth by Padgett and McLean [1] is that the partnership system, what Melis (1962) called the *sistema di aziende*, was constructed not out of whole cloth, but by adopting a formerly existing system of apprenticeship that already operated in the guilds for the purposes of business partnerships. Padgett and Powell [2] define the emergence of new organizational processes in much the same way as biological evolution, as the adaptation and proliferation of one pattern in a different context, and the improvement of that process incrementally over time.

In the context of the emergence of partnership systems, Padgett [2] in Chapter 6 defines this particular economic invention as "a set of legally autonomous companies linked through one person or through a small set of controlling partners." He argues not only that this partnership system emerged from domestic bankers adopting the partnership paradigm of the guilds, but that the impetus for this invention came in the aftermath of the Ciompi Revolt of 1378. In this turbulent aftermath, lawmakers sought to stifle the negotiating power of the tradesmen and so, unwittingly, encouraged them to form partnerships with the relatively few domestic bankers, thus propelling these men into international commerce.

A. The Ciompi Revolt and the Aftermath

In 1378, a revolt of the *ciompi*, known collectively as the *popolo minuto*, or "little people", succeeded in kicking the wealthy patricians (known as the popolani and the magnates) out of Florence for a time, in the only successful worker's revolt in pre-industrial European history. As this forced much of the wealth out of the city, export-oriented commerce ceased. This prompted the minor guilds and the liberal popolani to retake power in September 1378. This regime, in turn, was crushed by the major guild leaders and the domestic bankers in 1382.

The revolt sparked waves of political reactions, each one more elitist than the last. Each regime added layers of oversight onto guild leadership. The 1382-1393 regime, paradoxically, aimed to limit the very autonomy which granted its power by forcing approval, and eventually the selection, of guild consuls to an external body, the Mercanzia. Eventually, the oversight of guild leadership and practices had the incidental effect of encouraging guildsmen and tradesmen to produce partnerships not within the guild, but outside of it, in order to garner more capital, both political and monetary. The domestic bankers, for their part, sought to seize upon this lucrative opportunity by adopting the partnership paradigms the guilds already had in place, the master-apprentice system.

This practice proved to be lucrative for both parties, and caused the economy of Florence to flourish, most notably for the banking families. While the specific actors changed over time, the success of the partnership system – ownership of various businesses and companies – was already well established by 1434, when Cosimo de Medici returned to Florence to end up becoming the de facto ruler, with power which relied heavily on his business partners.

B. Emergence and Analysis

The goal of this paper is to model and simulate the emergence of the partnership system, through the implementation of a revolt in the simulated environment. This model will simulate agents, representing individuals, making partnership decisions. At a point in simulated time, a revolt will occur in the model (replicating the Ciompi Revolt and the aftermath), which will prompt the agents to reassert their partnership paradigm based on the laws of the new regime.

II. Methodology

A. Agents

The model designed for this analysis uses heterogeneous agents to represent stylized individuals in the Florentine economy in the 14th century. These agents do not represent actual historical figures, but rather abstracted decision makers operating on a paradigm that has been hypothesized by historians on the mindset of conservative Florentine businessmen.

The two types of agents that are represented in this model are 'bankers' and 'tradesmen'. Bankers represent the merchant bankers of Florence, who began as almost purely domestic bankers in the early 14th century and, by the beginning of the 15th century, had become international businessmen. 'Tradesmen', in the context of this model, are loosely defined as guildsmen – men who were skilled in a trade and, per the usual paradigm of the High Middle Ages, were part of a guild in the early 14th century.

Agents are defined not only by their class, {banker, tradesmen}, but also by attributes. These attributes abstractly define an individual's place in society, as well as their desirability as a partner, which will be discussed in the next section:

- Capital (c_i) – this attribute represents the relative wealth of an individual.
- Expertise (e_i) – this attribute represents the agent's skill in his craft. While there were certainly different trades in Florence at this time, this model does not distinguish between guilds at the present time.
- Age (a_i) – a simple calculation of age, which increases each year. At random points, agents will die and be replaced with a new agent.

B. Partnerships

Partnerships, either business partnerships or apprenticeships, were formed by individuals selecting a different agent that was geographically close to them as well as held a significantly high attribute in either capital or expertise. Tradesmen of the medieval period would often form apprenticeships, with a master gaining a significant amount of the capital, and the apprentice gaining experience and expertise in the craft [source here]. These master-apprentice relationships would often become enveloped into guilds, where masters of a given craft would partner together for negotiating power.

Prior to the revolt, tradesmen make decision on who to partner with in the following calculation (assuming agent j is active):

$$\min_i \left[\left(d_{ij}\right)^2 - 0.1 \times e_i \right] \quad (1)$$

Where d is the Euclidean distance between tradesmen i and j. This represents tradesmen making connections to the most experienced tradesmen in their most immediate vicinity. These partnerships, like the master-apprentice partnerships they represent, are directed and non-equal.

Bankers make similar partnerships with other bankers, although the partnerships are undirected. They are formed along the following paradigm (assuming agent j is active):

$$\min_i \left[\left(d_{ij}\right)^2 - 0.1 \times c_i \right] \quad (2)$$

After the revolt, the partnership paradigm of the tradesmen changes to that of the bankers - the paradigm quantified in equation (2). In addition, any new partnerships the tradesmen make will be with bankers, rather than fellow tradesmen. This aims to replicate the 1382-1393 regime and the oversight of the guilds by the Mercanzia.

These partnerships also impact the attributes of those participating. For a tradesmen that has a partnership directed out of the agent (i.e. an apprentice), his expertise (e_i) increases by one for each outgoing partnership. For both partners of any partnership, capital (c_i) increases by one for each tick.

C. Simulation Setup

This model was coded and simulated using NetLogo 5.0, an agent-based toolkit that can graphically represent not only heterogeneous agents, but also links between these agents. This model defines two breeds of agents, tradesmen and bankers, with the attributes described in section II.A. Each tradesman is initialized with $c_i \sim U(0, 10)$ and $e_i \sim U(0, 100)$, where each banker is initialized with $c_i \sim U(0, 100)$ and $e_i \sim U(0, 10)$. Both types of agent are initialized with age ~ U(0, 1000), representing any age from 0 to 83 years old.

As the positioning of agents is important (both historically and in this simulation) to the creation of partnerships, the location of bankers and tradesmen needed to be defined. Tradesmen are randomly placed in the lower half of the model world, while bankers are randomly placed in the upper half of the world. The model world can be assumed to be a toroid, meaning that the edges continue along the opposite side of the simulated world. The graphical representation of the bankers are blue person icons, while the tradesmen are red person icons. A view of the model in the middle of the run can be seen in Fig. 1.

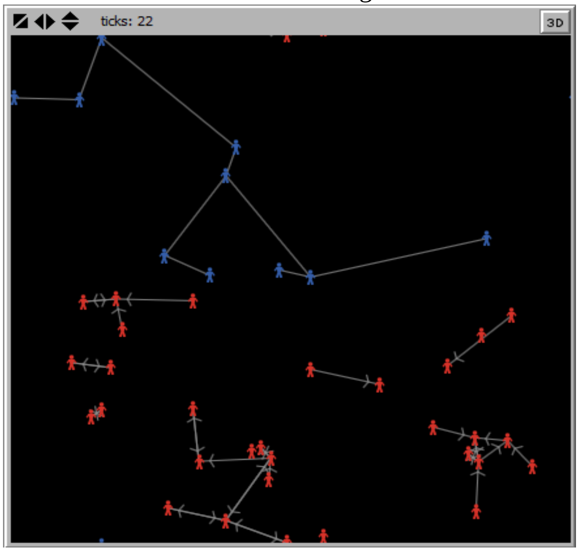

Fig. 1 Screen shot of simulation model

As time progresses from month to month, age increases by one each simulation tick. In each tick, each agent selects a random value with an exponential distribution and a mean of 600. If this is higher than their current age, then the agent dies and is replaced with a new agent with attributes holding zero values.

At a certain point in the model, the global Boolean variable "revolt", which always begins the simulation set to False, may be set to True. In the model runs described in this paper, the simulated revolt occurs in the middle of the simulation run, at t = 600. This represents the Ciompi Revolt, as well as the succeeding regimes of the following one and a half decades. Partnerships are not immediately disbanded, but a new paradigm is enacted which promotes new partnerships to form across trades, formed between bankers and tradesmen, as observed in the following section.

The model is populated with 10 banker agents and 30 tradesmen agents at time 0. The simulation is then run for 1200 ticks, where the revolt occurs at tick 600. The primary output of the model is the average per-capital capital across the entire agent population. The primary method of analysis of results was Monte Carlo Simulation, running the model for 1000 runs, with different random seeds.

III. Results

A. Rise in Capital

The primary output for this model, per-capita capital across the agent population, shows a consistent increase after the revolt occurs. The null hypothesis of H_0: $\mu_0 = \mu_1$ can be tested in respect to the alternative hypothesis, H_1: $\mu_0 < \mu_1$ (one-tailed Z-test). Two averages are taken from each run - the average of the 600 observations (1 per tick) of per-capita capital prior to the revolt (revolt = FALSE), and the average of 600 post-revolt observations (revolt = TRUE). The statistics for each of these populations across the 1000 runs is shown in Table I.

TABLE I.
STATISTICS FOR PER-CAPITA CAPITAL OUTPUT, PRE-REVOLT VS. POST-REVOLT AVERAGES

Statistic	Pre-Revolt (revolt = FALSE)	Post-Revolt (revolt = TRUE)
Average	3.3648	14.3325
Standard Deviation	0.4759	1.0231
Number of Observations	1000	1000

At any reasonable level of significance, the Z-test produces a p-value of 0, leading to the conclusion that the null hypothesis can be rejected in preference to the alternative hypothesis, meaning that the jump in per-capita capital across the model is statistically significant.

B. Network Structure

It is important to note that not only does the network structure shift across the model when the revolt occurs, but whether the networks both before and after resemble to some degree the networks that occurred in Florence in the 14th and 15th centuries.

Prior to the revolt, the tradesmen partnerships are limited in scope to 2-6 participants, usually due to the death of the master and the apprentice breaking his tie and forming new ties. Partnerships across the bankers tends to be reasonably diffuse, a banker only forming on the order of 1-3 partnerships at any given time.

This pattern changes rapidly after the revolt, when the bankers become the major hubs of networks. Qualitatively, this can be seen in the structure of the networks at the end of the simulation run, as shown in Fig. 2. Quantitatively, the number of links that bankers achieve throughout their life increases, , as seen in Table II, which displays the averages across all runs of the median and maximum degree values.

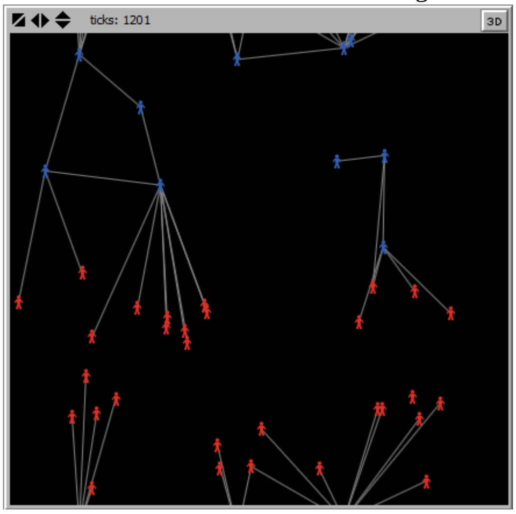

Fig. 2 Screen shot of simulation model at end of a simulation run

TABLE II.
STATISTICS FOR LINKS PER AGENT, PRE-REVOLT VS. POST-REVOLT AVERAGES

Statistic	Tradesmen Pre-Revolt	Tradesmen Post-Revolt	Bankers Pre-Revolt	Bankers Post-Revolt
Median No. Links per run	1.9051	1.1090	1.3340	3.9971
Maximum No. Links per run	4.8188	2.7604	2.5853	10.6292

IV. DISCUSSION

A. Findings

The model was able to simulate the emergence of two substantially different networks structures across the population, punctuated by the revolt global variable. This was not generated through a top-down infrastructure design, but from agents assessing their "best" choice for a partnership. Although the selection and partnership process may not be verifiable –as certainly every banker, guildsman and contract were different – the model was able to establish some abstract, stylized guidelines that produced a new model environment.

The second interesting finding was that the per-capita capital, or the capital across the individuals, was dramatically increased, due to these new partnerships forming. Although such mental constructs as "profit margins" and "utility maximization" are not generally appropriate in the medieval or renaissance mind [3], the access to capital was of importance to tradesmen and bankers both. The new partnership system dispersed across the Western World as a mechanism for generating capital.

B. Implications

The new partnership system not only increased the wealth and influence of those partners involved, but also led to emergence of Florence as a cultural hub. This system did not emerge from a completely new creation, but the reuse of one legal mercantile construct by new actors. Bankers became the new oligarchs of the Florentine republic, culminating in the dominance of the Medici in 1434, largely due to their power derived from the partnership system.

In a more subtle extension of this new partnership system, these new republican oligarchs had ties to numerous industries, as well as the business and political acumen to survive in both worlds. These new elites were the beginning of what today we would term "Renaissance men", being the archetype of the values made possible by the partnership system, as addressed by Padgett [2].

C. Further Research

To say that this is a highly simplistic, stylized, and abstract model is accurate. There were certainly multiple dynamics going on during this turbulent time in Florentine history that led to the exact nature of the partnership system as we know it. While this model has already shown the most basic conclusion – the emergence of a partnership system from the actions of agents – more elements can certainly be added to the model to garner many more results and descriptions about this simulated Florentine Republic.

More importantly, while the qualitative structure of the partnership networks were informally validated, more thorough, formal validation techniques will be necessary to quantitatively validate this model and the results. This can be done by comparing the statistics of networks (density, centrality distributions, etc.) of the simulated networks to that of the historical networks. These data have not been available until recently; new work in this field over the past decade has allowed for analysis, and comparison, of historical networks to be analyzed quantitatively.

Finally, agent-based modeling has offered interesting and complex views into the past, illuminating on patterns of culture and society that may not otherwise be discernible through lack of archaeological evidence [4]. It is possible that this model, and others like it, incorporating agent-based models with social network analysis, may shed light on the emergence of social invention at various points in human history.

V. SUMMARY

The goal of this paper was to present a simulation model aimed at replicating the emergence of the partnership system in early Renaissance Florence. Ultimately, the structure of the network produced both prior to and after the simulated revolt within the model showed similarities to the networks documented in the late 14th and early 15th centuries in Florence. Furthermore, the rise in capital that in part derived from this new network structure was an emergent property of the model, one that may explain the success that the partnership system garnered in reproducing across Western Europe. Through this highly abstract, simplified model of network construction between stylized agents, it may be possible to answer further questions on the nature of the emergence of capitalism and mercantilism in renaissance Florence.

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Modelling Interactions and Feedback Mechanisms in Land Use Systems

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Abstract — Land use change (LUC) is often a complex process. In such a process land use systems can show non-linear behaviours caused by mechanisms such as interactions between agents and feedbacks from higher system level. Land use systems might be very sensitive to such non-linearity, for instance in the form of tipping points, which lead them to a different land use regime. Many models deal with the causes and consequences of LUC but few focus on the non-linear process in land use systems. Thus there is a need for an explicit treatment of interactions and feedback mechanisms in LUC models to better understand the behaviour of land use systems. Two primary mechanisms are implemented with an agent-based model (ABM) to capture 1) the social interaction between land use decision makers (farmers) and 2) the positive feedback mechanism in agricultural production, with each applied to a case study showing how such mechanism can give rise to non-linear changes in land use systems. Due to a lack of focus on feedbacks in LUC-ABMs, we propose a framework to approach feedback mechanisms in land use systems in a structured way.

1. Need for modelling of non-linear process in Land Use Systems

Land use (and land cover) changes marked one of the most prominent changes of the Anthropocene (Crutzen, 2002; Ellis et al., 2013; Goldewijk, 2001; Zalasiewicz et al., 2011). Descriptive land use change models seek to understand the dynamics of coupled human and environmental systems. Land use change is often a complex process, in which complexity arises from the multiplicity of interlinked driving forces (Lambin et al., 2003), the interaction between land use system and the driving forces, the interaction between land use decision makers, the spatial and temporal dimensions, and the cross-scale dynamics due to the feedbacks from higher system level (Rindfuss et al., 2004; Veldkamp & Lambin, 2001; Verburg et al., 2004). Such a complex process may result in non-linear behaviour in land use systems. It thus requires models to not only analyse the causes and consequences of the land use change (Verburg et al., 2004), but also capture these non-linear characteristics. Land use systems might be very sensitive to such non-linearity, for instance in the form of tipping points (Scheffer et al., 2009), that lead to a different land use regime. A model which is able to approximate the non-linear development of land use change is valuable for policymakers, for whom it is essential to know how a land use system will respond to an external trigger or policy.

2. A focus on interactions and feedbacks

Depending on the goal of research, a model should include part of the complexity typical for land use systems (Veldkamp & Lambin, 2001). As research on tipping points and regime shifts of land use system is still at its infant stage, a solid step forward can be the modelling of non-linear land use change, which needs to incorporate, amongst others, 1) the interactions between system components and 2) feedbacks from higher levels. Bousquet and Le Page (2004) summarized three types of interactions that Agent-Based Models (ABMs) applied to ecology need to capture, namely (i) direct interactions (communication and exchange of information between agents), (ii) physical interactions (e.g. one exerting physical action such as pull, push, or predation on the other), and (iii) interactions mediated by the environment. This classification can help to clarify interactions and communication between modellers and audience. We propose that land use change researchers not limit interactions to the widely studied relationship between aggregated driving forces and land use system properties (i.e. type ii) but to incorporate explicitly social interactions between individuals and groups (i.e. type i and the combination of type i and type ii), which usually take place over a specific space or via a network. We hypothesize that these social interactions contribute to the non-linearity of land use systems. The second aspect is the explicit treatment of feedback mechanisms. In our framework, Bousquet and Le Page's (2004) type iii interactions are considered as feedback mechanisms. Feedbacks from high system levels either accelerate (positive feedback) or mitigate (negative feedback) the land use change process. This way, they give rise to the non-linearity of land use system. Different types of feedbacks in land change models are discussed by Verburg (2006).

3. Complex Adaptive Systems and Agent-Based Modelling as theoretical and methodological guide

Non-linear changes caused by interactions and feedbacks as well as the co-evolving drivers and system states, classify land use systems as Complex Adaptive Systems (CAS) (Brownlee, 2007; Holland, 1992; Holland, 2002; Lansing, 2003; Levin, 1998). Land use change, in particular land use transitions or regime shifts, can be understood as an emergent property of CAS (Lambin et al., 2003). Following the CAS perspective of investigating land use systems, one would be interested in how micro level behaviour among a (heterogeneous) set of interacting agents leads to macro level phenomena, i.e. the emergent properties (Holland, 1992; Janssen, 2005) such as observed land use transitions and regime shifts. Agent-based modelling (ABM), is well suited to facilitate our requirements of capturing interactions and feedbacks (Gilbert, 2008; Janssen, 2005). As a process-based modelling approach, ABM is also ideal for modelling non-linear land use changes. Bousquet and Le Page (2004) discussed the strength of ABM on linking spatial and social aspects and the potential of application to land use change. Parker et al., (2003) reviewed the applications of ABM in land use and cover change and summarized the challenges that researchers face. Another review of ABM applications to Coupled Human and Natural Systems (CHANS) can be found in the work of An (2012). The author summarized nine types of decision models based on complexity of behavioural theories, spatial interactions, social interactions, learning and adaptability of agents, each contributes to the generation of agent's decision making rules.

Though many LUC-ABMs have explored interactions in land use systems, they lack a focus on feedbacks from higher levels. This is probably because of the small scale of the cases in which aggregated effect is hardly considered to result in such change that it could feed back to the lower level.

4. Interactions and Feedback mechanisms implemented in two cases

Land use change models are considered in this research as learning tools that help researchers and policy makers understand different components and functionalities of land use systems. Two primary mechanisms are presented here: 1) the competitive behaviour of farmers captured as a type of social interaction, which can lead a non-linear growth of farm size, as observed in 20th century U.S.; and 2) the positive feedback between local land users, supporting companies, and policy regulations leading to the rapid growth of soybean production in Sorriso, Brazil and rapid decline of sugar beet production in Ireland.

4.1 Farmers' social interaction and non-linear farm size growth in the U.S.

Non-linear farm size growth remains a puzzle
Farms in the U.S. underwent tremendous transformation in the 20th century. Average farm size increased from around 40 hectares on average to around 180 hectares (Dimitri et al., 2005). Even though decreasing margins and the development of technology have been identified to contribute to the growth of average farm size, the s-shaped curve of farm size development remains a puzzle. Traditional approaches may have predicted continuous growth (Gardner, 2002) while stabilization is observed (see Figure 1). The levelling off of farm size after the rapid growth has not been formally explained. Our research objective is to explore and generate hypothesis of the non-linear (s-shaped) growth curve of U.S. farm size in the 20th century by a stylized agent-based model. Figure 2 shows the social interaction of farmers operationalized in our ABM.

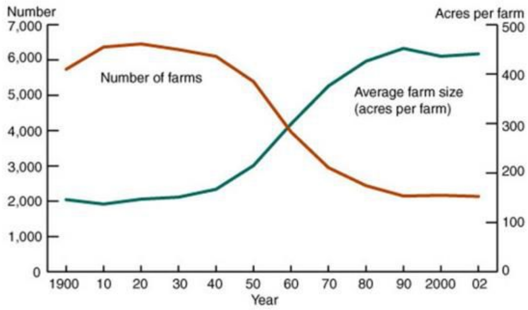

Figure 1. The S-shaped curve of U.S. farm size growth. Source: Dimitri et al. (2005)

Storyline of the model
The gradual decline of margins made farmers poorer and poorer. For a while they could cope, but once all economic buffer capacity was exceeded, some farmers (or banks) decided to grow by confiscating land from those who had to quit. This caused anxiety among remaining farmers, who sensed it as "eat or be eaten". A positive feedback was initiated of farmers trying to grow or having to quit. Farmers continually compared to their neighbours to check if they were lagging behind. This process slowed down once the system ran out of small shrinking farms.

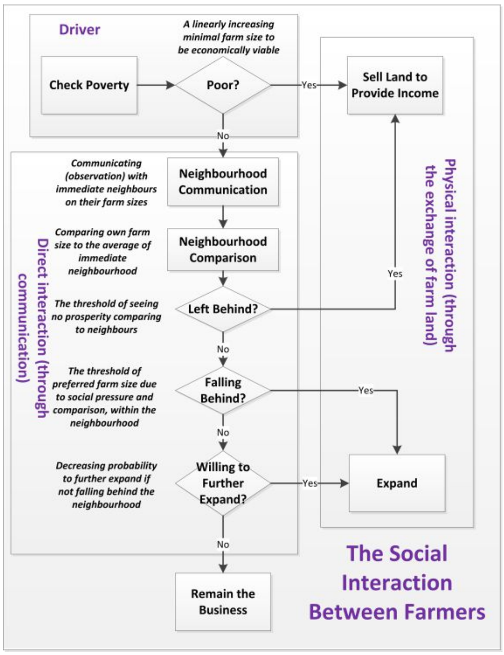

Figure 2. Farmers' social interaction as implemented in an ABM

Model assumptions
The model implements a number of principal social interactions. As farmers constantly communicate within their reference group (in this case their neighbourhood) to maintain social coherence, recognition and identity, peer pressure from such social interaction makes them compete—a satisfactory income (based on neighbourhood comparison), safeguarding for the future

competitiveness (by keeping up with the growth of neighbourhood), and gaining recognition and identity to the farming community (Gasson, 1973). In order to investigate the role of social interactions between farmers, the following assumptions are made:

- Because of decreasing margins and increasing need of income, farmers need more land to be economically viable (Hurt, 2002). We assume a linear, positive relationship between prosperity and farm size.
- Farmers as social agents compare with neighbours (Festinger, 1954; Manski, 1993, 2000) and are motivated to expand if they fall behind. They are less motivated to grow once they are satisfied.
- Land transactions are made spatially continuous — farmers can only buy the land neighbouring their current farmland — to avoid land segmentation.
- When investigating the effect of farmers' interaction along a considerably long time span, succession is assumed constant.

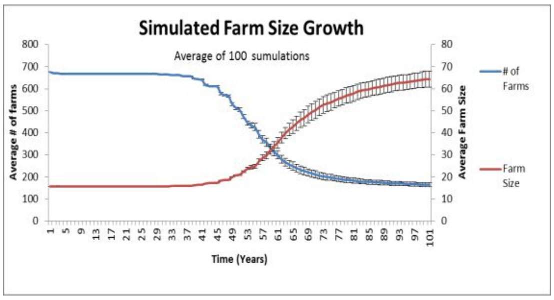

Figure 3. The s-shaped curve of farm size growth--model results, based on 100 simulations

Discussion based on the farm size growth model

- Compared to traditional economic reasoning (technological development (Gardner, 2002), economies of scale (MacDonald, 2011) and relative factor price (Kislev & Peterson, 1982), etc.) which only explained the growth of farm size, our model captures a more complete picture (Figure 3), including both the rapid growth and the subsequent levelling off of farm size.
- In our model, farm size responds to the driver non-linearly, whereby complexity arises from famers' interaction. Such social interaction implemented in the ABM contains the direct interaction and physical interaction (see Figure 2) described by Bousquet and Le page (2004).
- As farmers compare within their immediate neighbourhood to remain competitive, their individual behaviours lead to the increase of average farm size in the neighbourhood. As time progresses, this feeds back to each individual, pushing them to further expand their farms. This seems to be a feedback, but from the same level.
- This model captures the decision making behaviour of farmers as social agents, whose decisions are dependent on the behaviour of their reference group (in this case their immediate neighbours). There are other types of social behaviours (homo socialis and homo psychologicus) which might play important roles in socio-ecological systems and contribute to the explanation of observed land use changes.

4.2 Feedback mechanism in the production of soybean (Sorriso, Brazil) and sugar beet (Ireland) (work in progress)

From narrative description to modelling

Despite the fact that feedback mechanisms are well recognized in land use systems, the way they are treated is mostly at a narrative level. For example, Garrett et al., (2013) explained the rapid conversion of land to soybean production in Sorriso, Brazil with a positive feedback loop resulting from agglomeration economies, which create a concentrated and diverse supply chain allowing for technology innovation, and wider access to information. Such agglomeration economies concern easier access to credit and fewer environmental regulations whereas in the comparing case of Santarem producers are challenged by difficulties to credits (due to land tenure) and strong environmental regulations and supervision, which prevent such agglomeration economies, even though it has a relative advantage of cheap transportation costs.

A framework of modelling feedback mechanisms

Feedback mechanisms in land use systems, such as the positive feedback of agglomeration economies, can take place across different scales — spatially, temporally, and organizationally — linking different dimensions of the system such as biophysical conditions, market conditions, policy regulations, etc. We propose a systematic approach to the description of feedbacks in land use system by providing a framework (work in progress) which may help to clarify the system process and better facilitate modelling. By answering the following questions, one can have a clear description of the feedback mechanism under study and can better approach it at the model designing phase.

(1) Who/what is the sender of the feedback?
(2) What is the nature of the feedback signal? (e.g. economic, psychological, biophysical, informative, and legislative)
(3) Is there a time lag or a spatial lag between the sending the reception of feedback?
(4) Is the feedback positive or negative?

(5) Is the initiation of termination of the feedback subject to excess of thresholds or tipping points?

The cases of soybean and sugar beet production

We present an agent-based model in which feedback mechanisms are explicitly treated and apply it to the narrative cases of Brazilian soy production case (Garrett et al., 2013) and the sugar beet production in Ireland (Busse & Jerosch, 2006). The feedback mechanism of these two cases is composed of multiple individual local producers (land users) and several firms (processing, seed company, R&D, etc.) whose existence depend on the amount of the individual producers and whose function can influence the decisions of producers. The feedback mechanism functions by changing the market dimension (supply, demand, price, and cost) as well as biophysical conditions, which might be under the adjustment of policy regulations.

Model in progress

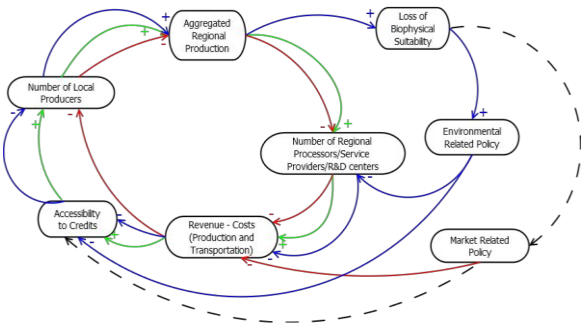

Figure 4. A conceptual framework of feedbacks in three cases. (Green: positive feedback leading to the rapid conversion of land use to soybean production in Sorriso; Red: positive feedback of the breaking down of sugar beet production in Ireland; and Blue: feedbacks (both positive and negative) in the production of soybean in Santerem.)

5. Conclusions and recommendations

With the explicit treatment of the interaction between individual decision makers and the feedback mechanisms in land use systems, we demonstrate how these can lead to the non-linear behaviour of land use systems with an agent-based approach. That land use systems might be very sensitive to such mechanisms to come across some tipping points and move to a different land use regime opens the research arena in which different approaches can contribute to the knowledge pool. The challenge of applying an agent-based approach to the modelling of regime shifts in land use systems lies in the identification of interactions and feedback mechanisms. In doing so one has to strike a balance between realistic representation of agent behaviours (micro level validation) and the modelling of emergent properties (macro level validation).

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Multi-Scale Agent-Based Simulation of Long-Term Dispersal Processes: Challenges in Modeling Hominin Biogeography and Expansion

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***Abstract*—The *Out-of-Africa-Theory*, as a model of the early migration of anatomically modern humans, describes Africa as geographical source of dispersal processes to Eurasia. However, there is no scientific consensus on the reason or the exact route of the migration. In this paper key challenges for modeling hominin biogeography and expansion using agent-based approaches are being proposed.**

I. Introduction

According to the *Out-of-Africa-Hypothesis*, the geographic origin of the hominids known to be the ancestors of the anatomically modern humans such as *homo sapiens*, is located in Africa. Due to the discovery of numerous fossils, there is archaeological evidence on the existence of waves of early dispersal from Africa to Eurasia, but the reason and the concrete route of the migration are being discussed controversial among experts. There are currently four competing hypotheses concerning possible routes for the human dispersal out of Africa: Along the Bad-el-Mandeb Strait which connects the Red Sea to the Gulf of Aden, the Levantine Corridor between the Mediterranean Sea and the deserts connecting Africa to Eurasia, the Sicily Route and/or the Gibraltar Route. [1]–[4]

Looking closer at the different scenarios, several factors seem to matter in the context of hominin dispersal, such as ecological variations and demographic pressure [4], climatic changes [5]–[7], biological and social organization [7], dispersal of megafauna in Asia [8], carnivore competition [9] or vegetation [6] along these trails. However, there is a scientific consensus that the conjunction of the mentioned local circumstances and interactions caused the global effect of hominids migrating to Eurasia to happen. In order to understand these emergent phenomena and to validate the different hypotheses given, the dispersal processes needs to be reproduced.

II. Modeling Dispersal Processes

Based on archaeological discoveries, partially contrary hypotheses and assumptions made the development of a simulation platform as shown in fig. 1 seems to be a suitable approach for comprehending the migration processes which occurred 1.5-0.5M years BC. By executing multiple simulation runs, a variety of potential dispersal scenarios can be generated, visualized and analyzed by the researchers for further consideration. In this regard, by considering the computer science view, it is an important challenge to enable domain experts, i.e. researchers in the field of early human dispersal, to specify hypotheses and to support the interpretation of the results by providing the possibility to navigate through them in an adequate way. As a visionary approach, we are working on assistance functionalities for performing and varying simulation runs in an automated way. [10]

Especially for reproducing emergent phenomena in complex environments, like the conditions given in the context of the *Out-of-Africa-Hypothesis*, we propose the application of agent-based modeling (ABM) as an innovative methodology for modeling, simulating, and analyzing dynamic effects within artificial societies. [11] By simulating an artificial environment and defining mechanisms for possible interactions between actors, the so-called agents, the routes hominids may have chosen on their way to Eurasia shall be recreated. Furthermore, a detailed consideration and junction of mono-disciplinary expertise regarding different relevant external factors such as botanical or predator models is provided.

III. Environmental Abstraction

Earlier research conducted by the authors revealed potential fields to be a suitable approach for modeling the environment in migration simulation. [12] By converting the landscape being settled by hominids into a 3D-environment containing particular points describing possible places which can explored, individual values representing the potential of certain points can be evaluated. As a result of this specific models about the climate, weather, botany and geography conditions, the access to food like animals and other resources, but also the competitive situation especially regarding predators or the social structure between different tribes can be used for the determination of a particular location's potential.

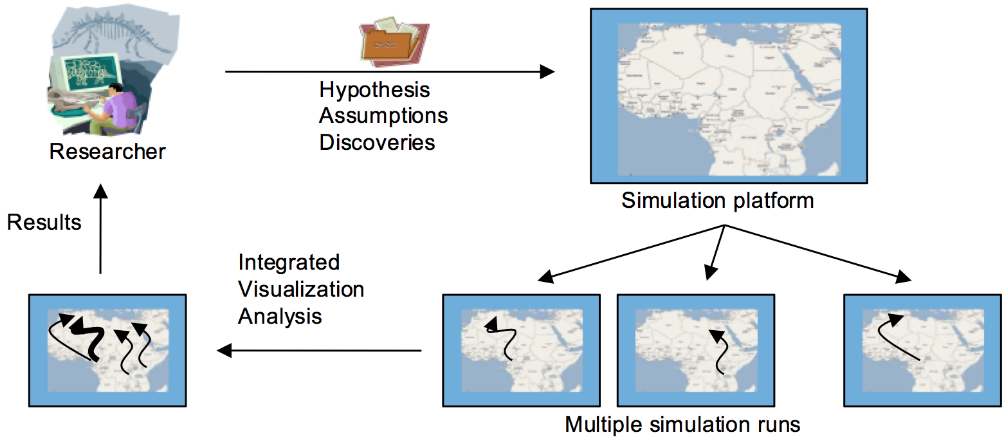

Fig. 1. How the simulation platform can be integrated into the process of validating hypotheses.

Within the context of potential fields representing the environment, reactive approaches for modeling agent behavior are no longer suitable, as they are intended for the use in simply assessable environments. In order to consider these highly sophisticated partial expert models for describing the different factors influencing the dispersal process, the use of alternative approaches for modulation purposes is required. We propose the use of deliberative (intentional) agents for the representation of the simulated actors, as this type of agents possesses an explicit symbolic model of the environment it is located in and therefore is capable to plan its actions by the use of symbolic reasoning.

IV. Challenges for Agent-Based Modeling

However, when describing actors as agents, the model's granularity has to be defined. The question whether an actor represents a single entity (e.g., hominid) or an amount of entities (e.g., tribe) has to be evaluated. Alternating hypotheses may result in different resolutions to be reasonable. On a superior level, the consideration of a whole tribe as a single actor is conceivable, due to performance issues resulting from the huge number of represented groups. Apart from that, hypotheses can as well be of peculiar interest for certain smaller areas. Therefore the simulation is required to be of increased granularity on a particular point or region, namely taking each individual entity into account.

With due regards to the variances in the model's granularity and the unknown quantity of actors to be simulated, scaling issues become an additional challenge. As the period of time being of peculiar interest for the dispersal processes exceeds more than one million years, the data volume being generated needs to be maintained thorough. Besides the data storage during the execution of the simulation, checkpoints representing relevant interim stages must be gathered regularly. Especially when individual archaeological findings prescribe the achievement of a specific landmark at a certain point of time during the simulation, the integrated storage of data needs to be ensured. In summary, four main challenges for scaling were identified when modeling hominin dispersal processes for simulation purposes:

- Scale 1: *Expertise*. A variety of highly complex partial expert models, e.g., weather, climate, or botany, containing information about certain considerable factors influencing the hominin dispersal, need to be integrated.
- Scale 2: *Space*. The model's granularity concerning the spatial and temporal resolution of the simulation needs to be determined.
- Scale 3: *Time*. Particularly influenced by the granularity, scaling challenges emerging from the extraordinary long lapse of time being simulated need to be solved.
- Scale 4: *Actor*. The fourth dimension is influenced by the number of actors to be modeled and simulated. Here, at least each tribe has to be modeled. However, more detailed simulation could include any hominid as well as any predators.

V. Conclusion

In this contribution, we propose key challenges for modeling hominin biogeography and expansion as a first step approach for further and detailed elaboration. However, agent-based simulation seems to be a suitable technology for reconstructing potential dispersal processes considering these challenges, different scenarios and theories.

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Organizational Routines: An Agent Based Model Replication

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***Abstract*—this extended abstract focuses on organizational routines as an emergent phenomenon of individual behavior within collectives. Micro foundations related to dynamics of performing and remembering organizational routines are based on psychological constructs such as procedural, declarative and transactive memory. Replicating the agent-based model "Dynamics of Performing and Remembering Organizational Routines" in a different programming language is used to analyze the model´s credibility. To enhance the replication transparency and quality the existing model is initially transferred into an ODD protocol before its re-implementation. If the model can be replicated without significant errors, it can be used in further research to examine organizational routines in accounting.**

I. Introduction

Theory on organizational routines was revised in 2003, when Feldman and Pentland illustrated duality of organizational routines adhere a recursive connected performative and an ostensive aspect [2]. Miller et al. provided in 2012 an agent-based model to examine the roles of procedural, declarative and transactive memory related to a shared holistic ostensive routine. Therewith they presented the first multiple-agent simulation to model the micro-foundations of organizational routines [1]. Modelling groups of individuals facilitate to examine the internal structure and dynamics of organizational routines. This social simulation model is crucial to examine accounting routines in view of coordination of activities and organizational learning. Prior to adopt the model to an organizational accounting routine its credibility is tested with this model replication. Technical transferability of the model implemented in MATLAB 7 will be verified by its re-implementation in NetLogo 5.04. To enhance the replication transparency and quality the model is initially transferred into the revised ODD (Overview, Design concepts, Details) protocol originally suggested by Grimm et al. [3] [4]. Further the replication provides technical transparency to the first agent-based model, which is appropriate to examine the roles of procedural, declarative and transactive memory related to shared holistic ostensive routines [5].

II. Replication Design and Project Survey

1. *Initially ODD Transfer*

The replication project was started in February 2014 with the transfer of provided information into an ODD protocol. With this transfer process lacks of information are revealed. The complemented ODD protocol will be useful as universal basis for model implementations in different programming languages. The ODD protocol is actually close to completion and hence there is no lack of information.

2. *Re-Implementation in NetLogo 5.04*

NetLogo is chosen as implementation software, it is a widespread and typical agent-based simulation software based on an agent-based programming language Therefore it is different to MATLAB whose utilization is rather focused on numerical problems [6]. Furthermore MATLAB can be used with interface programs written in C, C++, Java and FORTRAN. Re-implementing the model in a different programming language countervails that any programming mistakes or assumptions will be repeated in the replication simulation [7]. This phase is scheduled for April and May 2014.

3. *Determine the Statistical Signature*

It is expected that the "overall" character of the simulation results of the replication model will be consistent with its original. However, an exact model alignment will be conducted until June to reveal minor bugs, ill-defined implementation issues, and to determine the so-called "statistical signature" [7].

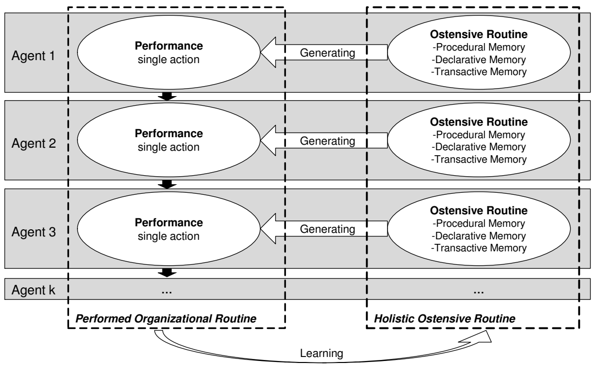

Fig. 1 Performative and ostensive aspect of an organizational routine

III. The Model

Organization and Problems

The general model setup is an organization, made up of n heterogeneous individuals who are capable of searching and learning due to transactive and declarative memory. Each agent represents an individual, which possess a skill and an awareness to recognize and perform tasks. Several tasks have to be performed by the individuals to solve a single recurring problem. The task order 1, 2,..., k represents a standard problem. New problems are assigned to an agent selected randomly among those able to complete the first required task. If an agent is not able complete the next sequential task, it transfers the problem to another agent who is able or remember a further skilled agent to perform the task. Each agent can complete on task per period. Upon completing a whole problem, the organization receives a new problem in the next period [1].

Task Awareness

The model allows to consider individual cognitive skills which are crucial for behavioral accounting research [8]. An agent is aware of a of possible k tasks ($1 \leq a \leq k$). Hence an agent is able to identify those tasks in its awareness set and blind to unfamiliar tasks [1].

Procedural Memory

In the original model each agent possesses a fixed single skill, which is content of the procedural memory. I am going to examine an increased number of skills in the re-implemented agent-based model to examine the opportunity of staff training [1].

Transactive Memory and Random Search

If an agent is not able to perform a task, it consults transactive memory to check, whether it remembers another agent that has the skill for the task. If consulting transactive memory is not successful the agent conducts a random search to find an agent with the required skill. During the random search the agent can ask the selected agent, whether it remembers another agent with the skill for the task. Transactive memory is updated with the probability p_t ($0 \leq p_t \leq 1$) after the searching agent has found an agent to whom the problem can be transferred. This updating process represents an individual learning process [1].

Declarative Memory

Agents learn from experience about the sequences in which tasks occur. As long as an agent is skilled to perform a task or can pass the task on to another agent, which possesses the required skill, it has the chance to learn the past two-step task sequence. This chance is represented by the probability p_d ($0 \leq p_d \leq 1$). Human individual bounded duration of remembrances is incorporated in the agent-based model by the factor w_d ($0 \leq w_d \leq \infty$) [1].

Output Parameter Cycle Time

The output parameter *cycle time* represents the number of periods the agents need to complete a proble. This is computed as the number of periods in which a task is completed plus the number of periods in which an agent´s search did not result in transferring a problem. Minimum *cycle time* and therefore maximum problem-solving efficiency occurs when the cycle time equals the number of tasks in a problem [1].

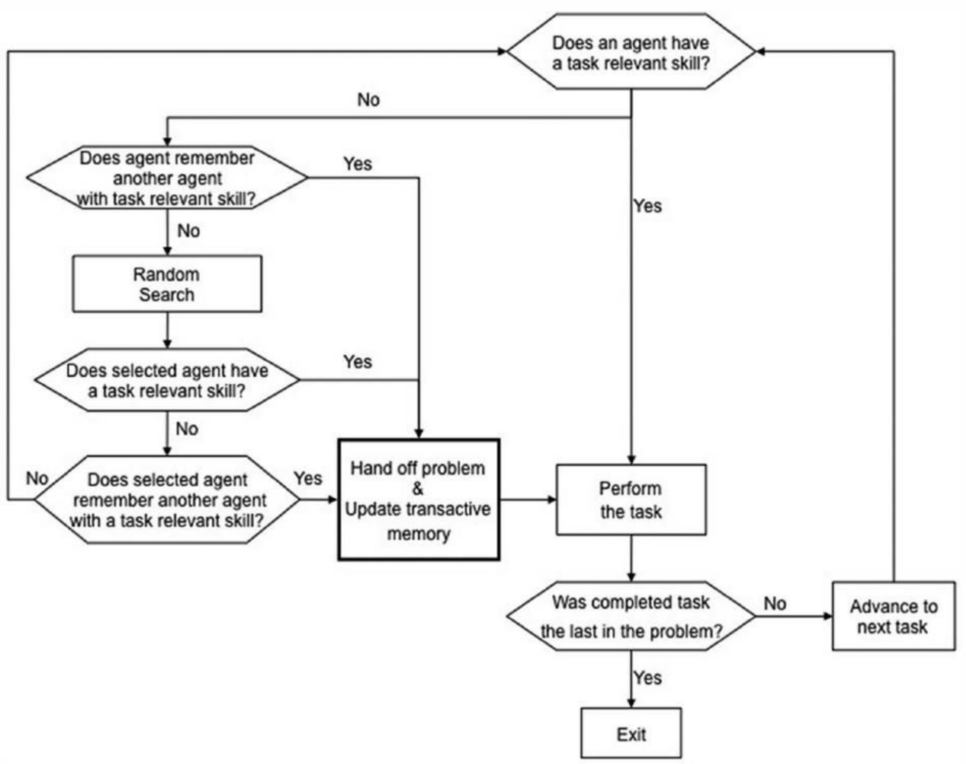

Fig. 2 Flow chart for search and task completion of the model [1]

TABLE I
MODEL PARAMETERS [1]

Parameter	Meaning	Default settings	Altered values in original model	Intended Additional value tests in the re-implemented model	Reasoning for additional tests
n	Number of agent in the organization	50	10, 30	>50	To examine Additional staff assignment
k	Number of different tasks in a problem	10	-	<10, >10	To examine routine complexity
a	Number of discernable tasks for any given agent (task awareness)	5	1, 10	-	-
p_t	Probability of adding an entry to an agent´s transactive memory	0.5	0.25, 0.75, 1.0	-	-
p_d	Probability of adding an entry to an agent´s declarative memory	0.5	0.25, 0.75, 1.0	-	-
w_d	Number of remembered subsequent tasks in declarative memory of a given performed task	1	50	-	-
s	Number of skills to solve tasks	1	-	>1	To examine staff training

IV. FURTHER EXPERIMENTS AND IMPROVEMENTS

After a successful model replication the following simulation experiments are scheduled, which are not conducted or mentioned in the paper "Dynamics of Performing and Remembering Organizational Routines" [1].

1. *Testing Additional Staff Assignment*

The replicated model was developed to examine personnel downsizing phenomenon in organizations. However it was not tested how the *cycle time* is effected by adding additional staff.

2. *Testing Staff Training*

It is expected that giving agents more than a single skill increases problem solving efficiency after a problem change or downsizing.

3. *Examine Routine Complexity*

The model could be beneficial to analyze the complexity of organizational routines. In particular varying the number of tasks in a problem admits to examine problem-solving efficiency for a single large problem e.g. $k = 100$ compared with a disaggregated problem with 10 task packets e.g. 10 * k ($k = 10$).

4. *Improved Output Measurement of Stability*

A first result is that the term stability is not adequately defined. There is no exact definition, when a routine is deemed to be stable. There is merely an indication given that a routine is stable, when it shows the same cycle time after a change occurred some periods before [1]. In practice organizational routine stability will be more target or context-dependent.

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Modeling Population Dynamics of Online Communities

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***Abstract*—Online communities are more dynamic in terms of composition compared to traditional physical communities. This can affect the conditions for cooperation. We discuss empirical results from online communities and extend the evolution of firms model of Axtell to discover the conditions of cooperation in groups.**

I. Introduction

IT was just a few decades ago that most people spend most of their time in a local community within in physical proximity of other community members. Nowadays we spend an increasing amount of time online. These online activities could relate to social networking, but also creating content for encyclopedia (e.g. Wikipedia), software (e.g. github), book review (e.g. Amazon), answering questions (e.g. stackoverflow). People can participate in diverse communities facilitated by online communication.

For communities to be productive members need to spend effort. For example, farmers in small-scale irrigation communities invest time and effort in maintenance of common infrastructure, meeting to coordinate the scared resource and sharing food in periods in need. Ostrom [1] has demonstrated that communities can be very effective in self-organizing their activities to be productive and avoiding overharvesting of the commons. A key factor thought to explain this are boundary rules which define entry and exit to the communities.

Online communities are different since boundary rules are less strict. People can participate in different communities and leave or reduce their effort if the direct benefits are not sufficient for the persons involved. This lead communities to compete for effort among potential members. The question we explore is to understand what the conditions are for productivity and long-levity of online communities.

The importance of this question can be seen by efforts to solve collective action problems by online communities such as creating encyclopedia (Wikipedia), and open source software (Sourceforge), and various sustainability problems [2]. But is groups are more fluid, cooperation within a group might be less stable. The study on the evolution of cooperation shows that repeated interaction (direct reciprocity) and indirected reciprocity (if having reliable reputation information) can explain high levels of cooperation in human societies. But when group composition changes frequently, what are the conditions in which cooperative arrangements can persist.

A relevant model in this context is the study of Axtell on firms [3]. Axtell formulate firms by having a population of agents where agents have preferences for income and leisure, and groups invest effort to the group, the firm, to produce output. There are increasing returns to cooperation, and agents can benefit from the group efforts since the output is divided equally among the participants. Agents define their effort level to maximize their utility. As a consequence agents may free ride on the investments of others. Agents are permitted to join other firms or start up new firms when it is welfare-improving to do so. As a firm becomes large, agents have little incentive to supply effort, since each agent's share is relatively insensitive to its effort level. This gives rise to free riders. As free riding becomes commonplace in a group, agents will leave. Hence firms change in size all the time, but the distribution of firm sizes is a stable Zip distribution similar to the empirical data [4].

We have replicated the Axtell model in Netlogo and will adjust it to explain observations in online communities. Let's first show some of the findings from online communities, and then we will discuss how we will change the Axtell model.

II. Patterns In Online communities

The data investigated in the current study are the log files of Baidu Tieba system, a collection of many topic-specific forums. Please refer to http://en.wikipedia.org/wiki/Baidu_Tieba for a more comprehensive introduction of this system. Among the millions of forums in the system, we select the top 1,000 forums, whose size (the average daily page views in two months) varies from hundreds to millions. For each forum, we recorded the hourly number of unique visitors and total clicks in 58 days from Feb. 28, 2013 to Apr. 27, 2013.

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We find that the two rules suggested in the model of Malcai et al. [5] , i.e., the converged power-law distribution of organization size and the symmetric levy-stable distribution of the growth rate of average size in time, also shape the growth of online communities. Different from previous studies on organization evolution which usually focus on the dynamics of only one variable [4, 6, 7], we analyze both of the size (visitors) and productivity (clicks) of online communities. The richness of data allows us to explore the relationship between two variables in time, and we observe the super-linear scaling relationship of productivity vs. size, quantifying the economics of scales in collective action online. We also find that the scaling exponent is not universal, but decreases gradually to unity with the growth of community size, indicating the limits of the economics of scales. This pattern calls for a more comprehensive model than Malcai's on the growth dynamics of online communities.

We analyze the hourly-based distributions of the top 1,000 forums in terms of visitors and clicks, and find that the shape of the distributions do not change in time, as given in Figure 1. Both of the number of visitors and clicks satisfy power-law distribution, where the scaling exponents of the power-law distributions of visitors and clicks are 1:33 and 1:11, respectively.

We also looked at the distribution of effort among different communities, and find that 30% of the members participate in more than one forum during a day (Figure 2).

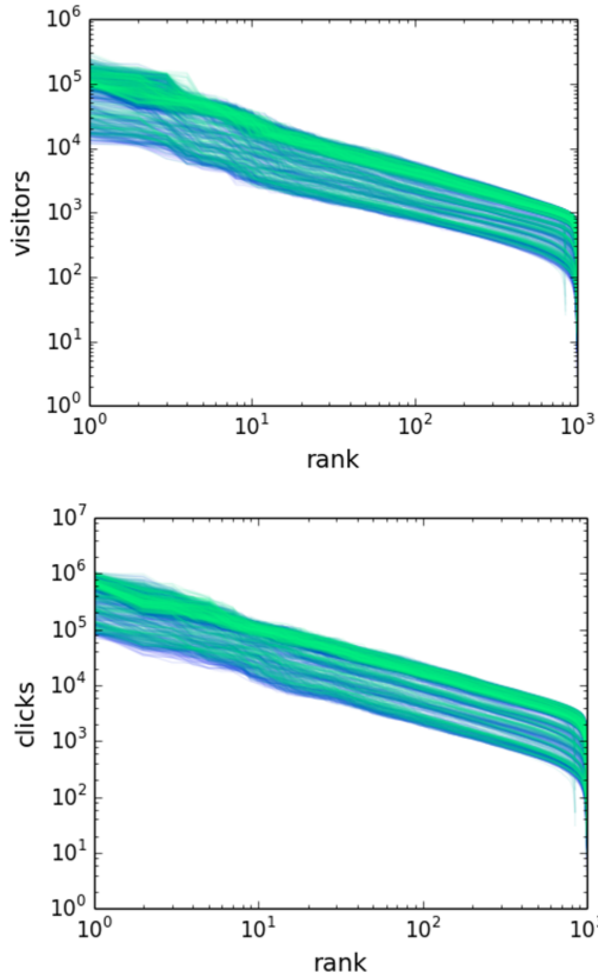

Figure 1. The hourly-based distributions of community size and productivity. (A) and (B) give the hourly distribution of visitors and clicks, respectively. The distributions were plotted in rank-order curves, in which y axis shows values and x axis shows the decreasing rank of the values. The color of data points change from blue to green gradually as time passes. We fitted the scaling exponents in every hour using ordinary least square regression in log-log axes and calculated the average value. We plotted the fitted line in red dotted line and denoted the value of the exponent in the lower left of (A) and (B).

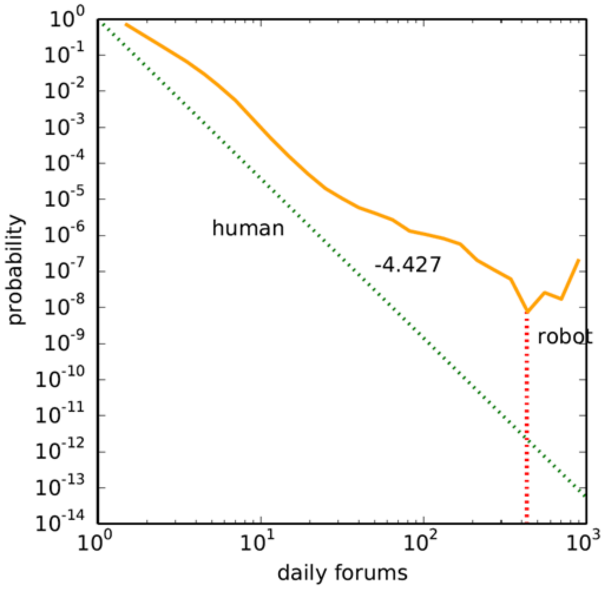

Figure 2. Distribution of daily clicks (left) and visited forums at individual level (right). The data contains the record of 16+ million active users. The results show that a user may visit many different forums in a day. The 430 forums as a separation between human and robot corresponds to the threshold of 1000 thread views/clicks per day, which is an arbitrary threshold to detect a robot.

III. EXTENSIONS

By September we expect to have done a more thorough empirical analysis of dynamics of online communities. For example, we like to explore the logs of stack overflow and identify population and effort levels of different topics and communities. In this extended abstract we use a simplistic number of clicks as effort. With stack overflow data we can measure effort based on feedback participants get on the quality of their work and the reputation they receive within the community.

We will extend the Axtell model by allowing agents to spend effort in more than one group, allow agents to have evolving social networks and allow agents to have preferences that affect which groups they move to. In the current Axtell model agents can move to groups that are known within their social network. There are no entree rules and we like to explore the effect of including entree rules (such having a minimum reputation level) on the population dynamics.

In the analysis we will explore the effect of increased mobility of the population on the ability to create cooperation. Janssen and Goldstone [8] showed that with traditional public good games this only happens with small levels of mobility. Since we observe cooperation in online communities with high levels of mobility, we will explore mobility rules, exit and entry rules, and reputation scores, to detect conditions for cooperation.

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Populating Virtual Cities with Diverse Physiology Driven Crowds of Intelligent Agents

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***Abstract*—When conducting archaeological excavations of ancient cities, 3D reconstruction has become an important mechanism of documenting the findings and showing the results to general public in an accessible way. Most such reconstructions, however, mainly focus on visualising buildings and artefacts, while rarely simulating the actual people that populated the reconstructed city and aspects of their everyday life. Simulating such people and their lives in all their diversity is a costly and time-consuming exercise comparable in cost and efforts to development of a commercial video game, involving years of development and millions of dollars in funding. In this paper we present a novel approach that can significantly decrease the cost and effort required for simulating everyday life of ancient inhabitants of virtual cities, while still capturing enough detail to be useful in historical simulations. We show how it is possible to manually design a small number of individual avatars and then automatically generate a substantially large crowd of virtual agents, which will live their lives in the simulated city, perform choirs and rituals as well as other routine activities that are consistent with their social status. The key novelty of our approach that enables simulating such sophisticated crowds is the combination of physiological needs - for generating agent goals, emotions and personality - for choosing how to fulfil each goal and genetically informed propagation of appearance and personality traits - to propagate aspects of appearance and behaviour from a small sample of manually designed individuals to large agent groups of a desired size. The usefulness of our approach is demonstrated by applying it to simulating everyday life in the ancient city of Uruk, 3000 B.C.**[1]

I. Introduction

Using 3D visualisation in reconstruction of lost sites of high historical significance has become a popular way of communicating the results of years of research conducted by archaeologists and historians to general public [1]. Initially, such works were predominantly focused on reconstructing destroyed or partially destroyed architecture (e.g. Roman Colosseum) [2]. Such reconstructions help to simulate significant historical sites in all their former glory and facilitate appreciation of what remained from that glory (normally in the form of ruins). With modern advancement in research in development, we are now reaching the stage when reconstructing a heritage site can become relatively cheap. A procedural approach to generating historically informed designs of high complexity can be automated by design grammars, so that a large city can be created in a matter of days. One of the well known examples of using this approach in historical reconstructions is the Rome Reborn project [3], where a virtual reconstruction of the entire city of ancient Rome in the period of 320 AD was procedurally generated.

While 3D simulation of buildings and artefacts provides a unique possibility for general audiences to examine the architectural details of the heritage site it still does not help an observer to understand how this site has been enacted in the past. Without being able to see ordinary people performing their daily choirs and rituals the observer is unable to immerse in the actual culture of the reconstructed society and have a complete picture about their way of life. It is possible to simulate such people using so-called "virtual agents". These virtual agents are essentially autonomous computer programs that are represented by human-like 3-dimensional figures (called avatars) that move around the reconstructed environment and simulate ancient citizens of the reconstructed site. Modern video games are a good illustration in regards to possibilities that arise with employment of such virtual agents in simulating human behaviour. But the cost of developing video games is enormous. For example, the estimated cost of developing Crysis 3, one of the popular modern video games, is $66 Million [4]. It's hard to imagine such level of spending when it comes to historical simulations, so populating a historical environment with virtual agents needs to be automated.

Aiming to achieve cost saving, some researchers do not model their societies at the level of individual agents, but employ "virtual crowds" [2]. While such crowds essentially consist of a large number of virtual agents, designing a crowd normally comes down to designing a few individuals and then replicating them a desired number of times with slight modifications so that the crowd appears to be diverse [5]. In regards to agent behaviour, crowds simulation techniques predominantly rely on automated algorithms for large scale obstacle and collision avoidance and individual agent behaviour is rarely complex enough to illustrate various aspects of daily life of the reconstructed society [5]. The state of the art in using agent crowds in historical simulations is outlined in [6] where a virtual City of Pompeii is populated

[1]See the prototype video at: http://youtu.be/ZY_04YY4YRo

with a large number of simulated people, who simply walk around the city avoiding collisions. In this work the virtual agents give a perception about the appearance of the ancient people who used to populate Pompeii, but these people are not involved in historically authentic interactions. So they play a role of moving objects and can only extend the atmosphere of the culture simulation, while offering little in regards to understanding everyday life in the simulated society.

A number of crowd simulation and crowd generation approaches appear in the literature but hardly any of them advance beyond having avatars moving around and carrying objects with them. Further in the paper we show how through simulation of physiological needs and motivations together with personality traits we can achieve much more sophisticated simulations of human behaviour. Furthermore, employing genetic methods for inheriting personality traits and appearance characteristics together with connecting virtual agents with formalisations of social roles and social norms allows for a similar level of complexity in crowd based simulations as seen in commercial video games.

The remainder of the paper is structured as follows. Section II presents motivation for selecting the combination of genetics, social norms, personality and physiological motivations as a way of advancing the state of the art in historical simulations. Section III presents our methodology for creating such simulations. Section IV shows how the aforementioned methodology was applied to a particular case study: simulating everyday life in the ancient city of Uruk, 3000 B.C. In section V we analyse the results of the Uruk study.

II. Approach

The essence of our approach to building historic simulations lies in automating generation of diverse ethnic crowds in terms of the appearance and behaviour of individual avatars, while allowing for a high degree of complexity in the resulting behaviour. Simulation of life in 3D reconstructed historical cities is a costly and time-consuming process, comparable in cost and efforts to development of a commercial video game (involving years of development and millions of dollars in funding [4]). But costs and effort can be decreased with automatic generation of population. This is a two-fold process, in which we need to generate the unique appearance and the behaviour of each individual. Unique appearance can be generated by mimicking the biological reproduction, as for example in [7]. One way of automatisation of behaviour is to represent individuals as autonomous virtual agents that can generate their goals and act upon them [8]. To generate such goals, we propose to use motivation, and in particular physiological motivation, such as hunger, thirst, fatigue and comfort. In this case agents generate their goals upon physiological trigger, e.g. getting hungry. If needed, other types of motivation can be employed, such as safety, love, or self-realisation [9] [10].

The problem with classical approaches to agents driven by physiological motivation is that in a historical simulation all such agents would follow the same circadian rhythm [11] (get hungry, thirsty at the same time), what leads to undesired, uniform behaviour. To avoid this we propose to configure *motivational modifiers*, which affect the decay rate of a given motivation. For example, a hunger modifier affects the pace in which an agent gets hungry. If such modifiers are different for every agent - then every individual follows its own circadian rhythm, executing goals at various time intervals, increasing believability of the simulated population.

A. Personality and Emotions

In classical Artificial Intelligence (AI), many agent-based simulations follow the BDI model [12] which assumes individual agents being active by continuously pursuing some goals. In order to achieve a goal each agent needs a plan. Such plans can be automatically generated using traditional planning techniques [13] [14]. Such planning techniques normally model perfectly rational behaviour, which is not always suitable for simulating humans as this results in emotionless, "robotic" behaviour. To avoid this we enrich agents with personalities and emotions, which affect their decisions when creating a plan for a current goal. This approach may even lead to emergent agent behaviour that appears to be closer to human-like reasoning. As an example, imagine a fisherman agent with no personality and emotions, who catches fish when it's hungry. The agent will fish until it succeeds, or until it dies of hunger, unless we manually specify a possible change of plans when hunger level raises to a critical value. In contrast, fishermen who have various personalities and emotions may produce quite diverse behaviour, which will be more human-like and believable. For example, a phlegmatic agent may continue fishing until it succeeds, while a neurotic fisherman may get easily frustrated when hungry and unsuccessful with fishing. This neurotic agent may "decide" to stop fishing when frustration level overwhelms the rational decision for fishing and will search for alternatives to feed, such as begging or stealing food. The decision whether to beg or steal would also depend on the agent's personality.

B. Social Norms and Institution

In the above example, fishermen represents a specific *social group* of the simulated population. Social groups combine certain classes of individuals that fulfill their goals in a similar way. Combining individuals into social groups allows us to define and program actions on a group level, rather than having to do this on individual level, reducing effort in defining crowd behaviour. In human societies, it is not uncommon for members of different social groups to interact with each other and even cooperate in order to fulfill their goals. For example, imagine a fisherman who has to trade fish with a spear-maker in order to replace his broken fishing spear (see Section IV). A common technique being used in AI to facilitate the kind of interactions between different social groups as in the example above is to employ Organisation-Centred Multi-Agent System (OCMAS) [15]. The OCMAS approach is to explicitly formalise social norms of the agent population and connect those norms to the social roles, which represent different population groups. Such social norms capture rules

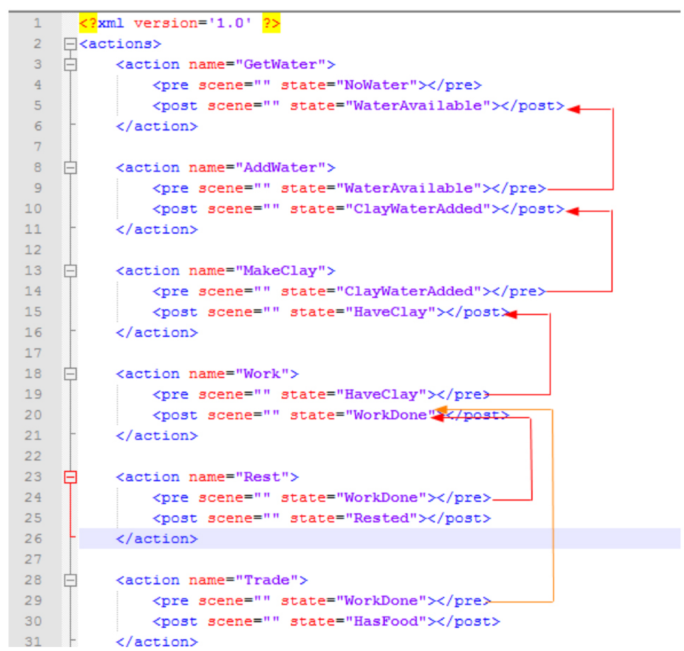
Fig. 1: PotMaker Planning Example: AddWater → MakeClay → Work → Trade.

and protocols that drive agent interactions. As a result, agents can use these norms in reasoning to create plans for their current goal. This provides agents the ability to automatically perform their actions depending on their assigned social group.

C. Dynamic Planning

Once the social norms are formalised, the agents can use them in combination with dynamic planning techniques to construct their plans that lead to satisfying the goals that result from individual physiological needs of the agents. Rather than having a complete recipe provided for every situation the agent can encounter - the agent is simply given the list of possible atomic actions and has to find a way of combining those to reach its goals. Our dynamic planing solution relies on environment annotation. The virtual environment contains a number of objects that can potentially be used by virtual agents and those objects can be acted upon. Through text annotations, those object specific actions are associate with pre-condition and post-conditions. So, those annotations define how an agent is potentially able to achieve its goal through atomic actions, given all possible states. Figure 2 shows a fragment of such annotation (in XML format) that the agent uses for building its plans at runtime and Figure 1 illustrates the resulting plan.

Consider an example where our agent represents a pot maker, who is responsible for making clay pots. To make his living the pot maker can trade clay pots he produces for food, water, milk and other necessary products. Now imagine a situation where our pot maker agent is supplied with a goal "HasFood". The result of this goal should be the agent possessing food. In the case of dynamic planning, there is no prescribed set of actions that satisfy this goal, so the agent must conduct a search for a sequence of atomic actions that would make its state evolve to the desired state (HasFood). Let's assume that the current state of the agent is "WaterAvailable". So, for satisfying the goal "HasFood" the agent must search for a sequence of actions that lead from "WaterAvailable" to "HasFood" state. This search is conducted using a method called "backwards state-space search" [3] where the agent starts with finding the actions that has its goal state ("HasFood") as a post-condition (so after completing this action the agent will satisfy the goal). In our example such action is "Trade". But to perform this action the agent must fulfil the necessary pre-condition of "Trade" (which is "WorkDone"). So the agent continues with searching for an action that has "WorkDone" as the post-condition. Such action is "Work". Again, action "Work" has the pre-condition "HaveClay" that must be satisfied, so the agent must continue its search until it gets to the action where the pre-condition maps to the current state of the agent "WaterAvailable" (in our example such action is "AddWater"). As the result of its planning the agent has a sequence of actions that lead from the goal state to its current state. Thus, the agent can simply reverse this sequence and then use it for making its state evolve from the current state to the goal state. The resulting plan in our example will be as follows: AddWater→MakeClay→Work→Trade→HaveFood. Some individual steps of this plan (e.g. Work) will depend on the particular role being played by the agent and will be performed following the social norms of the underlying institution.

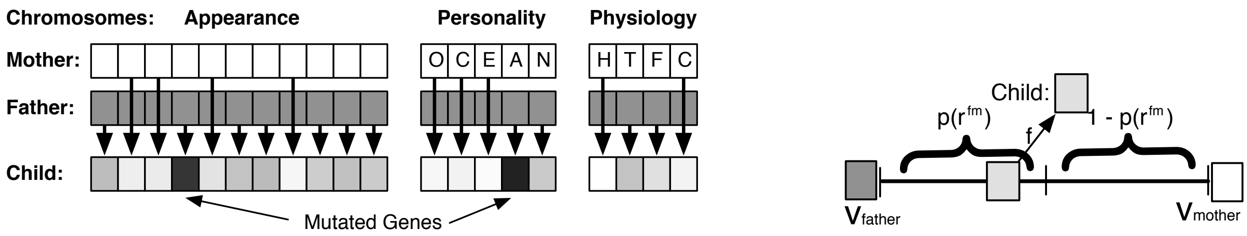


```
<?xml version='1.0' ?>
<actions>
    <action name="GetWater">
        <pre scene="" state="NoWater"></pre>
        <post scene="" state="WaterAvailable"></post>
    </action>

    <action name="AddWater">
        <pre scene="" state="WaterAvailable"></pre>
        <post scene="" state="ClayWaterAdded"></post>
    </action>

    <action name="MakeClay">
        <pre scene="" state="ClayWaterAdded"></pre>
        <post scene="" state="HaveClay"></post>
    </action>

    <action name="Work">
        <pre scene="" state="HaveClay"></pre>
        <post scene="" state="WorkDone"></post>
    </action>

    <action name="Rest">
        <pre scene="" state="WorkDone"></pre>
        <post scene="" state="Rested"></post>
    </action>

    <action name="Trade">
        <pre scene="" state="WorkDone"></pre>
        <post scene="" state="HasFood"></post>
    </action>
```

Fig. 2: Fragment of Environment Annotation XML file.

III. Methodology

Next we discuss the methodology that we suggest following for developing historical and social simulations following our



(a) Genetic reproduction using "Fuzzy" operator (b) Combining genes using fuzzy operator

Fig. 3: Using Genetic Operators to Form an Agent's Chromosome.

approach. This methodology is separated into several steps that facilitate automatic generation of intelligent agent crowds, where agents generate goals depending on physiological modifiers and plan their actions depending on their personality and in accordance with social norms.

A. Step 1: Design the base population

Base population represents the initial group of agents used to generate the rest of the crowd. This population has to define the fundamental visual properties of the resulting crowd. Therefore, for each ethnic group that will be generated, there must be at least one couple of avatars, where both individuals maintain the ethnicity-specific visual traits (e.g. asian eyes), while all other non-specific features (e.g. head shape) are varied. Following this approach, during genetic reproduction, ethnicity-specific features are carried on to the following generations [7], while diversity within ethnicity is assured.

This process requires a significant effort, as designers have to define all avatars with distinctive appearance and a library of related textures, clothing and attachments in order to ensure high variety. In order to reduce the effort, we propose to design and use *parametric avatars* [16] [7], which are avatars with visual features that can be modified using parametric values. For example, parameter "height" and "body fat" would modify the corresponding parameters of avatar body. Such parameter values of an avatar form genes combined in a chromosome used to reproduce children with diverse appearance.

To better understand how the diversity is achieved - we need to explain the process of genetic reproduction. In this process, an agent's appearance, motivational modifiers (in our case physiological modifiers), and its personality are encoded into "genes". As a result, these three groups of genes form three chromosomes, depicted in Figure 3a.

During reproduction, we take two parents and combine each of the three pairs of related parent chromosomes to produce the child's chromosome. We decide how many genes are inherited from the father and how many from the mother using a *father-mother ratio*. A *crossover* operator is responsible for combining chromosomes. Theory of genetic algorithms defines several crossover operators, i.e. split operator, but for our purposes, we define a specific *fuzzy operator*, that imitates the biological crossover using two pairs of chromosomes [17]:

Definition 1. *Given mother's chromosome c^m consisting of genes $c^m = g_1^m g_2^m \dots g_n^m$, the father's chromosome c^f consisting of genes $c^f = g_1^f g_2^f \dots g_n^f$, the parent gene selector function $s^i_{r^{fm}} : 2^G \to \{0,1\}$ which for position i, where $0 \leq i \leq n$, selects either mother or father gene depending on probability given by the father-mother ratio r^{fm} and the fuzzy function $f : \mathbb{I} \to \mathbb{R}$ which for gene on position i selects a random value in the interval given by $f(i) = [s(i), (g_i^m - g_i^f)/2]$, we define a **fuzzy** crossover operator $\oslash : C \times C \to C$ as $c^m \oslash c^f = f(1) \cdot f(2) \dots f(n)$.*

Fuzzy operator creates a new gene value by selecting a random value from the interval defined by the gene values of the parents and depending on the specified father-mother ratio takes this value closer to father or mother gene. This process is depicted in Figure 3b, where r^{fm} means father-mother ratio and $p(r^{fm})$ means probability of selecting value from the interval, depending on r^{fm}.

Another important process of the biological reproduction is mutation, which is the driving mechanism of evolution and novelty in species. We mimic the mutation process by modifying the value of pre-defined number of genes to the value from outside of the previously mentioned interval. The result of genetic manipulations is a new chromosome using which we can reconstruct a new child, its appearance, physiological needs and a personality.

Once the appearance of the avatars representing the base population has been specified in a parametric fashion - a diverse crowd of a desired size can be automatically generated following the aforementioned genetic principles. The agents in the crowd will have diverse appearance, while at the same time the important ethnic features of their appearance will be preserved. In order to introduce diversity of their behaviour - further steps of the methodology need to be completed starting with the configuration of motivational modifiers.

B. Step 2: Configure motivational modifiers

Genetic approach is also used to diversify agent behaviour. For this purpose, *motivational modifiers* are encoded into genes of the chromosome. Therefore, in this step, for each member of the base population the *motivational modifiers* are specified. In case of physiological motivation, these modifiers relate to hunger, thirst, fatigue and comfort, and represent the decay rate in which agents are getting hungry, thirsty, tired and sleepy. To avoid an impression that every single agent follows the same day cycle and performs the same set of actions at

	Temptation	Gregariousness	Assertivity	Excitment	Familiarity	Altruism	Compliance	Modality	Correctness
Beg	0	0	-0.5	0	0	0	0.5	0	0.5
Work	0	0	0.5	0	0	0	0	0	1
Search	0.5	0	0.75	0.5	0	-0.25	-0.5	0	-0.5
Steal	1	0	1	1	0	-1	-1	0	-0.75

TABLE I: Personality facets of agent actions.

the same time, these values must be different for every agent from the base population. The more diverse these values are in the base population, the more diversity will be present in the circadian rhythms of the resulting crowd. As the result of completing this step we will prepare the base population for using them as the basis for the generation of highly diverse ethnic crowds. Each individual in this crowd will borrow some appearance and behaviour traces from the base population and will also use their motivational modifiers (with some degree of mutation) to introduce and element of diversity in the circadian rhythms of individual crowd members.

C. Step 3: Specify personality traits

While diverse motivational modifiers assure execution of actions at various times, agent personalities determine the kind of actions the agents will execute. In this step, for each member of the base population its personality is specified using the popular OCEAN model [18], which captures five personality traits: *openness, conscientiousness, extroversion, agreeableness and neuroticism*. Openness relates to imaginative, creative aspect of a person. Consciousness captures the ability to be organised and careful. Extroversion defines, how social and outgoing a person is. Agreeableness relates to ability to cope with people, friendliness and generosity. Neuroticism defines tendency for negative emotions and instability.

Combination of the OCEAN values defines a specific character. Explaining, how to define a specific character is out of scope of this work, therefore we direct interested readers to existing publications [19] [20]. For the purposes of this methodology, it is important that agents forming the base population have different personality values, so that during genetic reproduction their children will have a high degree of diversity in their emerging personalities. In Section V, we present how the diversity of parent personalities affects their children, and how it determines which actions they select as the result of having a certain personality type.

In order for agents to be able to select an action that is most relevant for their personality, such action has to be annotated by following *personality facets* [21]: *temptation, gregariousness, assertiveness, excitement, familiarity, straightforwardness, altruism, compliance, modesty* and *correctness*. Using values of personality facets, the agent selects an action that provides the highest utility for its personality type [19] [21]. See Table I for an examples of annotations for *work*, *beg*, *steal* and *search* actions.

Often, actions such as "work" have various meaning in the context of different social groups. Working for fishermen means to catch fish, while for pot makers it means to make pots. Therefore, in the next step of the methodology, the institution is specified, which defines all the social groups, their interactions and also defines the meaning and parameters of specific actions, e.g. determines how quickly a particular object satisfies hunger.

D. Step 4: Formalise Social Norms and Roles

To define social groups, their actions and interactions, an Electronic Institutions (EI), a well established Organisation-Centred Multi-Agent System (OCMAS) is specified. EI establishes what agents are permitted and forbidden to do as well as the constraints and the consequences of their actions [22]. In general, an EI regulates multiple, distinct, concurrent, interrelated, dialogic activities, each one involving different groups of agents playing different roles. Definition of an EI consists of the following components:

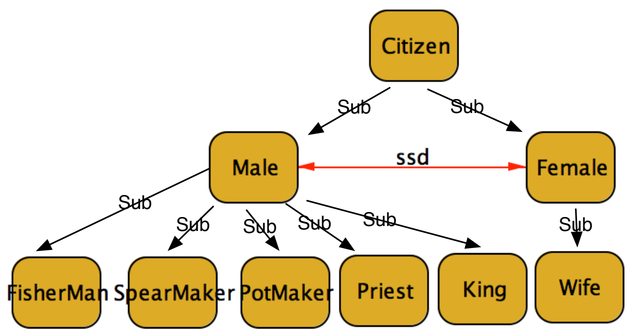


Fig. 4: Role hierarchy

First, a *dialogical framework* specifies social roles involved in the simulation and their hierarchy. Figure 4 depicts the role structure of the Uruk simulation (see Section V). Apart from the role structure, the dialogical framework defines ontology, a common language for communication between agents.

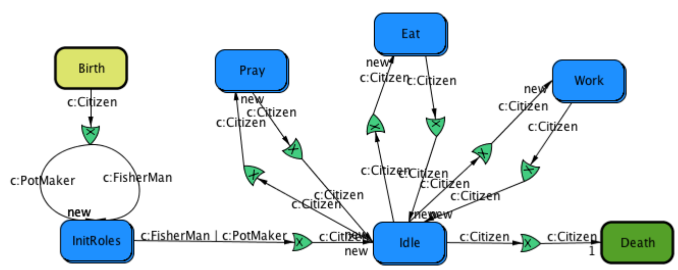
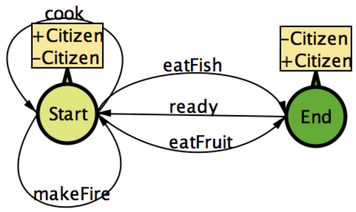
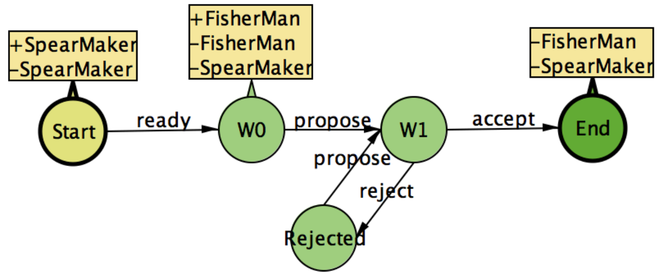


Fig. 5: Performative structure

Second, a *performative structure* isolates specific activities (also called scenes) that can be performed within an Electronic Institution. It defines how agents can legally move among different scenes (from activity to activity) depending on their role. Furthermore, a performative structure defines when new scene executions start, and whether a scene can be multiply executed at run time. A performative structure can be regarded



(a) Eat scene protocol



(b) Trade scene protocol

Fig. 6: Scene protocols in an Electronic Institution.

as a graph whose nodes are both scenes and transitions (scene connectives), linked by directed arcs (See Figure 5).

The type of transition allows to express choice points (Or transitions) for agents to choose which target scenes to enter, or synchronisation/parallelization points (And transitions) that force agents to synchronise before progressing to different scenes in parallel. The labels on the directed arcs determine which agents can move to which scenes.

Third, for each activity (scene), interactions between agents are articulated through agent group meetings expresses as *scene protocols*, which follow well-defined interaction protocols, whose participating agents may change over time (agents may enter or leave). A scene protocol is specified by a directed graph whose nodes represent the different states of a dialogic interaction between roles (See Figure 6). Its arcs are labelled with illocution schemes (whose sender, receiver and content may contain variables) or time-outs.

Definition of EI is fundamental to agent reasoning and our dynamic planning algorithm that constructs a list of actions to fulfill the current goal by finding a path (sequence of actions) that make the agent go into the desired scene and reach a desired state within this scene. An institution provides agents with knowledge about possible actions that can be performed. The next step of the methodology provides means of visualising these actions in the virtual world.

E. Step 5: Adaptation and Annotation of the Environment

For purposes of visualisation, institutional actions must have corresponding objects, animations and scripts. In this step, objects of the virtual world related to such actions are created and annotated with specific meta-data, so that agents know that a connection between institutional illocutions and objects is established. Agents use annotations in their planning, which is affected by the current state of the environment. Therefore, interactive objects have to contain information on what action they provide and what are the action parameters [23].

Adaptation and annotation of the environment is the last step that requires manual input. In this last step we generate the population of the simulation and make it act within the simulated virtual environment.

F. Step 6: Generating the Population

Generation of population is a fully automatic process, where the desired number of "children" is generated from the base population using genetic approach described in Section III-A. Initially, children are only sets of chromosomes and their appearance has to be reconstructed in a given virtual world. Once connected to the virtual world, they start automatically generate goals and act upon them by using our dynamic planning approach in combination with the Electronic Institution that was defined on Step 4.

IV. Case Study: Uruk 3000 B.C.

In order to highlight the key aspects of our approach, we have applied it to simulating one of the humanity's first cities - the city of Uruk 3000 B.C. To further address the agility of our approach, we apply our methodology first to Second Life[2], a well known virtual world platform, and then to Unity 3D[3], the popular game engine. The Second Life simulation aims to present the life of Uruk to wide public, using well-know virtual world platform with many existing users. Users of Second Life can experience the simulation by conveniently connecting to it from any place in the world and enjoy the multiuser aspect and role-playing features. In contrast, the Unity simulation is intended to be used on desktop computers and doesn't have multiuser support. Due to its network dependance, the drawback of Second Life is in its lacking capability of handling large societies of intelligent agents (or non-playable characters, NPCs). On the other hand, Unity 3D provides the possibility to execute large societies. The size of the society is limited by the computational capability of the hardware, on which the game is executed. In this section we describe how our methodology facilitates deployment of sophisticated historical simulation to both platforms and compare their workload estimates.

A. Preparation: Designing the World

Before we can apply our methodology, we need to design the 3D environment of the simulation. In Second Life, we started with an existing 3D model of the city (mainly designed by our project partners from the Federation of American Scientists) that included key buildings, plants, animals and terrain. This model was informed by archaeologists and provides some level of historical accuracy.

For Unity 3D, we have recreated this 3D model in Google Sketchup and Blender. Furthermore, we have modelled historical objects used by various crafts belonging to the epoch.

[2] http://secondlife.com (last visited 03/2014)
[3] http://unity3d.com (last visited 03/2014)

(a) Second Life

(b) Unity 3D

Fig. 7: 3D Visualisation of the city of Uruk 3000 BC

These objects include beds positioned on roofs, various chairs and tables, pots for cooking, market equipment, pottery ring, spears, and spare spear parts, fisherman boats and rows. 3D design requires a lot of effort, and the preparation step took significantly longer then design and execution of the city population. Figure 7 compares the visualisations in both, Second Life and Unity 3D. Figure 8 shows the market, executed in Unity 3D, with several, custom designed objects.

Fig. 8: 3D design of the Uruk market with live avatars

With the static 3D design of the environment in place, we can start applying our methodology an populate this environment with autonomous agents.

B. Step 1: Design the base population

When defining the base population is Second Life, we considered only one ethnic group of Uruk citizens. Therefore, we designed only two members of the base population portrayed in Figure 9a and Figure 9b, using which we have generated the rest of the population.

Figure 9c, depicts a child generated with a low level of mutation. This child carries visual traits from both parents, having mother's nose, but father's mouth. Figure 9d depicts the child of the same parents, but with high level of mutation. Some visual traits are still visible (e.g. nose, jaw shape), yet, there are new emergent visual features, such as skin colour.

In Unity 3D we have applied a slightly different approach and generated the base population using the *genotype rules* [7]. Using such rules we can specify a racial or ethnic profile, which limits gene values only to the specific range. For example, we can specify what shades of skin colour can be used, what is the approximate size of the nose, what is the range of person height and so on. Yet, this approach can only generate avatars belonging to the same race/ethnic and does not allow us to generate intra ethnic avatars. Since we are generating avatars belonging to the ancient Uruk ethnic, this is not a problem.

(a) Father

(b) Mother

(c) Child

(d) Mutation

Fig. 9: Generating crowd appearance in Second Life

Figure 10 depicts the sample of ten avatars generated from the initial population of five avatars. In the base population we have two ethnics, Caucasian (Adam and Bea) and Sumerian

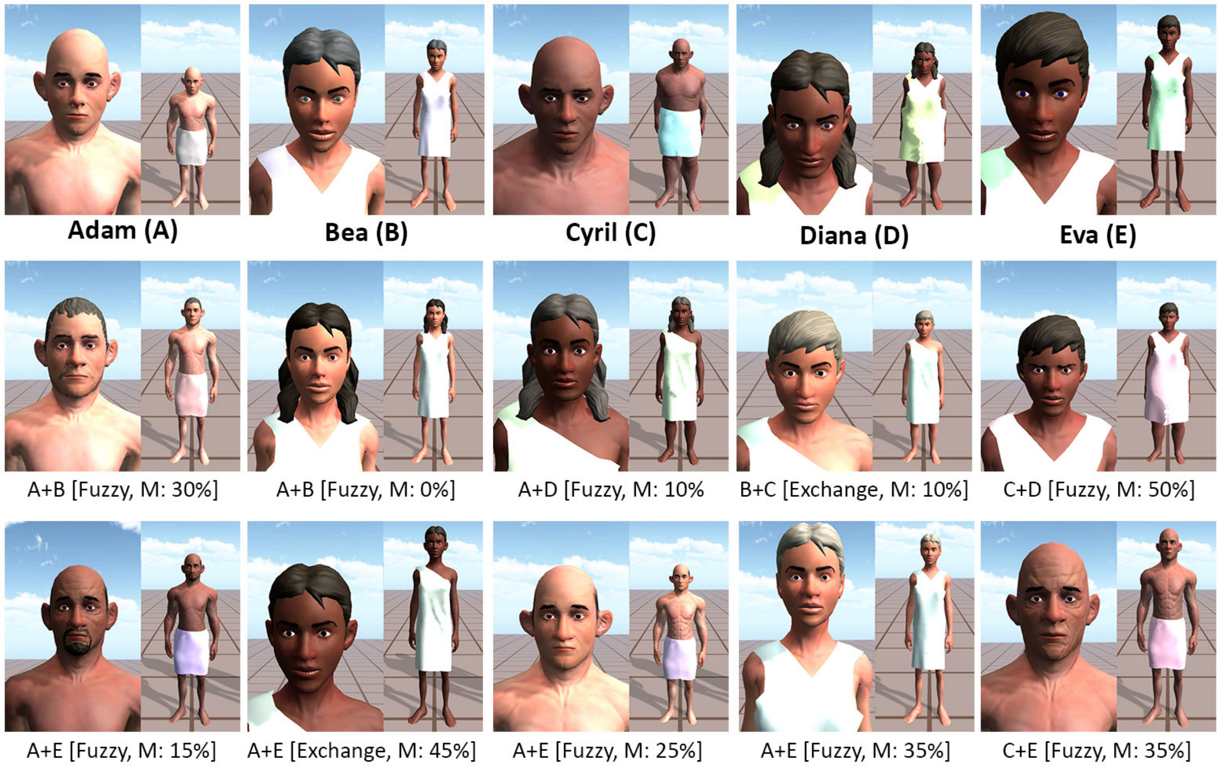


Fig. 10: Detail of the crowd generated for Unity 3D.

(Cyril, Diana and Eva). We have used western names for the Sumerian population only for convenience, in order to code them alphabetically by the first letter in their name (A-E). Generated children are named by coded names of their parents, the crossover operator and the mutation level used during generation process. To portray the preservation of ethnic features we have designed all members of the Sumerian population with bigger, distinctive noses and darker skin colour, while caucasian population has smaller noses and and lighter skin colour. Child of C+D in the first row and C+E in the second row obviously carry on only the Sumerian features, although C+D shows also very distinct features, due to the high level of mutation that has been used.

Interesting result is in the second row, where we depict four different children of A+E, each of them visually distinct, yet clearly carrying features from both father and mother. Two children are small, with lighter skin or bigger ears as their father, others are taller, or with darker skin and smaller ears as their mother.

Figure 12 depicts the society of 150 avatars, generated from the base population belonging to the same ethnic. As a result, none of the generated avatars carries caucasian traits and skin colour. The apparent difference is the overall graphic quality, which is prevailing in Unity 3D.

C. Step 2: Configure motivational modifiers.

Base population serves not only to generate avatars with unique appearance, but also with a unique (or non-uniform) behaviour. As a result, in the next step, we defined the physiological modifiers of the base population. We set various decay rates for hunger, thirst, fatigue and comfort for each member of the population. Avatars generated from the base population will obtain varied and mutated values of these modifiers. Since each modifier will have a different value, avatars will become hungry or tired in distinct intervals, executing their actions non-uniformly. Figure 11 shows the graphical user interface, that facilitates the specification of physiological properties.

D. Step 3: Specify personality traits

Physiological motivation solves the (when) problem of uniformity, when agents execute their actions at various time frames. On the other hand, having avatars with distinct personalities solves the (what) problem of uniqueness, when agents perform actions matching behavioural profile. As a result, we define personalities for each agent using the OCEAN model. Figure 13 shows the graphical user interface, that facilitates the specification of personality properties. In Section V we describe the setups for personalities that were used.

Apart from the definition of agent personalities, we annotated all actions and relate them to a specific personality, using personality facets (see Section III-C). Table I shows four actions that Uruk agents perform to satisfy the goal of "eating". In this table, there are four actions, i.e. beg, work, search and steal, and nine personality facets, e.g. temptation, gregariousness, assertivity with valued ranging from -1 (low) to 1 (high). These facets work as modifiers used to calculate

Fig. 12: Overview of the crowd generated for Unity 3D.

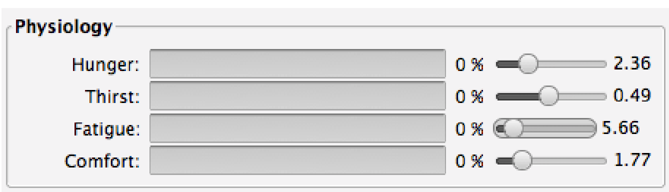


Fig. 11: Defining physiological properties of an avatar.

utility of a given action in relation to a specific personality. The higher the utility, the more probable is that the action will be selected. "Stealing" action is defined for agents with more aggressive personalities (very low correctness, low altruism), "begging" for agents with low-confidence (very low assertivity, higher correctness) and "working" and "searching" for more neutral personalities with varying sense of correctness.

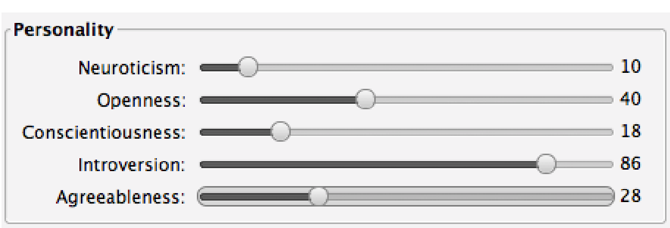


Fig. 13: Defining personality properties of an avatar.

E. Step 4: Formalise Social Norms and Roles

Next, we defined all components of the Electronic Institution, with roles of fisherman, spear-maker, pot-maker, priest, king and wife (see Figure 4). All of these roles are sub-roles of *citizen*, which holds all common properties for all roles, e.g. inventory of owned items.

Then, we defined possible actions of agents in specific scene protocols (see Figure 6). For current roles we defined pray, eat, make spear, make pot, trade and fish protocol. Make spear, make pot and fish protocol belong to the scene "Work", and agents select the correct protocol based on their role. Most of these protocols only command a single agent what actions need to be performed to achieve its goal. The exception is the fishing protocol, which defines collaborative actions for two agents, where one agent has to row a boat, while the other is fishing with a spear. Therefore, fishermen always have to agree to go fishing in pairs.

Finally, we grouped scene protocols in a performative structure (see Figure 5), which restricts execution of actions in scenes to specific roles.

F. Step 5: Adaptation and Annotation of the Environment

For all actions and interactions, we have recorded animations, such as begging or stealing food, using motion capture and copied them in ".BHV" format to Second Life and with the help of Blender 3D, we have converted ".BVH" file to Unity 3D. Recording animations and their subsequent processing in any platform is a very delicate task and usually requires professional crew and equipment. Since we had no such possibility our own acting performance sufficed.

Moreover, since 3D object carry no meta-information on their possible purpose, we have added related objects to the virtual world model and annotated the environment so that agents can use them in their planning. For example, agents use the 3D object camp fire to cook their food. Therefore, we annotate that this 3D object provides action (illocution) "cook" from the scene "Eat" (annotated as action:Eat.cook). As a result, when agent plans its action, it knows that it has to interact with camp fire object to perform the "Eat.cook" action. In another example, we annotated a pottery ring with "action:Work.PotMaker.makePot", which defines that pottery ring provides action makePot in the scene protocol "PotMaker" from the scene "Work".

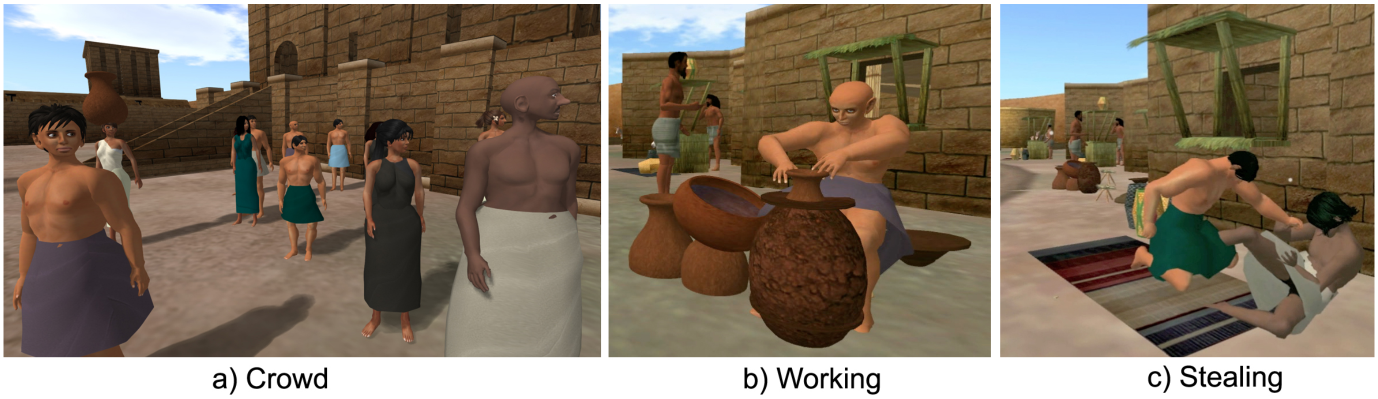


Fig. 14: Everyday Life in the City of Uruk 3000 B.C.

The underlying electronic institution puts these annotated objects into context and allows the agent to associate how its current physiological needs can be addressed using the help of particular objects, avatars or actions in the virtual environment.

G. Step 6: Generating the Population

In the last step, we generated a population of agents and integrated these into Second Life and Unity. Each agent had a unique appearance and automatically started fulfilling its goals. Agents were correctly selecting their goals based on their physiology, executing them at various intervals due to different physiological modifiers, planing their actions based on their personality and social norms, and executing them in the simulated environment. Figures 14, 15, 16 show some virtual agents from the resulting simulation.

Fig. 15: Praying Ritual

V. Evaluation

In this section we analyse our results and estimate the effort (in hours) needed to set-up and execute the simulation of Uruk in both environments. Then, we describe two experiments, that evaluate the diversity of generated agent behaviour.

A. Second Life

We estimate that the total time spent on completing the case study from Section IV was close to 7 days. The process was relatively fast as we have already had a model of the city and we focused only on generating the population. Step 1, definition of base population took us three days, where most of this time was spent on modelling clothing and attachments for avatars. Second Life provides parametric avatars with possibility to change more than 200 visual features. Therefore designing the body of the avatars took us only a couple hours per avatar. Steps 2 and 3, in our case took only one hour to complete, as the physiological modifiers and personality were defined only focusing on having wide range of values (rather than trying to achieve some pre-determined global personality skew in the resulting population). Step 4, definition of institution took 1 day, during which we designed all scenes and a performative structure and tested agent interactions. Also, we studied how to set-up the personality facets of personality-based actions. Step 5 took a lot of effort and time, in total 4 days. During this time we recorded and tuned all the animations, designed all interactive objects (e.g. pot-making ring) and scripted their behaviour. Step 6 is fully automatic, generation of 100 agents took a few seconds, visualisation of each avatar in Second Life takes about 30 seconds per avatar.

Fig. 16: Uruk School

B. Unity 3D

We estimate that the total time spent on completing the case study from Section IV was close to 25 days. The increase in time is due to the fact, that we needed to re-create manually the 3D design of the city (7 days) as well as all 3D objects (5 days) and avatar clothing (6 days). Since we were able to re-use animations from Second Life, we only needed to convert them from .BVH format to .FBX format in Blender 3D. Converted animations had to be adjusted and programmed to be used with Unity (i.e. Mecanim[4]). The conversion and animation adjustments took us 2 days. Then, we have annotated the environment with meta-data used by agents during reasoning about possible plans to accomplish their goals. In this case annotation is done directly in Unity 3D, via custom MonoBehaviour objects. Once all the platform-specific steps were taken we were able to reuse all other information from the Second Life setup. This information included the definition of the institution (which is exactly the same), personality setups for the base population, their daily plans and related cultural information for the institutional roles. It is here where our methodology proves its strong re-usability capability. As a result it took us only 1 day, to adjust steps 2-6 to Unity 3D.

C. General Methodology

Using our methodology, in combination with modern game engines and 3D virtual worlds, we significantly cut down the time to populate historical 3D simulations. The drawback of our approach is that we rely on parametric avatars with ability to modify the avatar appearance and clothing using declarative (visual) parameters. But, this is not a major issue, since we already possess the technology for Unity 3D and Second Life, and other game engines offer similar functionality, although in the form of paid plugins.

Having parametric avatars and employing our genetic approach we can generate unique, ethnic avatars in a very little time. Using motion capture, we can easily animate these avatars and believable results depend only on exact historical data and acting skills. Furthermore, using the Electronic Institution technology, we can declaratively specify the social structures and interaction protocols, used by agents to automatically reason about their possible actions. Electronic institution can be tweaked during the simulation runtime, decreasing the debugging efforts in comparison to traditional approach, where simulation has to be restarted after every change. As the result, with limited effort we receive a simulation in a semi-automatic way, where the degree of complexity of the actions the agents perform is much higher than what can be achieved with classical crowd simulation techniques.

D. Generating children of parents with diverse personalities.

To test the validity of generating agents with various behaviour, we performed two experiments. In the first experiment, we set-up diverse personalities of parents, where one parent had very low confidence, while the other was very aggressive (see Figure 17a). When hungry, the first parent would choose to beg, the second one to steal. Then, we have generated their 100 children, with father-mother ratio set to 30% (agents will have 70% of their genes closer to their mother). Figure 17b depicts the highly varying personality profiles of their children. We generated agents decide what to do when hungry and observed emerging behaviour of searching for food and working in 40% of generated children (see Figure 17c). Only a few children decided to steal as the father-mother ratio was in favour of the mother.

[4]https://unity3d.com/unity/animation (last visited 04/2014)

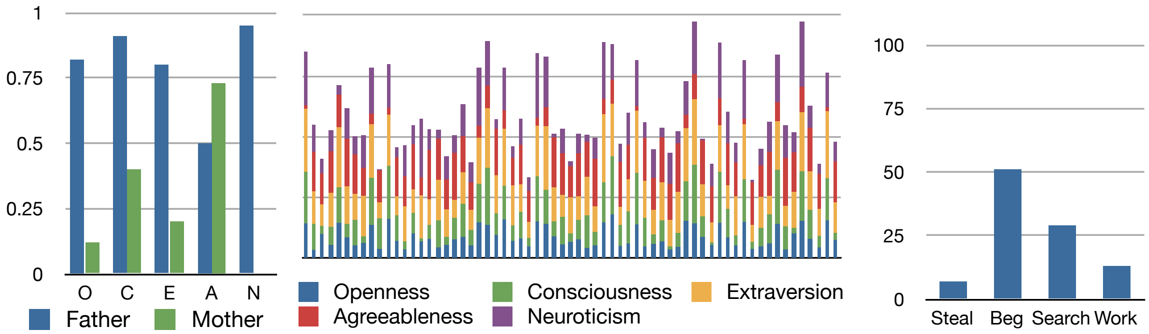
E. Generating children of parents with similar personalities.

In the second experiment we set-up father and mother with similar personalities (see Figure 18a) and during generation applied a high level of mutation (25%). We observed the children personalities and actions, depicted in Figure 18b. Generated children had very similar personalities, with occasional exceptions, due to mutations. In this experiment father choses to search for food, while mother choses again to beg. Having the same father-mother ratio (30%), most of children decide to beg, just like their mother (see Figure 18c). Several mutated children decided to work.

The above experiments showed that having a base population with diverse personalities leads to generating children with diverse behaviour. Parents with similar personalities result in their children having similar personalities and predominantly showing the same behaviour, unless they undergo mutation.

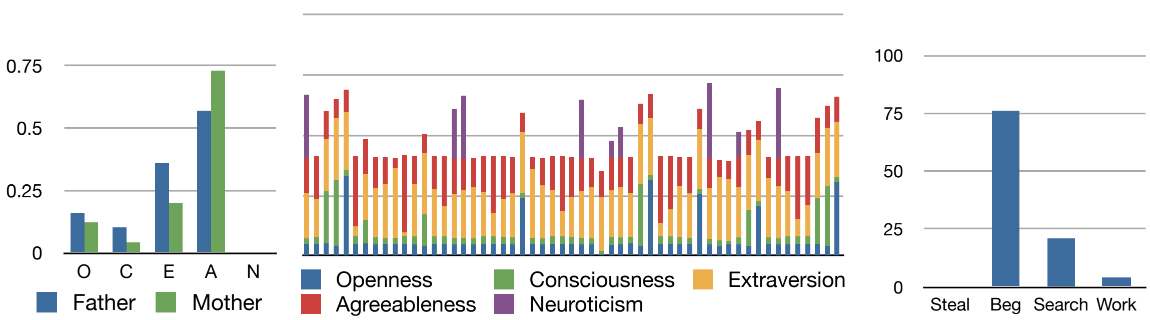
VI. Conclusions

In this work, we presented a methodology for generating crowds for the purposes of social simulations. This methodology is using genetic operations to produce individuals with unique appearance and behaviour. We have separated the methodology into six steps. First step is the definition of the base population, which specifies the visual traits of the whole population, although using mutation we may achieve novelty during generation. Second step is the definition of motivational modifiers, where motivation serves as the goal selection mechanism. In our case, we used physiological needs as the main motivation. Third step is the definition of personality traits, where personality affects agents decisions during planning and agents select actions that best match their profile. We are using well-established OCEAN model for the personality definition. In the context of social simulations, agents belong to specific social, ethnic or cultural groups and have to obey specific social norms. Therefore, fourth step is the definition of the social system and norms, in our case using Electronic Institutions. The fifth step is the adaptation and annotation of the environment that reflects all actions specified in the electronic institution. Agents are using these annotation to automatically plan their actions and interact with the environment. Following these steps results generating a diverse agent population having a high degree of variety in their appearance and behaviour, while also demonstrating substantially high degree of complexity of actions being performed by the agents.



(a) Parents (b) Children personalities (c) Actions

Fig. 17: Exp. 1: Children of parents with opposite personalities (no mutation).



(a) Parents (b) Children personalities (c) Actions

Fig. 18: Exp 2: Children of parents with similar personalities (mutation 25%).

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The Effect of Spatial Clustering on Stone Raw Material Procurement

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***Abstract*—Brantingham [1] proposes a neutral model to explain observed data on stone tool raw material procurement. Here we provide the results of investigating how real source locations, and their spatial clustering affect the raw material pattern outcome of the neutral model. Our initial findings are that spatial distributions mimicking empirical data challenge the validity of the neutral model. More specifically, increasing the source clustering increases the amount of time where the forager is without raw materials. In terms of foraging behavior, it is not realistic to expect that foragers go extended periods of time without raw materials to create and repair tools.**

I. Introduction

The archaeological record shows that foragers varied the stone tool raw material preferences, even when several types of stone materials were available. The changing use and co-use of different stone tool raw materials is well known from a wide range of environmental and climatic contexts, time-periods, and cultures (e.g., [2], [3]). What explains this changing raw material preference is a question of great interest, and it is debated whether changes in stone tool raw material frequencies could be considered a reliable proxy for human forager adaptive variability (e.g., [4], [5]). Explanations for change in raw material usage frequency include climate/environmental change and its co-variability with mobility and procurement strategies [6], selection of certain raw materials for their physical properties [7], changes in demography [3], the preference for appearance or color [8], symbolic value [9], and style [10].

Brantingham [1] challenges these explanations, providing a neutral model that can explain some of the observed patterns. Brantingham [1] argues that in order to demonstrate the deliberate selection of raw materials, patterning must be shown to be different from the results of the neutral model, which provides a baseline for comparison where archaeologists can be certain that observed raw material patterns is not the result of strategic selection.

We agree with Brantingham's sentiment [1]. However, the neutral model in its original form has two major limitations. To be able to make better comparisons with archaeological raw material frequencies these two limitations need to be explored and corrected: 1) the raw material sources are distributed randomly without any clustering across the model landscape, which is not the case on a real landscape where potential raw material source locations are controlled by the underlying geological structure and geophysical processes; and 2) each raw material location in the model represents a unique raw material, which is not realistic. Five thousand raw material sources are possible over an extended landscape but not 5,000 unique raw materials. It is more likely that a smaller amount of different raw materials, say 1-25, are represented by the 5,000 source locations. In addition, the 1-25 unique raw materials are not randomly distributed in isolation away from same type raw materials. As discussed under limitation 1, not only are source locations clustered due to the underlying geological structure and geophysical processes but also depending on the geological formation (several sources of the same material can be available in a cluster).

The overall question we address is how does the structure of a real landscape and real source locations affect the output of the neutral model? We specifically address a question related to the first limitation: What is the effect of spatial clustering of raw material sources on the model raw material procurement output?

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II. Empirical data

The test case is the landscape around the town of Mossel Bay, Western Cape, South Africa. The Mossel Bay region has several archaeological sites that, combined, offer a long sequence of change in raw material selection [11], [12]. The local geology is well understood [13], and thorough surveys for potential raw material sources have been undertaken. In total, 38 potential stone tool raw material sources have been discovered, which is likely an underestimate. These sources ranges greatly in size (Figure 1), are clustered according to geological structures and geophysical processes, and only 6-7 raw materials are represented among the 38 sources.

III. Model description

Brantingham [1] created a simple model of one agent with a mobile toolkit of fixed capacity that is randomly placed on the environment. At each time step, the agent moves to

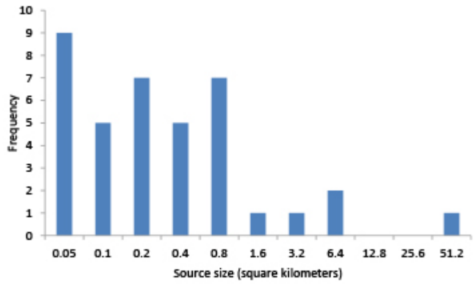

Fig. 1. Frequency of stone tool raw material source by size bin in the Mossel Bay area.

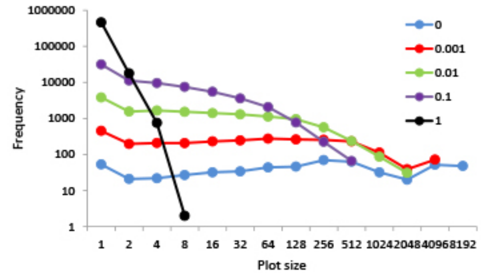

Fig. 3. Distribution of sizes of material resources in generated landscapes.

one of the nearest eight neighboring cells or stays in the present cell, with equal probability (= 1/9). Each time step a fixed amount of raw material is consumed dependent only upon its frequency in the mobile toolkit. If a raw material source is encountered, the toolkit is re-provisioned up to its maximum capacity before moving again at random. If no raw material source is encountered, the forager moves immediately at random. Simulations are run until 200 unique raw material sources are encountered, or the edge of the simulation world is reached. The model is replicated in Netlogo by Janssen and Oestmo [13].

For our analysis we use a maximum capacity of the tool kit equal to 100, the environment is 500x500 cells and consist 5,000 unique material resources. When we include clustering of resources, we include a probability p_r. When we place the 5,000 material resources on the landscape there is a probability p_r where the new material resource is placed on a randomly chosen empty cell. With probability 1 -p_r the new material resource is placed on a randomly chosen empty cell that has at least one neighbor (one of 8 neighboring cells) that already contains material resources (see Figure 2 for an example landscape).

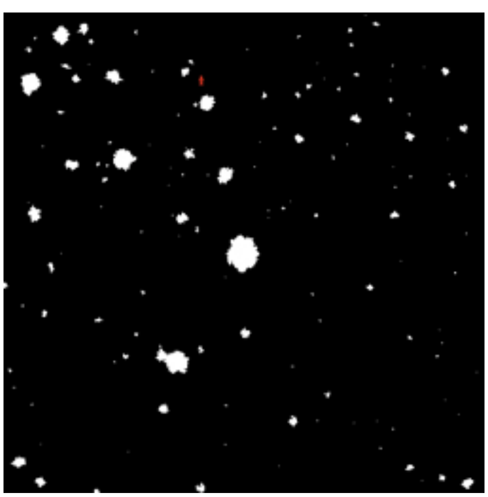

Fig. 2. Distribution of material resources (white) when p_r = 0.01.

IV. Model analysis

When we simulate the model 1,000 times for different clustering of material resources, we derive different outcomes on the metrics of raw material procurement. We consider different values of p_r (Figure 3) and see that a more clustered environment leads to a much larger tail of richness of material in the toolkit (Figure 4). The continuous refilling of the toolbox when the agent is moving on a large cluster of materials is causing this richness of materials. However, the richness value is inflated because it is assumed that each source is a unique raw material.

The distance that material resources are moved after collection remains similar (Figure 5) throughout the random landscape. We see that clustering leads to much longer times in which the agent has no materials. With p_r = 0 the average time agents look for resources is 3,700 steps, while it drops to 1,600 steps when p_r = 0.01 and to 107 steps when p_r = 0 (Figure 6). If resources are more clustered than simulated in the original model, we can expect that foragers will run out of materials for longer periods of time. If we calculate the percentage of time the agent is without materials we find this to be 14% for p_r = 0; 63% for p_r = 0.001; 83% for p_r = 0.01 and 0.1; and 34% for p_r = 1. Hence, the original neutral model might not be an appropriate model for landscapes with raw material sources clustered like empirically observed. It is not realistic to expect that foragers will go extended periods of time without raw materials to create and repair tools.

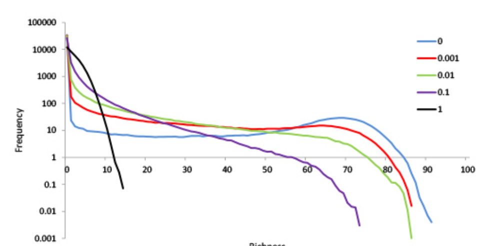

Fig. 4. Distribution of richness (number of unique material sources).

V. Open Issues

By the conference in September, we will have extended the analysis for different p_r values over more simulation runs. We would also like to address limitation 2, to test the effect if we

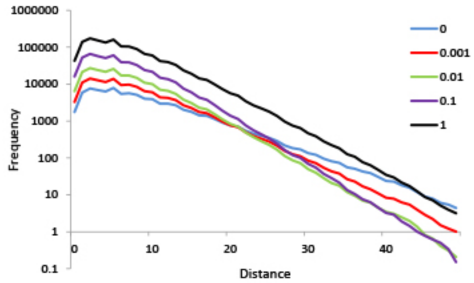

Fig. 5. Distance that material is moving until discarded.

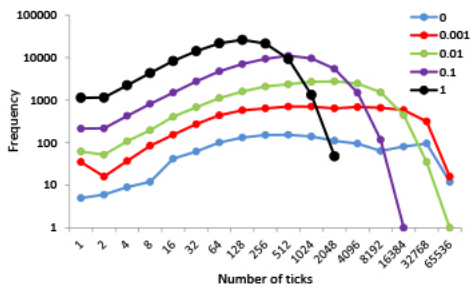

Fig. 6. Distribution of the number of steps that agents make when toolkit is empty.

assume that locally clustered materials are represented by the same raw material and not different raw materials. Finally, we would like to test the effect of different random walk implementations.

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The Effect of Landscape Patterns on Foraging Strategies of Hunter-Gatherers: An Empirical Agent-Based Modeling Approach

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***Abstract*—An empirically grounded model of Ache hunter-gatherers was used to test the performance of alternative foraging strategies for different distribution of resources.**

I. Introduction

We developed an agent-based model of foraging behavior based on ecological parameters of the environment and prey characteristics measured in the Mbaracayu Reserve Paraguay (Janssen and Hill, 2014; see also model documentation: http://www.openabm.org/model/3902/version/2/view). The model was implemented on 58,408 one-hectare cells using a time step of 5 minutes for an average of 6-hours-per-day hunting activities for one year. We then compare estimated foraging behavior from our model to the ethnographically observed behavior of Ache hunter-gatherers who inhabit the region and show a close match for daily harvest rates, time allocation, and species composition of prey. The model allows us to explore the implications of social living, cooperative hunting, variation in group size and mobility, under Ache-like ecological conditions. Simulations show that social living decreases daily risk of no food, but cooperative hunting has only a modest effect on mean harvest rates. Analysis demonstrates that bands should contain 7-8 hunters who move nearly every day in order to achieve the best combination of average harvest rates and low probability of no meat in camp.

In this extended abstract we will extend the analysis by exploring the hunting behavior on diverse landscapes. The Ache landscape has similar return rates for each of the seven vegetation types. This explains why random walk is such a good null model. However, many landscapes are more patchy, meaning that resources are clustered is certain areas. So, how sensitive is the hunting strategy of the Ache to alternative landscapes? We vary the original Ache landscape by including vegetation patterns and distribution of species among vegetation types, while keeping the expected food availability the same. We expect that more concentrated resources lead to more targeted movements of the groups, and more prolonged stay in higher productive areas.

TABLE I
Table 1: Types of landscapes

Clumpiness	Original Variation Quality	High Vegetation Quality
Low		
Original	**Original**	
High		

II. Hunting Strategies

The default strategy that agents use is to randomly define in the morning a location for the camp to move to in the evening that is 2 kilometers from the current camp location. Agents move towards the camp in a U-shaped pattern. Agents coordinate their movements such that they can execute cooperative hunting. This means that they walk through the forest within a distance of a few hundred meters. Although this clustering of hunters will suppress encounters of prey (due to hunter A scaring animals away for hunter B in the same area), the opportunity of cooperative hunting increases performance.

In the targeted camp version of the model, agents move towards a camp location with preferred vegetation type. We keep track where each camp has been. We don‘t want agents going to the neighboring patch if it will move, so we assume that a camp has an area of influence. We define that the new camp needs to be at least 1 km away from the old location. When a camp moves it will look for the nearest riparian patch (the vegetation type with the highest return rate) which has not been visited during the last 30 days, which is a kind of recovery period. If there is no patch available, we will look for available patches with high forest.

When the direction is defined, we will check whether the target is between 1 and 3 km. If so, the new camp location will be the target level. Otherwise, the camp will move 2 km in the direction earlier defined.

The original Ache model assumed agents move camp locations after a certain amount of days (say one day). In the adaptive camp version of the model, the agents in a group consider whether the average weight of meat hunted is above a certain threshold. If so, the agents stay, if not, the agents move on.

We run 64,800 simulations with the Ache model, 100 runs for each of the about 108 configurations on each of the 6 landscapes where we vary adaptive/non-adaptive camp, targeted/non-targeted camp, the group size and the threshold when an adaptive camp is abandoned.

III. Creating Alternative Landscapes

The next step is to change the distribution of encounter rates. We multiply the encounter rates of riparian by about 3 and those of the high forest by 2. The other vegetation types are multiplied by about 1 or lower to make sure that the encounter rates over the whole landscape remains the same for each species. The multipliers lead to a more unequal distribution of expected return rates for the vegetation types. The figure below is based on calculations of the null model (thus no cooperative hunting). We see now that riparian is more than ten times as productive as the meadow.

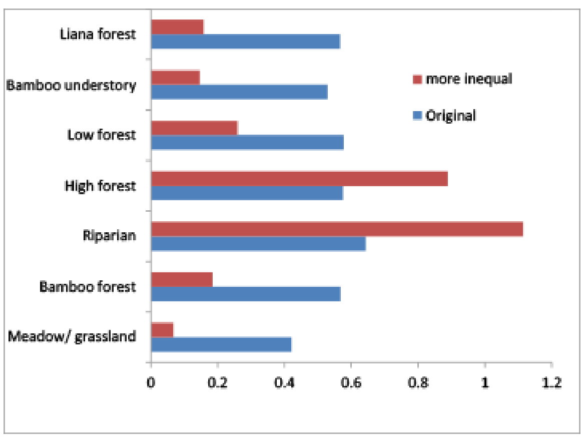

Fig. 1. Expected return rates of one hour of hunting on the 7 vegetation types with the original distribution and with the encounter rate distribution that leads to higher vegetation variability.

We vary the landscape by changing the configuration of vegetation types. We want to see what happens if we have more concentrated blobs of the same vegetation. We take the original landscape and perturb this by including an algorithm which checks if randomly swapping the land cover of two cells leads to a higher degree of different types of vegetation on direct neighboring cells. We can also go the other direction and see whether we can make the landscape more random. In the original landscape a patch has on average from the 8 neighboring patches 60% of the same vegetation type. We explored the consequences for landscapes with 30% and 90% of the neighbors with same vegetation type.

IV. Analysis

We ran for each of the 6 landscapes, 108 strategies 100 times for each parameter setting. We see that for non-patchy landscapes the best strategy is that groups move each day (Table 2). When the landscape is patchy a non-adaptive

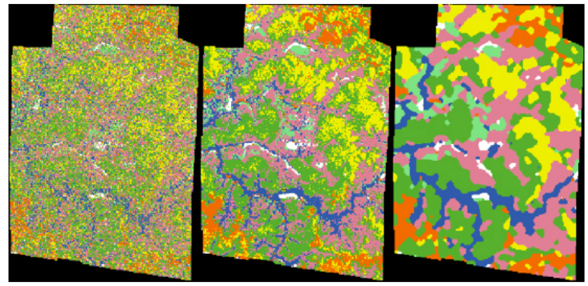

Fig. 2. Vegetation maps for less clumpy landscape, original landscape, and more clumpy landscape (right).

movement is best when the vegetation is distributed more randomly (clumpiness is low). Groups go to most productive vegetation types (targeted camp) except when vegetation types are more randomly distributed (similarity = 30%).

In all landscapes we find that 7 hunters is the optimal strategy. Perhaps this number is defined also for other landscapes by the encounter suppression assumptions (see Janssen and Hill, 2014). The optimal strategy for the Ache landscape is that groups target the more profitable vegetation types and move each day.

If landscapes are more patchy than the Ache landscape and vegetation types are more concentrated, movement of groups is more adaptive. When vegetation is more clumpy we also see that the minimum kg of meat caught required for a camp to stay in the same location becomes higher.

TABLE II
Table 2: Optimal strategies for different landscapes.

Clumpiness	Original Vegetation Variability	High Vegetation Variability
Low	Non-targeted camp, 7 hunters, non-adaptive camp	Non-targeted camp, 7 hunters, non-adaptive camp
Original	Targeted camp, 7 hunters, non adaptive camp	Targeted camp, 7 hunters, adaptive camp. Threshold = 2kg
High	Targeted camp, 7 hunters, non-adaptive camp	Targeted camp, 7 hunters, adaptive camp. Threshold = 2.5kg

In Table 3 we present the meat per hunter per day for different strategies. The average meat per hunter per day remains the same if species are distributed equally among vegetation types (OVV) independent of the strategy. If species are more concentrated in riparian and high forest (HVV), we see that the average meat per hunter per day increases sharply for the optimal strategies if vegetation becomes more concentrated. In contrast the Ache hunting strategy will not do well in landscapes where resources are more concentrated in specific vegetation cells.

To conclude, the distribution of resources on the landscape affects which hunting strategies are most effective. This is not surprising, but this empirically based model analysis shows that the Ache hunting strategy is not effective if the relevant animal species are concentrated in a few small areas within the

TABLE III
TABLE 3: MEAT PER HUNTER PER DAY (KG/DAY) OF OPTIMAL STRATEGY AND FRACTION OF DAYS WITHOUT MEAT.

	Null model	Ache strategy	Optimal strategy
LC/OVV	2.96 / 0.531	2.85 / 0.041	2.85 / 0.041
OC/OVV	2.99 / 0.531	2.83 / 0.041	2.87 / 0.049
HC/OVV	2.96 / 0.531	2.84 / 0.041	2.86 / 0.051
LC/HVV	2.83 / 0.559	2.79 / 0.049	2.79 / 0.048
OC/HVV	2.83 / 0.561	2.79 / 0.049	3.18 / 0.045
HC/HVV	2.84 / 0.561	2.67 / 0.125	3.84 / 0.026

landscape. In all other landscapes the Ache hunting strategies performs close to the optimal strategy.

V. REFERENCES

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Models of Information Spread in Structured Populations

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Abstract—**This paper presents a birth-death model of diffusion processes on graphs, making use of the full population state space consisting of 2^N binary valued vectors together with a Markov process on this space with transition matrix defined by the edge weight matrix of the given population graph. A set of master equations is derived that allows computation of fixation probabilities for any given initial distribution of new information. The transition matrix of the Markov process gives information about most likely initial states, and preferred starting states. A simple example illustrates the apparently paradoxical fact that some population structures allow enhancement of fixation probabilities relative to random drift only for limited values of fitness (or, e.g., rumor believability). In addition, an exact solution is given for complete bipartite graphs. Results obtained are compared to results obtained from a probabilistic voter model update scheme. In addition, the edge-weight matrix of the population graph defines a graph Laplacian that provides information as to increasing or decreasing polarization in a population and this is illustrated with simple examples.**

I. INTRODUCTION

The spread of information in a heterogeneous population is a topic of major interest in a number of fields of study and various models have been devised to better understand how information spreads in structured populations. Such models are very general, applying equally to the spread of rumors and innovations, the spread of computer viruses, and the spread of genetic mutations, to mention only a few cases.

In developing a mathematical approach to this question, populations are represented by directed or undirected graphs with internal population structure coded into an edge weight matrix that specifies interaction probabilities between population members. Different modeling paradigms are used to describe the nature of these interactions, including birth-death, death-birth, voter models, probabilistic voter models, and game-theoretic versions of these. The major emphasis in this paper is on the birth-death paradigm but a probabilistic voter model will be briefly discussed.

A significant quantity to determine is the fixation probability. This is the probability that if an innovation (rumor, virus, genetic mutation, new invention) is introduced at a single vertex in the population graph, it will proceed to become fixed in the population. The Australian statistician Patrick Moran utilized a birth-death model to find the fixation probability for a mutant gene introduced into an initially genetically and structurally homogeneous population in 1958 [1]; but, while the spread of a mutation in homogeneous populations has been studied for over 50 years, the effect of population structure received far less attention until the work of Lieberman, Hauert, & Nowak highlighted its importance [2].

It is now clear that population structures can exert a strong influence, either suppressing or enhancing the effects of selection/retention on fixation probability relative to the original Moran process, and evolutionary dynamics on directed and undirected graphs has become a major focus of research attention [e.g., 3,4,5,6,7]. Much of this effort has been directed to the study of fixation probabilities for single mutants randomly introduced into an otherwise genetically homogeneous population but the mathematical form used applies equally well to other processes of information spread and fixation. This work shows that population structure can enhance or suppress selection relative to drift [8,9,10,11] and that whether selective effects are enhanced or suppressed may depend on both fitness and initial placement of the mutation/innovation [12,13,14].

II. THE BIRTH-DEATH MORAN PROCESS

These models involve a graph in which a member of a population, who either does or does not possess a particular characteristic (e.g., a mutant gene, a particular belief or opinion, an innovative practice, a disease), occupies each vertex. Vertices occupied by population members possessing this characteristic are labeled 1 and those occupied by members not possessing it are labeled 0. The distinguishing characteristic is assumed to have a fitness r ($0 \leq r$) as compared to the fitness 1 of the normal population. The birth-death process is a discrete time process in which, at each iterate, a vertex is chosen at random, biased by fitness, to "reproduce." Following on this choice, a vertex adjacent to the reproducing vertex is chosen to die and be replaced by a copy of the reproducing vertex. This choice is made according to the edge weight probabilities for outgoing edges of the reproducing vertex. Edges can be directed or undirected and the edge from vertex i to vertex j is labeled by the probability that *if* vertex i is chosen for reproduction

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then vertex j will be chosen for death. If the population size is N then, at any given time, there will be m "mutants" and N - m normal population members. The Moran process is a biased random drift Markov process on the state space {0,1,…,N}, where the state m indicates a population state with m mutants and N – m normals. States 0 and N are absorbing states. If $p_{m,m-1}$ and $p_{m,m+1}$ are the respective probabilities of state transitions m → m – 1 and m → m + 1, the size (N+1)×(N+1) Markov transition matrix has the form

$$P = \begin{pmatrix} 1 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ p_{1,0} & p_{1,1} & p_{1,2} & 0 & \cdots & 0 & 0 & 0 \\ 0 & p_{2,1} & p_{2,2} & p_{2,3} & \cdots & 0 & 0 & 0 \\ & & & & \vdots & & & \\ 0 & 0 & 0 & 0 & \cdots & p_{N-1,N-2} & p_{N-1,N-1} & p_{N-1,N} \\ 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

Thus, if x_k is the probability of reaching fixation (state N) from state k then

$$\begin{aligned} x_0 &= 0 \\ x_k &= p_{k,k-1}x_{k-1} + p_{k,k}x_k + p_{k,k+1}x_{k+1} \\ x_N &= 1 \end{aligned} \quad (2)$$

and the single vertex fixation probability is x_1, which is given by

$$\rho = \frac{1}{1 + \sum_{j=1}^{N-1} \prod_{k=1}^{j} \frac{p_{k,k+1}}{p_{k,k-1}}} \quad (3)$$

For the Moran process

$$p_{m,m-1} = \left(\frac{m}{N}\right)\frac{1}{N-m+rm}, \quad p_{m,m+1} = \left(\frac{N-m}{N}\right)\frac{rm}{N-m+rm} \quad (4)$$

and a brief calculation yields

$$\rho = \frac{1 - \frac{1}{r}}{1 - \frac{1}{r^N}} \quad (5)$$

Any graph with fixation probability given by equation (5) is fixation equivalent to a Moran process--the population structure described by the graph has no influence on fixation probabilities, although it may affect time to fixation.

III. The effect of population structure

In their seminal paper, Lieberman, Hauert & Nowak [2] give examples of graphs that suppress fixation probabilities and graphs that enhance fixation probabilities relative to the Moran probability of equation (5) and showed that suppression or enhancement of fixation probability is related to the structure of the edge weight matrix for the population graph. In particular, an edge-weighted graph is said to be *isothermal* if the sum of all weights leading into a vertex is the same for all vertices. The Isothermal Theorem [2] states that a graph with stochastic weight matrix W is fixation equivalent to a Moran process if and only if it is isothermal; or equivalently, if and only if W is doubly stochastic.

In addition to computation of fixation probabilities, other questions relating to information spread in populations have been seriously investigated. Two questions of interest are:

I. What initial node (or set of nodes) leads to the greatest fixation probability?
II. Given an observed distribution of mutants, what is the most likely starting node (or set of nodes) producing this distribution?

The first of these questions becomes significant for inhomogeneous population structures since the fixation probability itself is defined as the average of the fixation probabilities over all nodes, and the fixation probability at different nodes may differ (see Fig. 4b). A graph is fixation equivalent to a Moran process if and only if all single vertex fixation probabilities are equal [2], [15], [16].

The second question is significant for tracing the source of rumors, epidemics, mutations, computer viruses, and other epidemic-like events. Answers to both of these questions arise naturally from an approach via the full state space.

IV. The State space approach

In [17], [18], a state space approach is developed to study computation of birth-death fixation probabilities. Two vectors $\vec{a}(\vec{v}), \vec{b}(\vec{v})$ are defined by $\vec{a}(\vec{v}) = \vec{v} \cdot W, \vec{b}(\vec{v}) = \vec{v}' \cdot W$ where $v_i' = 1 - v_i$ and W is the edge weight matrix describing population interaction structures. Mutant vertices are labeled 1 and normal vertices are labeled 0. For a state vector $\vec{v}$, $a_j(\vec{v})$ is the probability that an edge originating at a mutant vertex terminates at vertex j and $b_j(\vec{v})$ is the probability that an edge originating at a normal vertex terminates at vertex j. For a population of size N, this allows construction of the state transition matrix T = (T_{uv}) on the state space of all length N binary sequences. Confusion between the N vertices of the graphs G and the 2^N elements of the state space is avoided by indexing entities defined on the state space with letters chosen from the latter part of the alphabet (e.g., u,v) while entities referring to vertices of the graph G will be indexed with the letters i, j, and k. State vectors $\vec{u}, \vec{v}$ are also binary numbers and the corresponding indices u and v are set to the denary value of these numbers.

Any set of mutants less than the full state space will go either to extinction or fixation, hence the Markov process with transition matrix T has only two absorbing states: extinction, represented by the vector $\underline{0}$ of all zeros; and, fixation, represented by the vector $\underline{1}$ of all ones. The birth-death (or other) modeling process gives a functional equilibrium between the opposing poles of extinction and fixation. Writing $v = \sum_{i=1}^{N} v_i 2^{N-i}$ and taking x_v as the probability that the corresponding state $\vec{v}$ goes to fixation, the equation $(I - T) \cdot \vec{x} = 0$ for the Markov steady state, with boundary conditions $x_0 = 0$ and $x_{2^N-1} = 1$, yields the system of master equations

$$\left[N+(r-1)m-r\vec{a}(\vec{v})\cdot\vec{v}-\vec{b}(\vec{v})\cdot\vec{v}'\right]x_v - r\sum_{i=1}^{N}a_i(\vec{v})v_i' x_{v+2^{N-i}} - \sum_{i=1}^{N}b_i(\vec{v})v_i x_{v-2^{N-i}} = 0 \qquad (6)$$

These are linear equations that can be solved by standard packages in Maple, Mathematica, Matlab, and other programs. The catch is that that there are $2^N - 2$ of these equations in an equal number of unknowns. Thus, solution is only possible for small values of N (say N < 20), and even in these cases, exact solutions are likely to be cumbersome. For example, the graph of Fig. 1 represents a cycle with a constriction. Symmetry conditions reduce the 30 equations arising from (6) to 16 equations in 16 unknowns. The fixation probability is given by a ratio of two degree 16 polynomials in the fitness r, with coefficients of up to seven digits in length. It is best represented graphically in terms of the difference between this probability and the corresponding Moran probability on five vertices, as indicated in Fig. 2. The fixation probability for the graph of Figure 1 is greater than that of a Moran process for 1< r < 2.267235117. This is a surprising result, showing that the general assumption, that a population structure will always suppress or enhance fixation probability, is wrong.

In [17], [18] a class of graphs called circular flows is defined. This class contains many of the graphs that have been studied in the literature, including cycles, funnels, cascades, and layered networks. Fig. 3 shows a structural schematic of what such graphs are like.

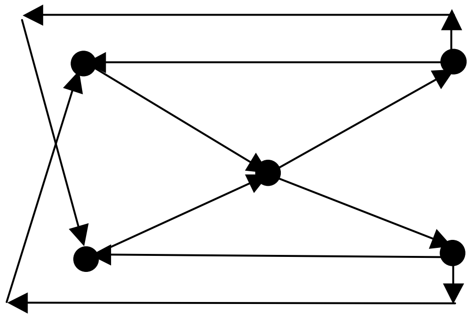

Fig. 1
N = 5 Cycle of Width 2 With Constriction

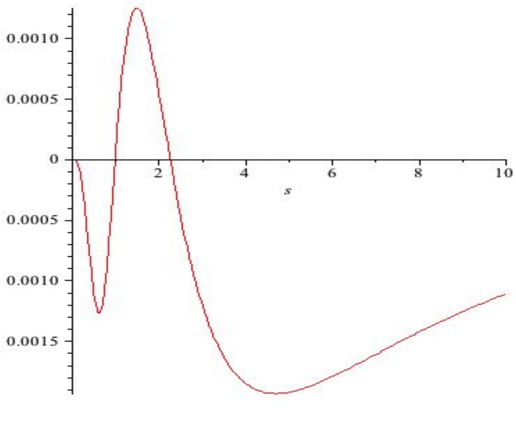

Fig. 2
Difference between Fixation Probability for Graph of Figure 1 and the Equivalent Moran Probability

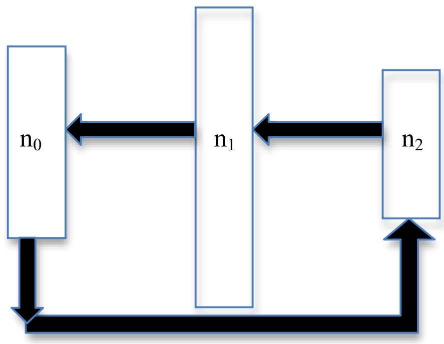

Fig. 3
Illustration of a 3-Level Circular Flow

The numbers n_k indicate the number of vertices in the corresponding equivalence classes of vertices while the arrows indicate that each node in class n_{k+1} is connected to every node in class n_k with probability $1/n_k$ (with indices taken mod s+1 where s is the maximum number of classes).

Of particular interest are the complete bipartite graphs $K_{n,m}$, in which there are only two equivalence classes of vertices. Setting $n_0 = n$, $n_1 = m$ the general solution for the fixation probability of these graphs has been found [18]: for the graph $K_{n,m}$ the fixation probability is

$$\rho_{K_{s,n}}(n,m)=\left(\frac{r^{n+m-1}}{nr+m}\right)\left[\frac{\left(nmr+m^2-nm+n^2\right)\left(mr+n\right)^{n-s-1}}{P(s,n)}\right] \qquad (7)$$

$$P(n,m)=\frac{r^{n+m}(mr+n)^{m-n}-(nr+m)^{m-n}}{r^2-1}.$$

Writing $x_{0,1}$ for the fixation probability for a vertex in the k=1 layer and $x_{1,0}$ for the fixation probability of a vertex in the k = 0 layer,

$$x_{1,0}/x_{0,1}=\left(n^2+nmr\right)/\left(m^2+nmr\right) \qquad (8)$$

Thus, if m > n the fixation probability is greater for a vertex located in the k = 1 layer.

If there are k+1 equivalence classes in a circular flow with n_i vertices in the i-th class then this is represented by the k+1 tuple $(n_0,n_1,\ldots,n_k)$. All vertices in each class are equivalent and this symmetry condition reduces the number of equations and unknowns involved to the product of all terms n_s+1, $0\le s\le k+1$ for k levels [17].

The question of the significance of the initial site where an innovation is introduced has been studied in [12], and can be explicitly illustrated with solutions to equations (6). Fig. 4 shows several examples of three level funnel graphs $(n_0,n_1,n_2) = (1,2,n)$. For the (1,2,n) graphs with n < 6 the average fixation probability is enhanced with respect to a Moran process only for limited values of r > 1 (for n ≥ 6 it appears to be enhanced for all r > 1), as indicated in Fig. 4a. Fig. 4b, however, shows the corresponding fixation probabilities for initial placement in the n_0, n_1, and n_2 equivalence classes of vertices. For each case in Fig.4b the lowest curve corresponds to the central n_1 level and the highest curve to the n_2 level while the middle curve corresponds to the n_0 level.

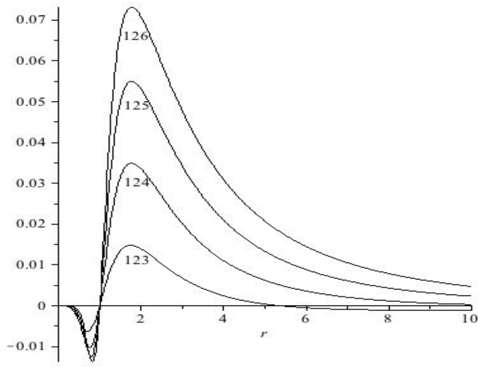

Fig. 4a
Difference between Fixation Probability for Circular Flows (1,2,n) and the Equivalent Moran Probability for n = 3 – 6.

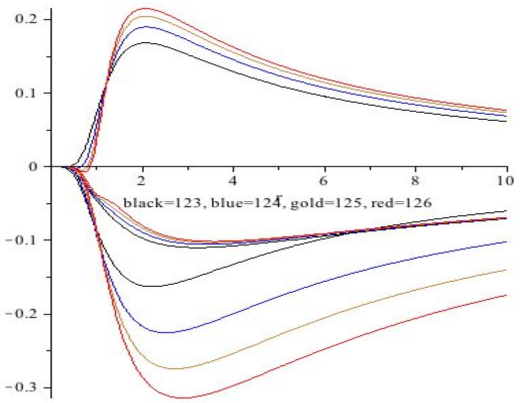

Fig. 4b
Single Vertex Fixation Probability Minus Moran Probability for Circular Flows of Fig. 4a.

This illustrates that for these graphs fixation probability is enhanced relative to a Moran process only if the initial mutant is placed in the n_2 equivalence class.

These sorts of results indicate that if the goal is to enhance the probability an innovation will spread throughout a population careful attention must be paid to where it is introduced.

V. The State Transition Matrix

Useful results can be obtained by consideration of the state transition matrix T. A state $\vec{u} = (u_1, u_2, ..., u_N)$ defines the binary number $u_1u_2 \ldots u_N$. The 2^N population states listed from the top down in numerical order define a $2^N \times N$ matrix S with $S_{ui} = u_i$. As a direct consequence we have:

Lemma 1:

The probability that vertex i will contain a mutant after k iterations, starting from initial state $\vec{u}$, is given by $[T^kS]_{ui}$.

Theorem 1:

Given initial state $\vec{u}$, the probability of fixation is $x_u = \lim_{k\to\infty} \left[T^k \cdot S\right]_{ui}$.

Theorem 2:

Given an initial state $\vec{u}$ and a number of birth-death iterations k, $\left[T^k\right]_{u\underline{1}} \le x_u \le 1 - \left[T^k\right]_{u\underline{0}}$.

Lemma 1 and Theorem 2 are reported in different language in [19], [20].

Interpolation of the equation in Theorem 2 yields an estimate for the fixation probability of any initial state $\vec{u}$: set $\Delta_u(k) = 1 - [T^k]_{u\underline{0}} - [T^k]_{u\underline{1}}$ and the linear interpolation estimate fof fixation probability is:

$$est_k(x_u) = \left[T^k\right]_{u\underline{1}} + \frac{\Delta_u(k)}{\left[T^k\right]_{u\underline{0}} + \left[T^k\right]_{u\underline{1}}} \tag{9}$$

This makes it possible to tentatively answer question (II): given that the observed state after k iterations is $\vec{v}$, what are the most likely initial states to produce this observed configuration? The answer is obtained by finding $\max\left\{T^k_{uv} \middle| \vec{u} \in V\right\}$ for sufficiently large values of k. A detail that arises is that for large k these terms may become very small, leaving numerical results vulnerable to rounding errors. This problem can be addressed by dividing each entry of T^k by the appropriate column sum with each iteration.

Let $D(\vec{v},k) = \sum_{u \in V(H^N)} \left[T^k\right]_{uv}$ and D(k) = diag[D($\vec{v}$,k)]. Then the column entries in $T^kD^{-1}(k)$ will be relative rather than absolute probabilities and these can be computed from $T^{k-1}D^{-1}(k-1)$ as $T^kD^{-1}(k) = [TT^{k-1}D^{-1}(k-1)][D(k)D^{-1}(k-1)]$ where $D(k)D^{-1}(k-1)$ is just the diagonal matrix formed from the column sums of $TT^{k-1}D^{-1}(k-1)$.

VI. Simultaneous Updating

In this section another updating process is considered, a probabilistic voter model, in which at each discrete time the individual at every vertex will change or remain the same with probability determined by the average of the weights assigned to incoming edges of a vertex from other normal and mutant vertices. If the sum of weights of incoming edges from mutant vertices is x while that from normal vertices is y then that vertex will be normal or mutant at the next iteration with probabilities y/(x+y) and x/(x+y).

As with the birth-death process, a Markov transition matrix is constructed which acts on the system state space. If $\vec{u} = (u_1, ..., u_N), \vec{v} = (v_1, ..., v_N)$ are two states the probability of a transition $\vec{u} \to \vec{v}$ is determined in two stages. For given u_j, the probabilities that v_j will be 0 (p_j) or 1 (q_j) are:

$$p_j = (1-u_j)\left[\frac{ra_j(\vec{u})}{N^*(\vec{u})}\right] + u_j\left[1 - \frac{b_j(\vec{u})}{N^*(\vec{u})}\right]$$

$$q_j = (1-u_j)\left[1 - \frac{ra_j(\vec{u})}{N^*(\vec{u})}\right] + u_j\left[\frac{b_j(\vec{u})}{N^*(\vec{u})}\right] \tag{10}$$

$$m = \sum_{j=1}^{N} u_j, \quad N^*(\vec{u}) = N - m + rm$$

The $\vec{u} \to \vec{v}$ transition probability is then

$$T_{uv} = \prod_{j=1}^{N}\left[v_j p_j + (1-v_j)q_j\right] \tag{11}$$

Use of this transition probability allows computation of fixation probabilities. In this case, however, the process is far more computationally expensive and only the simplest examples have been studied. Fig. 5 shows a comparison for the cases of three vertex star and complete graphs.

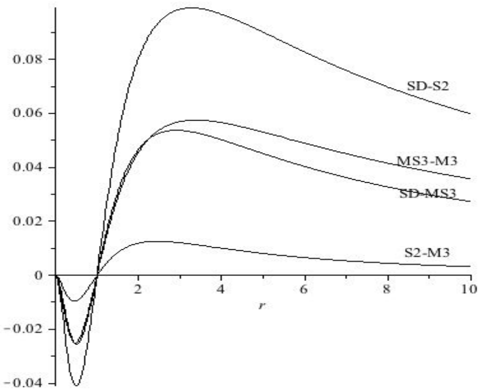

Fig. 5 Comparison of Simultaneous and Birth-Death Updating Paradigms on Two Simple Cases

In this figure SD is the fixation probability for a 2-star with simultaneous updating while S2 is the corresponding birth-death fixation probability. Likewise, MS3 is the fixation probability for simultaneous updating on a complete graph with three vertices while M3 is the birth-death fixation probability.

Based on these examples, it appears that fixation probabilities are greater in the simultaneous update paradigm, which may be more appropriate for cases in which information spreads to multiple population members (as with a spam e-mail, for example).

VII. The Graph Laplacian

There is much useful information contained in the graph Laplacian matrix. If the eigenvalues of this matrix are ordered from smallest to largest the first is always 0 and the remaining eigenvalues satisfy $0 \le \lambda_1 \le \lambda_2 \le \ldots \le \lambda_{N-1} \le 2$ for an N vertex graph. The number of 0 eigenvalues equal the number of connected components, hence $\lambda_1 > 0$ if and only if the graph is connected. The value of λ_1, called the algebraic connectivity, provides information about the difficulty of cutting the graph into disconnected parts.

Until recently, the graph Laplacian has only been defined for undirected graphs, but recently this has been generalized to the directed case [20].

If W is the edge weight matrix for a directed graph and μ is the steady state solution of $\mu \cdot (I - W) = 0$ then the graph Laplacian is defined as $\Gamma = \mu^{1/2} \cdot (I - W) \cdot \mu^{-1/2}$ where $\mu^{1/2}$ and $\mu^{-1/2}$ are respectively the diagonal matrices with diagonal entries the square roots of the elements of the steady state vector μ. Characteristic equations have been computed for the following graphs:

1. A biased cycle with probability p in the clockwise direction and probability 1-p in the counter-clockwise direction:
2. A k+1 level circular flows $(n_0,\ldots,n_k)$.
3. A complete graph in which the vertex set is divided into two components U and V with n vertices in U and m in V. Every vertex in U connects to every other vertex in U with probability p/(n-1) and to every vertex in V with probability (1-p)/m. Every vertex in V connects to every other vertex in V with probability q/(m-1) and to every vertex in U with probability 1/n.
4. A graph similar to case 3 excepting that there is only a single connection between subsets U and V with probability 1-p going in the direction U→V and probability 1-q going in the direction V→U, setting n = |U|-1 and m = |V|-1 (i.e., excluding the distinguished vertex in each subset where the connection occurs).

Cases 3 and 4 are of particular interest in that they provide the possibility of a cut in lines of interaction between sub-populations and thus allow studies of the development or decline of communication among population groups as populations either become polarized, or a consensus (or at least agreement to keep talking) emerges. These two cases are also end points of a sequence in which connections between vertex sets U and V are through subsets: C_U of U and C_V of V.

If p = q = 1 in cases 3 and 4, corresponding to the complete severing of communication between the two subsets of vertices, then the characteristic polynomial reduces to just the product of the polynomials for complete graphs on n and m vertices respectively.

The characteristic polynomials are listed in Table I, setting x = λ – 1 with λ an eigenvalue of Graph Laplacian. Case 1 is given in terms of a recursion relation; all others are explicit formulas.

TABLE I
CHARACTERISTIC POLYNOMIALS OF CASES 1-4

Case	Characteristic Polynomial
1	$\sum_{s=0}^{(N-1)/2} C_s(N) p^s (1-p)^s x^{N-2s} + p^N + (1-p)^N \quad N\ odd$ $\sum_{s=0}^{(N-2)/2} C_s(N) p^s (1-p)^s x^{N-2s} - K^N \quad N\ even$ $C_{2k}(N) = C_{2k}(N-1) - C_{2k-1}(N-2)$ $C_{2k+1}(N) = C_{2k+1}(N-1) - C_{2k}(N-2)$ $C_0(N) = 1,\ C_1(N) = -N$ $K^N = \left[p^{N/2} - (1-p)^{N/2}\right]^2\ N = 0 \bmod 4$ $K^N = \left[p^{N/2} + (1-p)^{N/2}\right]^2\ N = 2 \bmod 4$
2	$x^{N-k-1}\left[x^{k+1} + (-1)^k\right],\ N = \sum_{s=0}^{k} n_s$
3	$\left(x - p/(n-1)\right)^{n-1}\left(x - q/(m-1)\right)^{m-1}\left[x^2 + (p+q)x + p + q - 1\right]$
4	$\left(x - \frac{1}{n}\right)^{n-1}\left(x - \frac{1}{m}\right)^{m-1}\left\{\left[x^2 - p'q'\right]\left(x - \frac{n-1}{n}\right)\left(x - \frac{m-1}{m}\right)\right.$ $\left.-\frac{p}{n}\left(x - \frac{m-1}{m}\right)x - \frac{q}{m}\left(x - \frac{n-1}{n}\right)x + \frac{pq}{nm}\right\}$ $p' = 1-p,\ \ q' = 1-q$

A measure of the degree of communication between separate sets of vertices can be defined in terms of the eigenvalues of the graph Laplacian, although an exact general form for this is still being investigated. If λ_1 is found to be decreasing in time, for example, it may suggest increasing polarization in the represented population.

For the graph of case 3 a relatively easy measure is obtained: there are n-1 eigenvalues equal to (n+p)/n, m-1 eigenvalues equal to (m+q)/m and two remaining eigenvalues of 0 and 2-p-q (recalling x = λ-1). This suggests use of the 2-p-q eigenvalue, although a measure incorporating both the magnitude and direction of communication bias requires knowledge of both the relative magnitudes of p and q, and the norm of the two dimensional vector $\vec{b} = (2-p-q)(1-p, 1-q)$, given by

$$\left|\vec{b}\right| = (2-p-q)\sqrt{2-2(p+q)+p^2+q^2} \qquad (11)$$

Fig. 6 gives a plot of this norm for 0≤p,q≤1. In this figure p = 1 corresponds to no communication from the subset U of the population to the subset V, while q = 1 corresponds to no communication from V to U. Thus the communication bias goes in the direction determined by the relative sizes of p and q while the magnitude of bias is given by (11). If p > q, for example, then the population subset U is favored (i.e., there is a greater degree of contact from V to U than in the other direction). In Fig. 6 it is clear that the greatest degree of communication between subsets U and V occurs when p = q = 0, i.e., when there is no within subset communication and the graph is a complete bipartite graph. Likewise, there is no communication between U and V when p = q = 1.

As an extension of this idea, dynamical interactions can be posited, leading to the coefficients p and q varying in time. In this case, the degree of communication between subsets U and V will follow a path on the surface of Fig. 6.

Fig. 7 shows plots of the fixation probabilities for case 3 as a function of p and r, with q = 1/2 and n = m = 3.

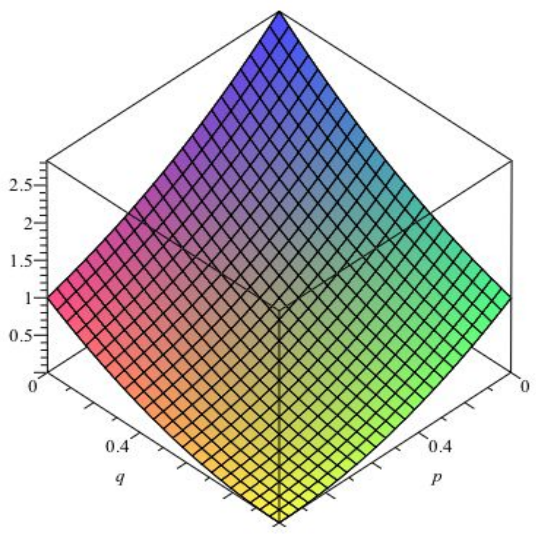

Fig. 6 Plot of $\left|\vec{b}\right|$ From Case 3

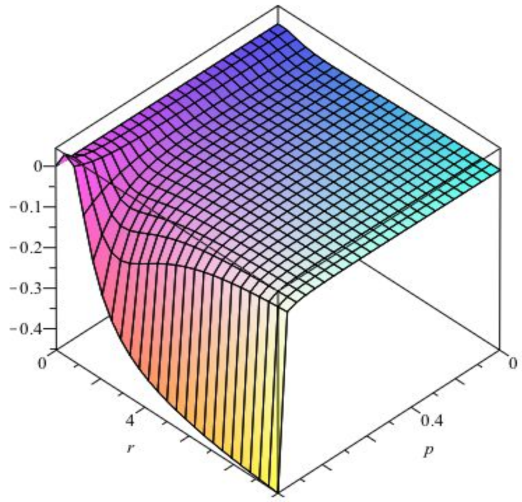

Fig. 7a Fixation Probability Minus Moran Fixation Probability for Case 3 With n = m = 3, q = 2/5

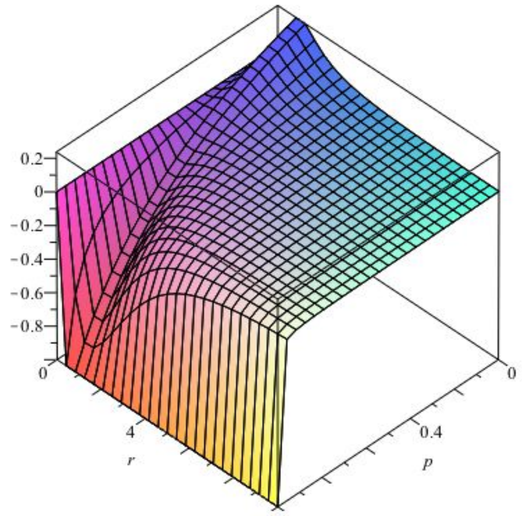

Fig. 7b U Minus V Fixation Probabilities

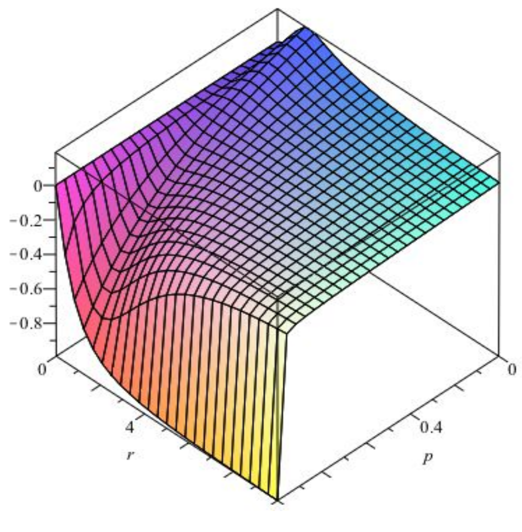

Fig. 7c Fixation Probability for Case 3 With Two Vertices of U Set to One Minus That for Two Vertices of V Set to One.

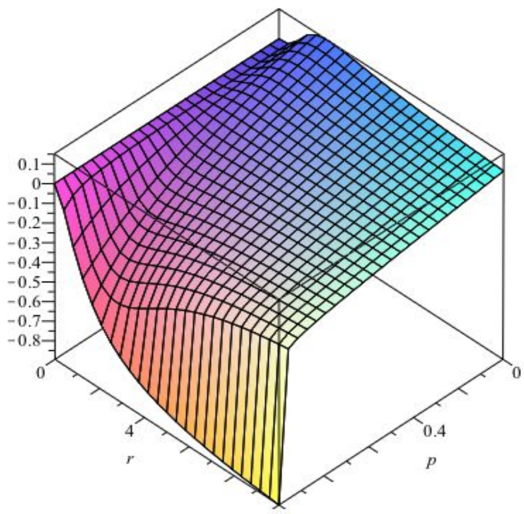

Fig. 7d Fixation Probability for Case 3 With a Single Vertex in U Minus That With a Single Vertex in V Set to One.

In Fig. 7 the parameter q is set to 2/5 (so the weights connecting vertices in V with all other vertices in U and V are 1/5) while p varies between zero and one. By symmetry, if p = 2/5 the values in Figs. 7b, 7c, and 7d equal zero while they are positive for p < 2/5 and negative for p > 2/5. If p < 2/5 this means that there is a bias in the direction from U to V and vice versa for p > 2/5. Thus the greater fixation probability goes with vertices in the subgroup of vertices that have a greater probability of communicating with the other subgroup. Comparison to Fig. 6 with q = 2/5 shows the increase in communication degree as p decreases from one to zero. Note that in there is a sharp drop in all of the graphs in Fig. 7 at p = 1. This corresponds to no communication from population U to population V hence the fixation probability for any innovation introduced into the U population will be zero, fixation can only occur in this case if the innovation is introduced into the V population. This is illustrated in Fig. 8, which shows the separate fixation probabilities U and V from Fig 7b.

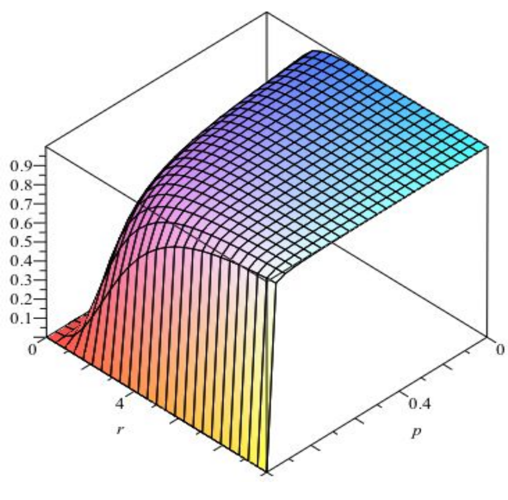

Fig. 8a Fixation Probability if Initially U is All Ones, V All Zeros.

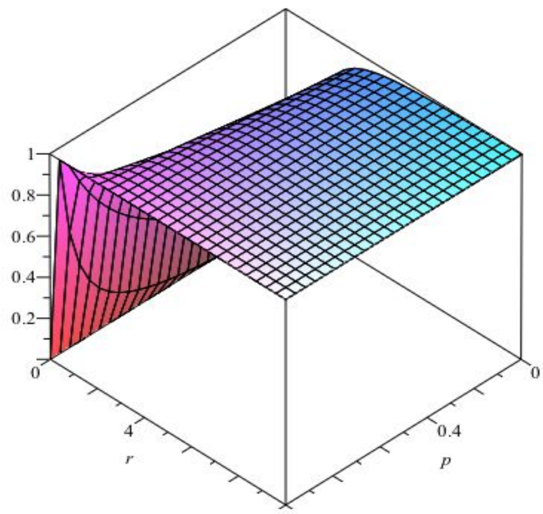

Fig. 8b Fixation Probability if Initially U is all Zeros, V is All Ones.

In Fig. 8a the fixation probability drops to zero for p = 1 (i.e., there are no non-zero links from U to V) while in Fig. 8b it rises to one, indicating a certainty of fixation. This is because all of subgroup V shares the innovation but there is no connection from U to V that could cause a change in V, while there are non-zero links from V to U.

VIII. A THERMODYNAMIC ANALOGY

Given a population graph with N vertices and edge weight matrix W, the temperature of vertex j is defined as $t_j = \sum_{i=1}^{N} W_{ij}$ and the probability that a single mutant introduced at vertex j in an other wise normal population will go extinct in one iteration of a birth-death process is t_j/N. If N is considered as an "effective volume" then t_j/N is analogous to the pressure exerted on vertex j by the population distribution (described by specifying a state $\vec{u}$) and the terms $a_j(\vec{u})/N, b_j(\vec{u})/N$ are analogous to partial pressures exerted on the population member at vertex j by the mutant and normal sub-populations, respectively. This concept shows up in population ecology, for example, with the concept of *propagule pressure* used in studies of the spread of invasive species in an ecosystem [21].

Various entropy measures are useful is studying graph structures [e.g., 22]. Two of use here are the "temperature" entropy, and the fixation entropy. The temperature entropy

$$I_t = -\frac{1}{N}\sum_{j=1}^{N} t_j \log\left(\frac{t_j}{N}\right) \qquad (12)$$

provides information about the in degree structure of the graph G. If the fixation probability for a vertex j is ρ_j then the corresponding fixation entropy is

$$I_\rho = -\sum_{i=1}^{N} \frac{\rho_i}{N\rho} \log\left(\frac{\rho_i}{N\rho}\right) \qquad (13)$$

where ρ is the average fixation probability (the usual fixation probability of the graph). In [12] analysis of all 853 undirected graphs with seven vertices show finds that the average fixation probability is positively correlated with the variance of the vertex degree, and this carries over to the variance of in degree for directed graphs [18].

IX. DISCUSSION

The value of the Moran process is that it provides a standard for comparison, corresponding to a completely homogeneous population (as represented by a complete graph). The example of Fig. 1 illustrated that fixation probability may be enhanced or suppressed with respect to the Moran probability for only limited values of fitness. To see how surprising this is, suppose that a rumor is introduced into a population with believability $r > 1$ (i.e., it is more believable than normally held belief). What the example of Fig. 1 (and other similar cases) are saying is that there may be lower and upper bound on believability such that if r is outside this range, the spread of a rumor will be suppressed when compared to its spread in a homogeneous population, even though it is more believable than the belief it is intended to replace.

A point that needs to be discussed is that with the exception of the general cases presented (the fixation probability for the complete biparte graphs, the characteristic polynomials listed in Table I) the graphs studied have very simple structure and can only be considered as toy models for far more complex situations. Nevertheless, toy models can often have value as a means of developing intuition. The graphs of case 3 considered in section VII, for example, would not be expected to apply directly to any real group where different individuals would have different probabilities of interacting, communicating, and influencing others, both in-group and out-group. But it can be considered with the probabilities 1-p and 1-q for influence between the subgroups U and V taken as averages over the respective populations. Likewise, the graphs described by case 4 can represent cases in which the two subgroups U and V have selected single individual representatives to negotiate their group interests.

The value of the state space approach is that it provides immediate results for the fixation probability of any state, not just the average over all single vertex fixation probabilities, as illustrated by the graphs of Fig. 7. The difficulty involved is the large number of equations that are required unless symmetry considerations can be used to reduce this to manageable size, and even in these cases the actual solutions can be unwieldy. These problems can be avoided in part through analysis of the state transition matrix rather than direct solution of (6). This has been discussed in section V where a method to obtain estimates of initial states for observed patterns of innovation is provided.

Nevertheless, it is important to emphasize the need to develop approximation methods. While equation (6) can be solved in principle for any graph, the computational task grows exponentially with the number of vertices and even when exact solutions are obtained they are difficult to grasp unless represented graphically (the solution for R in Fig. 7a, for example, runs to 34 lines with numerical coefficients ranging into the trillions). In this regard, it may be useful to fall back on some of the various information measures that can be defined.

ACKNOWLEDGMENT

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From evidence to criminal agents

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I. EXTENDED ABSTRACT

THE research outlined in the paper is part of the GLODERS research project, directed towards development of an ICT model for understanding the dynamics of Extortion Racket Systems (ERSs). These are criminal organisations of which the Mafia is but one example [1]. Here we concentrate on a scenario, describing the internal dynamics within a criminal organisation [2,3] that caused the breakdown on this particular criminal network. This data driven scenario builds on Police interrogations resulting from a number of investigations. Currently the research is in the step of transforming the analysis of semantic web of relation in the data into the code of a first model to analyse the effects of the model rules in simulation runs. This first test-bed model will be presented at the conference.

The Scenario applies a grounded theory approach [4] based on police interrogations in 2005 and 2006 of various police investigations of a criminal gang. Established in the early 1990s its business model consisted of drug trafficking and laundering the illegal money. Drug trafficking was done by ‘black collar criminals’ with access to the production and distribution of drugs. ‘White collar criminals’ were ordinary businessmen responsible for the money laundering. They got roped into the business in the early 1990s. Police files identified (at least) one white collar criminal working in the real estate business. It is important that the real estate trader had a good reputation in the legal society. This allowed him to invest illegal money in the legal market and give the return of investment back to the investor. Money laundering is essentially based on a norm of trust: the black collar criminals need to hand over the money to their partners and trust them that they will get the return of investment back from the trustee. In a covert organisation this cannot be secured by formal contracts. Therefore trust is essential. The network lasted for about 10 to 15 years until it collapsed. An initial divide went out of control, and the mistrust could not be encapsulated but spread rapidly through the whole network. Once trust was corrupted, a run on the bank was initiated. Attempts to get the money back led to extortion. Thereby the white collar criminal became victim of his criminal business partners. A formerly symbiotic relationship between black and white collar criminals (a long term relation of a win-win situation for both) became parasitic (i.e. a lasting but no longer profitable situation). This generated a cascading effect through the network which destroyed the overall network in a violent blow-up. This characteristic of the case makes the data particularly interesting to identify essential elements in the mechanisms of conflict resolution in the absence of a juridical court, i.e. the failure allows to identifying the elements which must not be missing.

Methodologically the approach from qualitative evidence to agent rules is particularly appropriate for dissecting cognitive complexity. The path from police interrogations to agent based models started by analysing the textual data with MaxQDA as a tool for qualitative text analysis [4]. Text passages were summarised into codes deriving concepts from data. Concepts stand for classes of objects, events or actions which have some major properties in common. This provides the path from qualitative data to a coded textual corpus which structures the content of the data by identifying recurrent themes such as ‘violence’ or ‘monetary transactions’ with CAQDAS tools such as MaxQDA. The coding derived with MaxQDA served as the basis for concept relation identification with the CCD tool (a software for creating Consistent Conceptual Descriptions) [5]. The CCD tool provides an environment for developing a conceptual model by a controlled identification of condition-action sequences (denoted as action diagram) which represent the micro-mechanisms at work in the processes described in the data. Whereas the data describes individual instantiations, the condition-action sequences represent mechanisms insofar as they describe general event classes. However, empirical traceability is ensured by tracing the individual elements of the action diagram resulting from the identification of condition-action sequences in the CCD tool back to text annotation in the data. These annotations are extracted from the coding derived with MaxQDA. This

This work was not supported by any organization

provides the path from a coded textual corpus to the recognition of behavioural patterns. This web of semantic relations derived from the empirical analysis is the basis for the development of an agent architecture. Theoretically this architecture builds on a theory of normative agents [6] which provides the grammar for social norms. It extends the theory by reasoning about aggression, namely whether aggression is norm enforcement (i.e. punishment) or norm violation (i.e. violation of trust between group members). The theoretical foundation of normative agents provides the path from behavioural patterns recognition to a set of regulative norms in agent architectures. The architecture provides the foundation for a software implementation.

For the purpose of an extended abstract the path from qualitative evidence to agent rules will be illustrated by one example from the data analysis and one example from the transformation of the empirical evidence in an agent architecture. First, one example of the action diagram resulting from the data analysis will be shown, describing the process of ordinary money laundering.

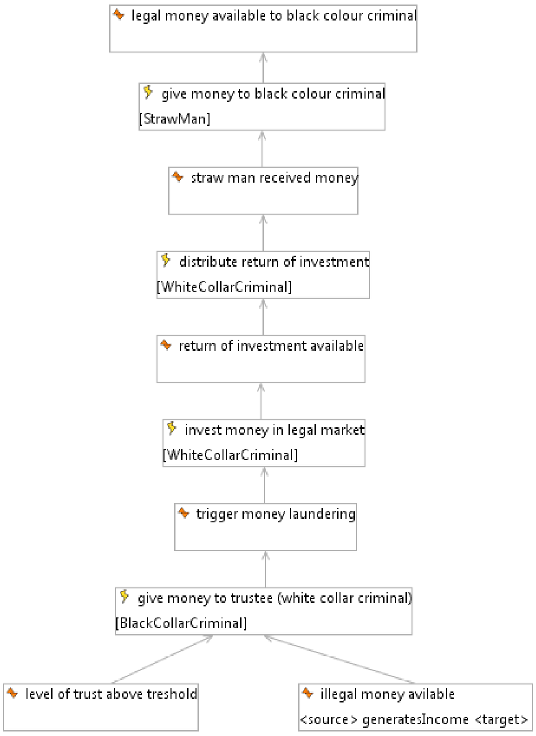

Fig. 1 Ordinary business of money laundering

In the talk it will be shown how this can be traced back to annotations from the evidence base. One example is the following annotation demonstrating the starting condition that illegal money is available

Annotation (illegal money available): "In the period between 1990 and 1992 police investigations had been undertaken. These revealed a criminal organisation concerned with drug trafficking. The report from 1992 estimated the income and the costs. It is estimated a transaction volume of nearly 300 million."

In the following, the first steps of the process of developing agent architectures for a simulation model from the conceptual description will be illustrated by the example of 'reasoning about aggression'. The intra-agent processes are defined as modules and specified by flow charts, focussing on processing of data, in this context mainly events for triggering processes, and different kinds of parameters determining the control flow. The most important kind of parameters is related to norms ruling the agents' behaviour. All actors are ruled by norms. As a result of the detailed examination of the empirical data, a restricted number of norms have been identified which implicitly govern the behaviour of the actors. As an example, for all types of criminals a 'top-level' moral norm exists:

```
NORM(1) "moral norm": NOT VIOLATE TRUST c o
```

where `c` is a criminal and `o` is the criminal organisation or network. This norm describes the commitment to the norm of trust within the organisation which holds in the case of unexpected events and is entangled with interpretation of aggressive actions, self-reflection and the consideration of own past actions. Related to this norm, a number of concrete obligations are defined. An example is

NORM(1.3) "obligation": PUNISH c_i c_j IF c_j VIOLATE NORM(1)

where c_i is a criminal who punishes the deviant criminal c_j for a norm violation.

Such a punishment triggers a 'reasoning on aggression' process within the punished agent, where the agent must decide whether the experienced aggression was such a punishment, or rather a self-interested act of aggression. This process is detailed to some extend in the following description of the architecture of one of the agent types, the black collar criminal.

The 'Reasoning about aggression' process (Figure 2) is triggered when the agent recognises an aggression against itself. It comprises the first of three stages of a decision process, eventually leading to possible reactions on the aggression. In the first stage it is decided whether the aggressor is reputable and the motivation for the aggression is not gratuitous. Information on trustworthiness of the aggressor from an 'image and reputation repository' (a data structure which stores the agent's belief on image and reputation of other fellow agents) is regarded here. If the aggressor is reputable, a possibly normative motivated aggression is anticipated and the normative process is triggered at the second stage. A possible result of the normative process might be that the inherent sanction recognition failed (see subsequent section), but the aggression poses a potential threat to the agent. In this case, and in the case that the aggressor is recognised as not reputable, reactions will be triggered by entering the third stage of the process in which the operational mode of the agent is either set to a rational or an emotional frame, amongst others depending on the strength of the initial aggression.

The actual switching to one of the two frames is done in two separate processes not shown here, followed by triggering the 'Reacting on aggression process', in which the agent decides how to retaliate the aggression (either by counter-aggression or by betrayal of the criminal network, depending on the mental frame which the agent has adopted before). This process can also come into play if the agent decides to cheat, i.e. a sanction is recognised within the 'Normative process' but the agent decides not to obey the norm behind the sanction but rather to follow some other (individual) drives.

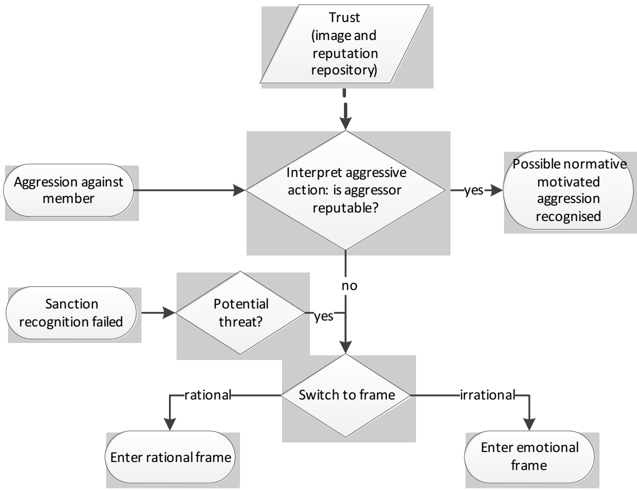

Fig. 2 Intra-agent process for reasoning about aggression (rounded boxes are start and end events for the process, rhombi are decisions, parallelograms stand for parameters influencing decisions)

This talk shows the results of the conceptual modelling of the collapse of a criminal network. The qualitative data analysis informing the conceptual model as well as the first formalisation activities towards a simulation model are outlined with emphasis on important design details, e.g. the realisation of normative behaviour. The conceptual modelling enables dissecting the micro-mechanisms of a complex empirical process which enable a certain degree of generalisation beyond a narrative story of a certain case to shed light on the wheels of social processes. Nevertheless, the evidence based modelling approach retains traceability of the abstract mechanisms to the empirical social world. The model implementation phase has just started. The simulation model will then contribute to computational normative agents [6,7,8,9,10] by implementing reasoning about aggression whether or not to interpret it as sanction.

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Mafia war: simulating conflict resolution in criminal organizations

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I. Target System

TARGET of the model is a representation of territorial conflicts and conflict resolution in Mafia Type Organizations (MTO) [1]. Prime example is the Sicilian Cosa Nostra. The business activity of MTOs is systematic extortion of economic actors. Thereby an MTO controls a territory in a monopolistic way. Typically it offers services, most likely protection, in return and establishes a quasi-political authority over a territory. For instance, the collective organization of the Cosa Nostra controlled most of Sicily, at least the city of Palermo, in the times of its maximum power [2,3]. Currently the power of the political authority of the Cosa Nostra is in decline [4]. However, the control is divided in a number of territories which are controlled by different so-called families of the Mafia. These territories are denoted as Mandamento. The families are subdivisions of the organization which have a considerable amount of freedom of action [5]. It is a norm of the Cosa Nostra that a territory which is extorted by one family shall not be extorted by other families.

Internally an MTO is a professional organization, constituted as a strict hierarchy. It has to be noted, however, that the leadership style varies between history and different leaders. At the top is commission, the so-called cupola. The cupola coordinates activities of the Mafia families and resolves conflicts. While at the times of its constitution it was a rather democratic commission of bosses of the families, it was often likely to be dominated by one boss (the 'godfather') of the Mafia, who may be assisted by advisors [6,7]. Moreover an interprovincial commission had been established in the 1970s which formally is above the cupola. However, in practice it was dominated by the commission of Palermo [6]. The families are governed by a capo di famiglia, at the bottom level of the hierarchy are the so-called soldiers which undertake everyday business [6].

However, the structure of the organization remains fragile, dependent on mutual commitment of the influential capos to the organizational status quo. The history of the Cosa Nostra is characterized by Mafia wars in the early 1960s (with an additional peak of violence in 1969) and early 1980s. Essentially the wars were power struggles between rivaling families. The war in the 1960s broke out when drugs got lost and a certain Mafiosi had been accused of being guilty. The case came up for trial at the cupola. He was discharged, but nevertheless been killed by other Mafiosi. This undermined the monopoly of violence of the cupola and became starting point for violent conflicts [6].

II. Research Questions

The specific *target* of the model is stylized fact representation of the internal conflict resolution within the organization and its collapse in Mafia wars.

- *Research question* a) is the analysis of the micro mechanisms of stability by a stylized fact representation of the internal conflict resolution within the organization.
- *Research question* b) is the analysis of the micro mechanisms of the collapse of organizational stability in so-called Mafia wars.
- *Research question* c) is to investigate whether patterns in the outbreak of violence can be detected that characterize the organization as semi-stable system.

External relations of the MTO such as extortion and the control over a territory are treated as given facts. Shops pay unconditionally, representing an unquestioned authority of the MTO over the territory. Likewise, historical contingency such as different styles of leadership are not represented.

III. Attributes of the Model

The simulated organization operates in a world divided in territories of different 'families'. The world is scattered with shops which provide the revenues for the organization. The model applies a stylised fact simulation to investigate effects of basic mechanisms. Space is restricted to a square which can in later stages be extended by a GIS interface of the territories of the Cosa Nostra clans in the city of Palermo. Soldiers and shops are placed randomly over the territory. The capo is placed in the middle of its territory.

This work was not supported by any organization

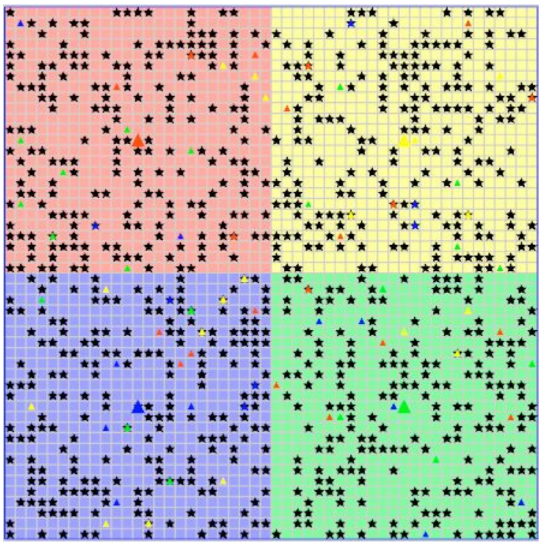

Fig. 1: The world. Different colors represent territories. The black stars represent shops. Big colored triangles are the capos, placed in the centre of their territory. Small colored triangles represent the soldiers, placed randomly in the world.

The MTO has a hierarchical structure: The bottom level of a family of the MTO consists of soldiers which undertake the extortion of the shops. A family is directed by a 'capo di familglia', i.e. the boss of a family. These are the hierarchy levels of the sub-divisions of the organization, the families. The capo knows the borders of his territory, the soldiers not. This is the most simple assumption that soldier's extortion is only tamed by sanctions. Different territories are represented by different colors. Furthermore a top hierarchy level of the overall organization represents the Mafia commission (cupola). This top level of the hierarchy above the single families is intended to resolve conflicts between families. For simplicity, one capo is selected randomly as the boss at the top level in the model. Political processes of power balance [6] are not represented. This agent has two roles: the role of a capo with a certain territory and the role of the boss (the 'godfather') of the overall organization of the MTO.

Moreover, each agent belongs to a family, which is publicly known and has a private list of friends. Friendship is reciprocal and not distributed along the line of the families or hierarchy levels. This is justified by the fact that Mafia members have friendship ties across families which became an important factor in the Mafia war in the 1980s by soldiers secretly changing sides. The friendship entails a differential degree of loyalty in case of conflicting demands.

IV. Scheduling

The implementation of the model follows a sequential approach: first a simple model of 'ordinary conflict resolution' has been implemented which provides the basis for an extension to include Mafia wars, i.e. first research question a) is investigated.

The process of extortion is not modeled explicitly. Soldiers walk randomly over the world. If they enter a patch with a shop they extort the shop with a certain degree of likelihood. If they extort, they gain a certain amount of extortion money from the shop. This handed over to the capo who periodically distributes the periodic income to his soldiers, while keeping a certain amount for himself.

In the initializing phase the soldiers learn to extort only inside their territory. If a soldier extorts a shop in the territory of a different family the capo sanctions the soldier. This decreases the probability that the soldier will extort a shop in the territory of this family. The action of the capo is guided by the norm 'not to extort in foreign territories'. The decision process of the capo is represented by the follow:

```
if
      mysoldier(ID-soldier)extorts
      shop(ID-shop)
      and (ID-shop) not in list(myshops)
         then
             if random-number < sanction-
             probability
sanction mysoldier(ID-soldier)
```

However, the norm is only imperfectly realized. If the income falls below a capo's threshold of satisfaction, it terminates sanctioning. In the absence of sanctions the soldier gradually forgets the norm and starts again extorting in foreign territories. At this stage the conflict resolution by the top hierarchy level becomes effective. The exploited capo complains against the exploiter. The complaint is sent to the 'godfather', who sanctions the deviant capo. In turn, this sanction increases the likelihood that the deviant capo will continue sanctioning its soldiers. This is the process of ordinary conflict resolution in the hierarchical organization.

However, it is an empirical fact that conflict resolution remains precarious and might fail. This leads to the outbreak of a Mafia war. The extension of the model to include Mafia wars is work in progress. If one of the capos constantly violates the organizational norms to a much larger degree than the other capos, a plan can made to murder the deviant capo with a certain degree of likelihood. The plan can be made by the top level boss or that capo which is mostly exploited. Also the deviant capo knows that it is in danger and might plan to murder the most likely aggressor in advance. Plans to murder are sent within the friendship network. However, it might be the case that one of the receivers of the plan has a friendship relation to the potential victim, leading to a situation of conflicting loyalties. The agent decides between two possibilities: participate at the murder or betray the conspirator. If the potential victim gets informed it generates in turn a plan of murdering the conspirator. This plan is again distributed in the friendship network of this agent [8].

Condition for the decision who initiates a war is the relative strength of the families. Strength is measured by the number of soldier. Soldiers may decide to change to another family dependent on the perceived strength of the capo. If they migrate they increase the strength of their new family. However, also the revenues need to be shared among a greater number of family members. This is an incentive to exploit new sources of income, whereas the increase in the relative strength makes it likely to win a war to gain access to new sources of income by subordinating a territory. The murder of a capo triggers a power struggle between the soldiers. If a soldier which changed the sides becomes the new capo it subordinates this family to the other family. In this case the winning family controls the territory of the assassinated capo.

V. PRELIMINARY RESULTS

First simulation experiments with ordinary conflict resolution, i.e. sanctions by the mandamento for deviant capos verify that the model works as intended.

- Increasing the number of shops increases the revenue of the families. This decreases norm violation.
- Varying the probability with which the capo sanctions extortion of his soldiers in foreign territories reveals that this parameter determines the speed with which the soldiers learn the border of the territory.
- If the average income of the capos is above but near their threshold of satisfaction the capos start to deviate from the norm to respect the territories of the families because of the variance of the revenues. This triggers conflict escalation towards Mafia wars.

For the purpose of an extended abstract this will only be illustrated by one example of a graphical display of the results (see Fig. 2).

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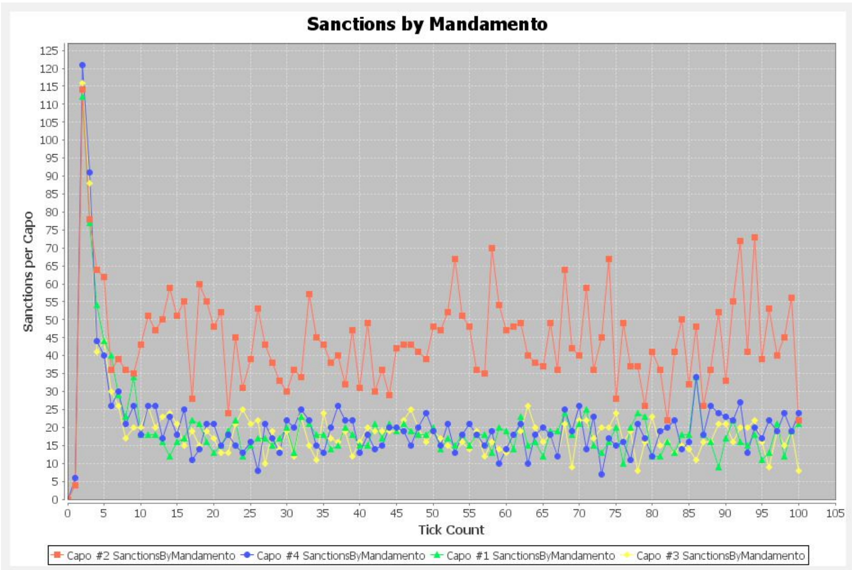

Fig. 2: Sanctions of the godfather to deviant capos. It can be seen that the capo of the red Mandamento (i.e. territory) constantly receives more sanctions than the other capos. This makes it likely that it will be a main actor in next war.

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The CEDSS Model of Direct Domestic Energy Demand

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***Abstract*—This paper describes the design, implementation and testing of the CEDSS model of direct domestic energy demand, and the first results of its use to produce estimates of future demand under a range of scenarios. CEDSS simulates direct domestic energy demand at within communities of approximately 200 households. The scenarios explored differ in the economic conditions assumed, and policy measures adopted at national level.**

Introduction

CEDSS (Community Energy Demand Social Simulator) is an agent-based model of direct domestic energy demand, created as part of the GILDED project (Governance, Infrastructure, Lifestyle Dynamics and Energy Demand) funded by the European Commission under the Socio-economic Sciences and Humanities Theme of the Framework 7 Programme (http://gildedeu.hutton.ac.uk) and written in NetLogo [1]. The project aim was to elucidate the socio-economic, cultural and political influences on individual and household energy consumption.

CEDSS models urban and rural communities, on the scale of around 200 households, in the area of Aberdeen and Aberdeenshire. The focus of CEDSS is on household purchasing decisions in the area of energy-using and energy-saving equipment related to space- and water-heating (boilers and insulation), and household appliances including cookers, refrigerators, freezers, washing machines, dryers, dishwashers and televisions. Its is designed for use in constructing policy-relevant scenarios of domestic energy use up to the middle of the current century, under a range of assumptions about economic and technological change, and policy choices.

This paper provides a description of CEDSS using the ODD protocol (section I), outlines the design process and the data used to parameterise the model (section II), and reports results from early scenario runs (section III). Finally, section IV discusses the model's strengths and limitations, and future work.

I. Description of the CEDSS model

We use an abbreviated version of the 'Overview, Design concepts and Details' (ODD) protocol [2], [3] to describe CEDSS. A full version is available along with model code, input files and explanatory text from the CoMSES OpenABM node: Network for Computational Modeling for SocioEcological Science (CoMSES Net), at http://www.openabm.org/model/3642/version/2/view.

A. Purpose

The purpose of CEDSS is to simulate the household energy demand of a small rural or urban community (e.g. a housing estate or village), with respect to energy used for space and water heating, and for household appliances, over the period 2000-2049.

B. Entities, State Variables and Scales

The agents in the model are households. Each household occupies a dwelling, and owns a set of appliances, some of which are regarded as essential (a heating system, cooker, washing machine and fridge), while others are not (freezers, dishwashers, dryers and TVs). The model does not cover lighting or computers because of limitations of the data sources used. A dwelling is of one of a range of types: bungalow, house or flat, with each of these categories subdivided according to situation and size.

The entities and relationships among them are summarised in Fig.1. Reified relationships (those having data stored about them) are shown in blue boxes. The most important state variables of the entities and reified relationships are summarised in the following tables.

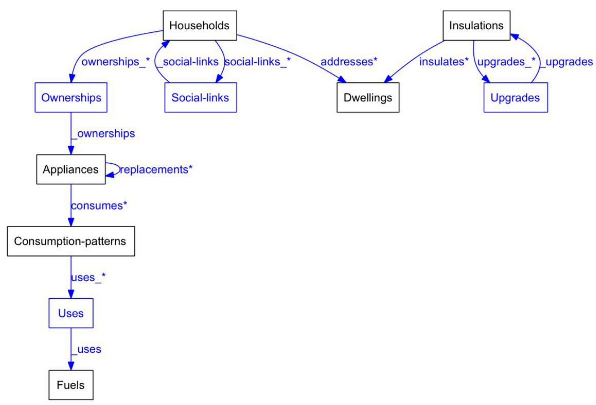

Fig.1 Entities and relationships in CEDSS

Table 1. Households

State variable	Type	Description
household-id	string	An identifier for the household
planning-horizon	integer	How far the household looks ahead when computing projected running and energy costs of appliances.
steply-net-income	double	How much income the household receives per step (one step represents a quarter here).
capital-reserve	double	How much money the household has in, e.g. savings.
goal-frame	string	The goal frame the household is currently using to make decisions.
gain-orientation	double	A representation of the household's egoistic value strength.
greenness	double	A representation of the household's biospheric value strength.
hedonism	double	A representation of the household's hedonic value strength.
steps-total-energy-use	double	How much energy the household has used in this step.
breakdown-list	Appliances	A record of the broken appliances that the household has not yet replaced.
wish-list	Appliances	A list of appliances that the household desires.

Table 2. Dwellings

State variable	Type	Description
dwelling-id	string	An identifier for the dwelling.
dwelling-type	string	A descriptor for the type of dwelling (e.g. 4-bedroom detached house, 1-bedroom flat).
tenure	string	The type of tenure – e.g. owner-occupied, or rented.

Table 3. Insulations

State variable	Type	Description
insulation-state	string	A descriptor for the state of the insulation (e.g. 270mm loft insulation, no double-glazing, cavity-wall insulation).
fuel-use-factor	double	How a dwelling's space/water heating fuel use is adjusted for this insulation, relative to a dwelling with minimal insulation.

Table 4. Appliances

State variable	Type	Description
category	string	A high level category for the appliance (e.g. TV).
subcategory	string	A subcategory for the appliance (e.g. LCD TV, CRT TV, plasma TV).
name	string	Make and model of the appliance.
cost-list	double	List of purchase costs for the appliance in each step for which it is available.
breakdown-probability	double	Probability the appliance will break down in any step.
energy-rating	string	Energy rating for the appliance, if provided to buyers.
essential?	Boolean	Is the appliance essential for all households?
last-step-available	integer	Last step in which the appliance is available, if this is bounded.

Table 5. Consumption-patterns

State variable	Type	Description
for-dwelling-type	string	Dwelling type with which the consumption pattern is associated.
for-purpose	string	Purpose of consumption.
in-step	integer	Time of year with which the consumption pattern is associated (consumption for space-heating varies seasonally).

Table 6. Upgrades

State variable	Type	Description
upgrade-cost	double	Cost of making the insulation upgrade.

Table 7. Ownerships

State variable	Type	Description
age	integer	How many steps the household has owned the appliance.
broken?	Boolean	Whether the appliance is broken.

Table 8. Uses

State variable	Type	Description
units-per-use	double	How many units of the fuel the consumption pattern uses.

C. Process Overview and Scheduling

The model does the following in each time step:

1. Decide which owned appliances break down. All ownership links between households and appliances are checked against the appliances' breakdown probabilities.

2. Each household then does the following:

a. Choose goal frame. The goal-frame is chosen by choosing a random number *R* in the range 0 to the sum of the goal-frame value strength parameters (hedonism, gain-orientation and greenness): the probability of each goal-frame being selected is proportional to the current strength of the corresponding value.

b. Adjust goal-frame value strengths. This is done to implement a 'habit' component – the more a goal-frame is used, the more likely it is to be used in future. The habit-adjustment-factor parameter (*H*) is used to make this adjustment. If *T* is the sum of all goal frame parameters, then let *A* be the parameter corresponding to the selected goal frame, and *B* and *C* be the other two. *A*is increased by *H*, and *B* and *C* decreased by *H*/2. If the result causes *A* to be more than *T*, then adjustments are made to ensure that $A + B + C = T$, and that *B* and $C \geq 0$.

c. Compute the total energy use for this step from using appliances and space/water heating. For each appliance owned by the household, the step's fuel consumption and energy use is computed based on the consumption pattern associated with the household's type, the type of their dwelling, the usage mode, and the time of year.

d. Compute financial situation. The monetary cost of heating and running appliances is deducted from the capital-reserve of the household, and the income for that step is added (the income represents what is available to spend on direct domestic energy and related goods rather than total household income).

e. Replace broken appliances. If the appliance is essential and the household only had one of them before it broke, then a new item will be bought. If the home is rented the landlord is assumed to choose the cheapest replacement; otherwise the cost falls on the household and the choice criteria depend on the current goal-frame.

f. Update wish list (if goal-frame is 'hedonic' only). The wish list of the household is updated to contain items chosen in all of the following three ways (*M*, *N* and *T* are model parameters):

i. Up to *M* appliances (not to do with heating) each belonging to a different new subcategory introduced in the last *N* steps.

ii. One random item not already owned, seen on a visit to another household.

iii. One random replacement for an item more than *T* steps old.

g. Buy insulation (if goal-frame is not 'hedonic'). If the goal-frame is egoistic, then the household chooses an insulation state reachable from the current state that will save the most money and make a positive monetary saving over the planning horizon of the household. If the goal-frame is biospheric, then the household chooses an insulation state reachable from the current state that will leave a positive capital reserve and save the most energy.

h. Buy (non-essential) new appliances. If the current goal-frame is hedonic, then buy as many affordable appliances as possible from the union of the breakdown list and the wish list, but not more than one from the same category. An affordable appliance is one costing less than the capital reserve, plus the household's income this step multiplied by the credit-multiple-limit parameter. If the current goal-frame is egoistic, buy the cheapest possible replacement for one item on the breakdown list. If the current goal-frame is biospheric, buy the replacement for an item on the breakdown list, choosing that with the best energy rating (if supplied) or lowest breakdown probability (if not).

i. Visit social neighbours. Up to *V* (= visits-per-step) randomly chosen linked households may be visited each step (the number of *visits* will be less than *V* only if the household has no social links, but there may be multiple visits to a household). For each visit, the visiting household adjusts their goal-frame parameters; if the reciprocal-adjustment parameter is set to true, then the visited household also adjusts their parameters. Each goal-frame parameter *G* is adjusted in the following way: let G_i be the goal-frame parameter of the household making the adjustment; let G_j be that of the other household; then: $G_i = G_i + F(G_j - G_i)$ where *F* is the frame-adjustment parameter, set on the CEDSS interface. After this adjustment, if G_i is less than zero, G_i is reset to 0.

j. Update social links. With probability 0.5 either way, the household either loses a social link, if it has one, or gains a social link, if it currently has fewer than the maximum set by a model parameter. To lose a social-link, the household first determines the set of weak links – those with minimum appliance similarity (the number of appliances the two households have in common, minus the number of appliances that one has that the other does not). If this set has more than one member, then the set is reduced to those who have the maximum block distance from the household. If the set still has more than one member, then the link dropped will be randomly chosen from those the household has visited least. To gain a social link, the household determines the set of strong contacts – those with maximum appliance similarity. One of these is randomly chosen, and one of the households it is linked to (but the household updating its links is not) is selected, again at random.

D. Design Concepts

1) Basic Principles

The model is based on the psychological theory of 'goal-frames' [4], [5], discussed in section IV, in which households make decisions in one of three modes: 'hedonic', 'egoistic' and 'biospheric'; which mode they choose depends on the current relative strength of the corresponding 'values': stored parameters representing the household's 'hedonism', 'gain-orientation' and 'greenness'.

2) Emergence

Emergent properties of the model are the community-level consumption of energy from various sources, and the numbers of different appliances owned.

3) Objectives

Households must ensure they keep essential equipment running, otherwise, households' objectives depend on their dominant goal-frame. Hedonists aim to buy as many of their desired appliances as they can afford, egoists aim to save as much money as they can, whilst biospherics aim to minimise their energy consumption.

4) Prediction

Households may compute the expected running costs and space heating costs when buying appliances and considering insulation options, depending on the mode in which they are making decisions.

5) Sensing

Households are aware of appliances owned by their friends when they visit them.

6) Interaction

Households visit each other, according to their social links. They adapt their social links according to how similar their profile of appliances is with that of the people they visit. The profile of appliances is used as a proxy for lifestyle characteristics in the model, and the assumption is made that people are more likely to be friends with those having similar lifestyles. Visits result in guests wanting to acquire appliances that hosts have and they do not; and in some convergence of host and guest value strengths.

7) Stochasticity

Stochasticity is used initially in setting up social links, and may also be used in setting households' initial value strength parameters. It is used during a run in updating social links, arranging visits, selecting items to buy, determining the current goal-frame, and determining appliance breakdowns.

8) Observation

The model collects data on energy use (broken down by fuel), how much money households have, how many social links they have, how many of each category of appliance are owned by households in the community, how many of each category of appliances have been thrown away by the community, goal-frames used to make decisions, goal-frame parameters, and numbers of visits made per social link.

II. Design and Parameterisation

Model design was determined jointly by the purpose of the model (constructing policy-relevant scenarios of future direct domestic energy demand); the environmental psychology literature; the peer-reviewed, grey and commercial literature on domestic energy and appliances; public domain datasets, related to domestic energy use in the UK (from the UK Department of Energy and Climate Change and Office for National Statistics); a series of "ontology-elicitation workshops"; and the results of a questionnaire-based survey of 397 households – 197 of them urban, 200 rural.

The model's key social-psychological assumptions are that households make domestic energy-related decisions under the influence of competing top-level goals [4], [5] which express individual or group values, often conflict, and vary in strength over time and with context; and that such decisions and such values have a habitual component [6]-[8], but are also subject to social influence [9]. "Hedonic" goals concern immediate good or bad feelings, "egoistic" goals access to resources, and "normative" goals, social norms. We found, however, no detailed work on how such goal/value conflicts are resolved, or on networks of social interaction in relation to domestic energy use, so the specific algorithms used in these aspects of the model are chosen for simplicity and computational convenience. The sources related to domestic energy use provided information on household demand for space- and water-heating; the availability, prices, energy requirements and other and properties of domestic appliances and energy-related equipment; time series of fuel prices, household income, capital and energy-related spending and percentages of households owning specific equipment. The workshops, with members of a project stakeholder advisory group and non-modelling members of the project team, produced informal ontologies that influenced the model structure, particularly in relation to electrical appliances.

The survey of households provided data on their dwellings, equipment and equipment use, energy demand (use of electricity, gas and oil is modelled – data from the few households primarily using other fuels was excluded), finances, and values as expressed in the answers to questions about energy use and environmental issues, as of 2010. To model changing energy demand over a future period of decades with any confidence at all, however, we needed to show that the model could reproduce to an acceptable level the past trajectory of such demand. We therefore needed to "retrodict" plausible states for the sampled households at some time in the past. If running the model forward to mid-2010 then gave energy demands close to the figures derived from the survey, we could have sufficient confidence in the model to extend such runs to mid-century with the expectation of getting meaningful and useful results. 2000 was the earliest "retrodiction date" for which we could collect adequate data.

A wide range of public domain sources was consulted, but the most important of those used directly in constructing the CEDSS parameter files were as follows:

- UK Department of Energy and Climate Change (DECC) time series of prices for domestic electricity, gas and heating oil (taken from files qep413.xls, qep551.xls and qep591.xls).
- DECC's *Great Britain's Housing Energy Fact File 2011* [10].
- DECC's calculations of the energy requirements of household heating systems and domestic appliances [11].
- UK Office for National Statistics (ONS) "Family Spending" series, used for 2000-2010 time-series estimates of spending on fuels, household appliances, and household maintenance and repair, by each gross income decile of the UK household income distribution; and the percentage of households with washing machines, tumble dryers and dishwashers in 2000 and 2010 [12].
- An Institute for Fiscal Studies Working Paper [13] provided figures on the net wealth of the UK population, stratified by income quintile, in 2000.
- Argos catalogues, 2000-2010. Argos is a UK retailer, selling a wide variety of household appliances. CEDSS requires a list of appliances offered for sale, with prices and (where they exist) energy efficiency ratings, for each quarter-year covered by a run. Those used in the model were sampled from these catalogues. The catalogues contained little computer equipment, so this could not be included in the model.

These and other data sources were used, together with the survey results, to construct a version of the survey households as they might have been in material terms most relevant to direct domestic energy use: dwelling type (assumed to be the same as in the 2010 survey) heating system, home insulation, domestic appliances (lighting was not surveyed in enough detail for modelling), income and liquid capital.

The 397 "millennium households" were divided into urban (Aberdeen, 197 households) and rural (Aberdeenshire, 200 households) subsets, and these were used to populate separate imagined communities – conceived of as an urban estate or a village respectively, and embedded in a grid of streets and junctions. CEDSS has the capacity to simulate demographic change, but this has yet to be used; instead, all households were given a "size" equal to the mean number of people in their subset (urban or rural) of households in the 2010 survey. (The model uses this number only in calculating energy used in water-heating: space-heating and domestic appliance demand are not affected.)

The households were assigned an initial set of value strengths. These were not drawn from data, since results from the survey did not indicate any clear relationship between values *as expressed in the answers to survey questions* and domestic energy demand. Instead, the value strengths (representing values that affect the purchase decisions being modelled), were assigned to households at random from distributions treated as free model parameters.

At the start of some model runs, households were also assigned initial social links, in ways that made closer neighbours more likely to be linked, but allowed the possibility of linkage for any pair of households.

The model readily reproduced qualitative features of domestic energy demand over the period 2000-2010, known from national statistics: the reduction in energy used for heating due to the installation of more efficient boilers and better insulation, and the partial offsetting of this improvement by the increase in the number of electrical appliances bought for and used in the home. The model was calibrated on the urban community, then the chosen version was validated by applying the same parameter settings to its rural counterpart, thus following the procedure of using half the available data to calibrate a model, then testing it on the other half. The calibration process involved two stages. The variants of the model were assessed primarily on the *sum* of the absolute differences in eight categories of all-household energy demand (electricity, gas and oil used for space-heating and water-heating, and electricity and gas used for domestic appliances) and the corresponding model results for 2010. The first stage varied parameter settings affecting the income, planning horizon (how far ahead the household looked in certain decisions), tendency to act habitually, ability to access credit, and values of the households, and whether social interaction was present or absent. The selected model variant from this phase was used as the basis for the second phase, in which income, and settings influencing the "wish-list" of desired appliances were varied. The variant selected from this second phase (henceforth, the "calibrated model") was then tested on the rural "community", with reasonably satisfactory results: the only areas in which there were errors (i.e. absolute differences between survey and model results in 2010) of more than 10% were gas used for appliances, and electricity for space heating, both minor contributors to total energy demand.

The collection and use of empirical data, their integration into the model, and the processes of calibration and validation, are described in more detail elsewhere [14].

III. Results

The calibrated model has now been used to explore a range of possible scenarios for the period to the end of 2049. In a scenario run, the calibrated model is run from 2000-2010, using past data about household incomes and spending, energy prices, and the availability and prices of domestic heating and domestic appliance technology; it then continues using data constructed to represent a scenario: a possible future set of conditions for domestic energy use. Our initial investigations have focused on four variable features of possible domestic energy futures: two are economic factors, the others directly concern policy options:

1. Economic factors:

a. Household incomes. We have examined scenarios where these are stable (in relation to appliances prices), and where they are rising at 2% per annum.

b. Fuel prices. We have examined scenarios where these are stable (relative to appliance prices), or increase at either 2% or 4% per annum. (Fuel prices are of course affected by policy decisions, and policies on taxation and/or subsidy may be aimed at reducing or increasing energy demand; but these prices are also affected by factors beyond the control of policy makers.)

The different trajectories for incomes and fuel prices, combined, define six families of "income-fuel-price scenarios".

2. Policy options:

a. Regulation of the energy efficiency of appliances. By default, we have assumed no such regulation. Alternatively, we have assumed that once sufficient choice is available of a particular type of appliance at or above a particular energy-rating, appliances with lower ratings are no longer allowed to be sold.

b. Subsidisation of boiler replacement and insulation measures. By default, we have assumed that prices of boilers and insulation measures remain the same. Alternatively, we have assumed that these prices are subsidised from 2015, falling by 30% at that date.

Regulation and subsidisation together define four clusters of "policy scenarios".

In total, we thus have 24 scenarios, grouped in four policy-defined clusters, which cut across six income-fuel-price defined families. We report results from using the urban millennium community (those from the rural millennium community appear similar). Each of the scenarios has been run 256 times, for a total of 6,144 runs. Statistical analyses undertaken so far are based on the energy demand, summed across the simulated community, for all uses, for space heating, for water heating, and for domestic appliances, recorded for each of the years 2009, 2019, 2029, 2039 and 2049.

Overall, the differences between scenarios were quite small (less than 5% for total demand and space-heating demand, even less for water-heating, although in some cases over 10% for domestic appliance demand). Total, water-heating and space-heating energy demand decline steadily over the whole period, although fastest before 2010, and increasingly slowly thereafter. Appliance energy seems first to grow, then from around the 2030s decline, in a jerky fashion, which awaits further investigation.

Both 2-way ANOVA (economy*policy) and 4-way ANOVA (incomes*fuel-price*regulation*subsidisation) were undertaken for each of the 20 combinations of year (2009, 2019, 2029, 2039, 2049) with type of demand (total, space, water, appliances), together with non-parametric Kruskal-Wallis tests. The last were added because the sample of runs did not fully meet the usual criteria for an ANOVA: in some scenarios, distributions of the some of the 20 demand measures showed significant deviations from normality, and for some measures, variances differed by more than a factor of 2 between some pairs of scenarios. We focus here on the 4-way ANOVAs; results from the other procedures were fully consistent with the 4-way ANOVAs, but less informative. The main results are fairly clear.

- In 2009, none of the main effects are significant for any of the 4 types of demand, as expected.
- For total demand, income and fuel-price both have effects significant at the .001 level from 2019 onwards (growth in income raised demand, increases in fuelprice reduced it by a greater amount) and both the interaction of these two factors (income:fuelprice) and regulation, have significant effect at the .001 level from 2029 (regulation reduces demand).
- For appliance demand, income, fuelprice, regulation and income:fuelprice have significant effects at the .001 level from 2019 onward (regulation and fuelprice increases reduce demand, income growth increases it; fuelprice has the greatest effect, followed by income and regulation). Subsidy also has effects (slightly increasing demand) significant at varying levels from 2019. It's interesting that this shows up here but nowhere else: if the effect is real, it is presumably a result of subsidies freeing up money to be spent on appliances.
- For space-heating, among main factors in the 4-way ANOVA only fuel-price has a significant effect, (at .001 level, with rising prices depressing demand).
- For water-heating, there are no significant effects.

Figure 2 shows heating demand (space- and water-heating combined) and appliance demand for those scenario runs without either regulation of inefficient appliances, or subsidies for new boilers and insulation. The difference made by both income and fuel-price factors to the appliance energy demand are evident. Effects of these factors on heating demand are less apparent, but it is clear that almost all the runs with heating demand below 3,150,000 kWh belong to scenarios in which fuel prices increase faster than income. Figure 3 illustrates the effects of regulation and subsidisation, in the case where fuel prices are increasing at 4% per year

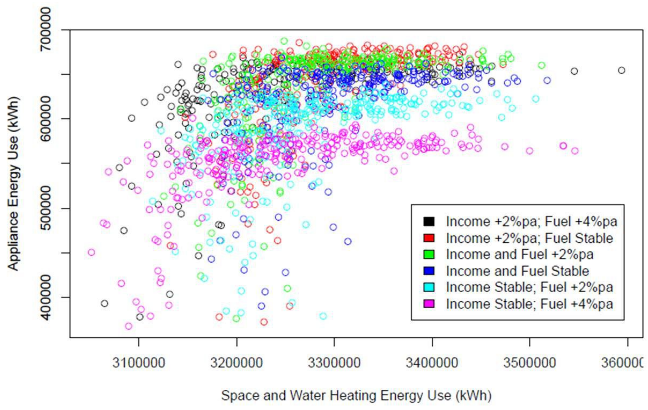

Fig. 2: Heating and appliance energy use 2049, no regulation or subsidisation

while incomes are stable. The effect of the regulation of inefficient appliances on appliance energy demand is reasonably apparent, in the clustering of black and green circles, representing those runs without such regulation, toward the top of the figure. The effect of subsidisation is less obvious, but among runs with the lowest appliance energy demand, most are those with regulation but without subsidy (blue).

The scatter plots of figures 2 and 3 also show a common spatial pattern, with most of the runs grouped toward the top of the figure (high appliance energy use), and a small number in the lower left quadrant (low appliance and heating energy use), but none with high heating energy use and low appliance energy use. Investigation indicates that this pattern is probably due to the dynamics of value strengths in CEDSS. The calibrated model has value strengths assigned to the households which were drawn once-for-all from distributions designed to favour hedonic and egoistic values over biospheric values; but by chance the average initial strength of hedonism is slightly greater than that of egotism, and most runs appear to end up with hedonism predominant in the community: the runs in the lower left quadrant are those

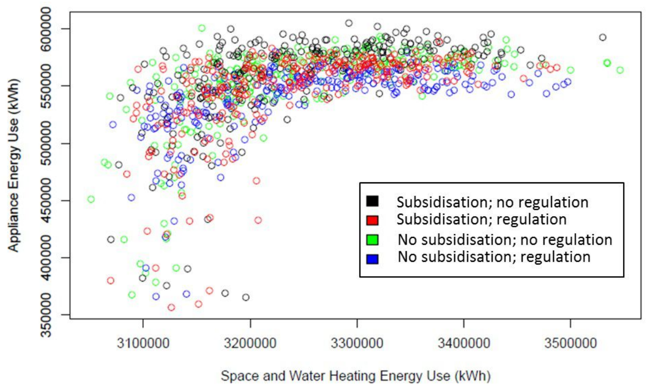

Fig. 3: Heating and appliance energy use 2049: incomes stable, fuel prices rising 4% p.a.

where this has not happened: a positive correlation between level of hedonism and total, space-heating and above all appliance energy demand is found in all scenarios.

It is also interesting to examine the changes in energy demand over time. Looking first at total energy demand, there is a common pattern across all conditions, of a relatively sharp drop during the first decade – the period up to the 2010 survey – followed by a markedly slower and nonmonotonic decline throughout the period to 2049. Fig. 4 illustrates this for the condition in which neither regulation nor subsidisation was applied, and both income and fuelprice were stable. Comparing this with the picture for space-heating alone (the largest component of demand), shown in Fig. 5, we see that the overall pattern is similar, but the decline is smoother in three respects: there is no longer an obvious kink in the curve at around 2010, the decline thereafter continues to slow, although more gently, and the "wobbles" in the curve disappear. The picture for water-heating (Fig. 6) is similar, but that for appliance demand (Fig. 7) has a completely different appearance: an initial rise and fall during the first decade, followed by an initially sharp then slowing rise, turning to a fall around 2040, and with a superimposed "saw-tooth" pattern of smaller but sharper rises and falls.

The patterns found in the space-heating and water-heating demands are due to a combination of the replacement of old, non-condensing boilers by more efficient condensing ones – something that would be expected to slow down as the proportion of households with a non-condensing boiler falls towards zero – and the addition of new insulation measures –

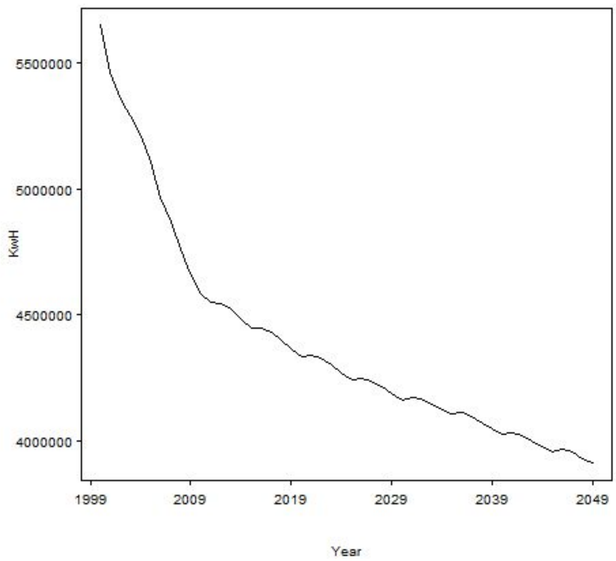

Fig. 4: Total energy demand over time, no regulation or subsidisation, incomes and fuel prices stable

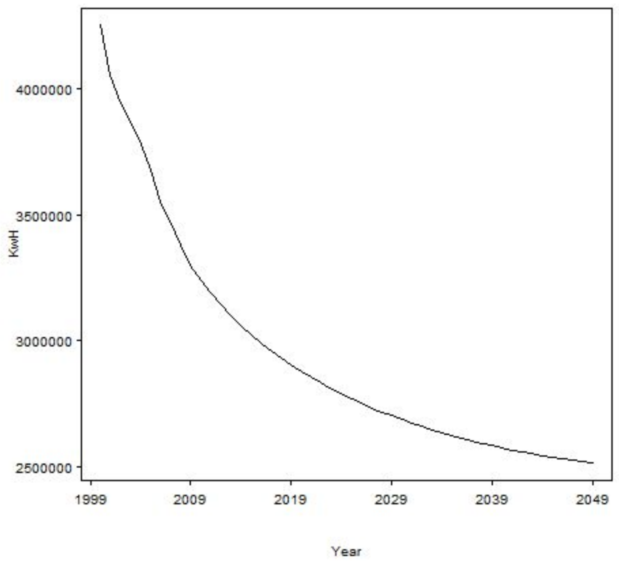

Fig. 5: Space-heating energy demand over time, no regulation or subsidisation, incomes and fuel prices stable

which might also slow down as the cheaper measures, such as double glazing and loft insulation are completed, leaving only the more expensive wall insulation as a possible heat-loss reduction measure. The pattern found in appliance energy demand is less readily accounted for, although the jerkiness may be a result of the schedule on which new, generally more energy-efficient appliances were introduced during the

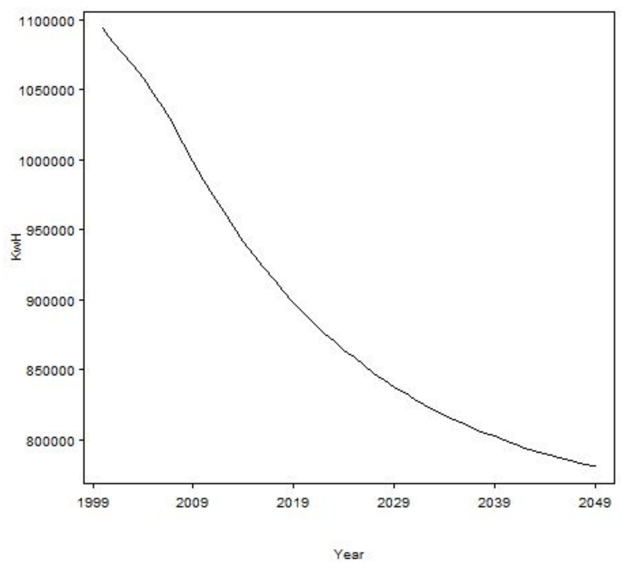

Fig. 6: Water-heating energy demand over time, no regulation or subsidisation, incomes and fuel prices stable

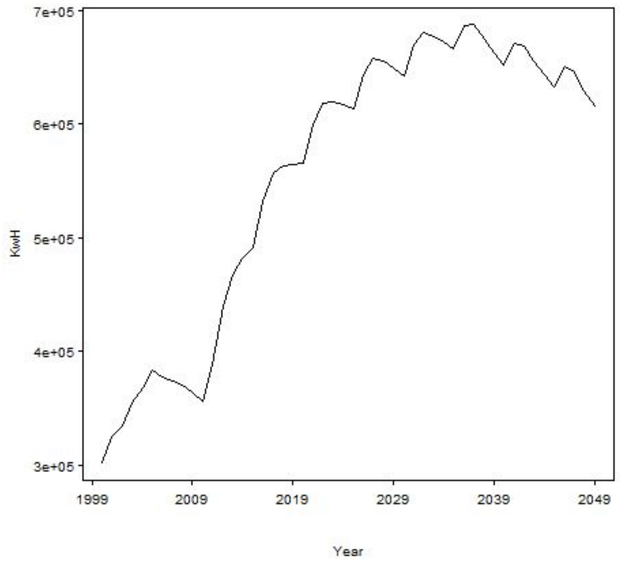

Fig. 7: Appliance energy demand over time, no regulation or subsidisation, incomes and fuel prices stable

post-survey scenario era: there does appear to be a roughly 5-year periodicity in the oscillations.

The overall pattern of usage does continue a key feature of that known to have occurred at a national level over the past decade, at least until the late 2030s,: reduction in demand for space-heating (after a long period when this demand rose as households became accustomed to warmer rooms) and water-heating, as more efficient boilers and better insulation have been adopted, while the demand for appliance use has increased considerably [12], because although there have been efficiency gains in this area too, they have been outweighed by increases in the number of appliances owned by households, and also the size of refrigerators, freezers and televisions – as described in [15], and reflected in the contents of the Argos catalogues we used. The transition to a fall in appliance demand toward the end of the scenarios probably reflects the fact that we have not yet attempted to extrapolate the trends to larger appliances, and to a greater variety of appliances in the scenarios. We have allowed the number of appliances per household to continue to rise, but this trend may have reached saturation point (reflected in the limits we set on the number of appliances of each category a household could possess) by around 2040.

IV. Discussion

Household energy use and personal transport account for a considerable proportion of total energy use, and greenhouse gas emissions, in rich countries. In Europe, about 35% of all primary energy use and 40% of all greenhouse gas emissions come from private households—with regional differences

[16], [17]. Home energy, personal travel, and food and beverages are the most important sets of activities. US studies find similar results [18]. Given the vital importance of reducing greenhouse gas emissions from energy use, it is surprising how little attention has been given to the dynamics of household energy demand; and in particular to the interactions between technological change – which can act both to reduce energy use through greater efficiency, and to increase it by producing an unending supply of new household appliances – economic conditions, policy, and socio-cultural forces. CEDSS goes some way toward filling that gap in the area of agent-based modelling.

We are not aware of any previous agent-based model that has investigated household decision-making processes in this area. Perhaps the most relevant previous studies have concerned water usage in the UK [19], [20]. The process of designing and implementing such a model in itself has revealed many of the complexities of how people think about their domestic energy use, and energy using and energy saving equipment. It has also perhaps clarified how agent-based modelling can complement more established approaches to social science, which in this area tend to focus on what people say about their energy use and its relationship to their values, as opposed to hard data about the decisions they make and their medium to long-term consequences.

Reference [21], surveying ABMs described in the literature between 2000 and 2008, distinguished three segments of a continuum with regard to a model's purpose: as a "Generator", "Mediator" or "Predictor", differing primarily in how well the system modelled is understood before the ABM is designed. When the real-world system is very well understood, the model is used "like a calculator to provide clear and concise predictions about the system": a "Predictor". When the state of understanding is intermediate, it "provides insight into the system, but is not a complete representation of how that system actually behaves" – acting as a "Mediator". When the system is little understood, the model is used as a "Generator", i.e. to generate hypotheses about it. In these terms, CEDSS is a "Mediator" (the definition of a "Predictor" is so strict that [19] found no "Predictors" among the 279 models surveyed. Even the assembly of data sufficient to inform the construction of a "Mediator" was a considerable task.

Another dimension on which ABMs can be classified is the relative importance of theoretical and empirical constraints in determining model design. CEDSS is near to the empirically-constrained end of this spectrum (as for most ABMs, and as has been made clear in this paper, there are also aspects of the model design that are constrained by neither theory nor empirical evidence). However, the theory of goal-frames has been a significant influence on our work, so we take the opportunity of this discussion section to outline it in a little more detail, and reflect on how far CEDSS captures its main features, and, in the context of future work, how we might expand or modify the model to improve this match.

Goal-framing theory [4], [5] proposes that human perception and decision-making are organized in a broadly modular way (broadly, in that the "modules" are not impervious to each others' influence), with the top-level modules corresponding to three overarching goals, each including and organizing a large number of subgoals and ways of achieving those subgoals. As already mentioned, these high-levels goals can be termed "hedonic" (feeling good), "egoistic" (protecting and improving resources) and "normative" (acting appropriately, in terms of social norms). At any one time, one of these top-level goals will be focal, establishing a "goal-frame" that directs attention and steers decision-making – although the non-focal top-level goals will still in general have some influence. The hedonic and egoistic overarching goals are considered, in general, to be stronger than their normative counterpart. It was noted in section II that the best match between CEDSS and the survey results on direct domestic energy use were found when the strength of biospheric values was assumed to be low relative to hedonic and egoistic values.

Within goal-framing theory , situational cues are considered capable of triggering goal-frame switches on the short timescales explored in psychology experiments [22], [23], but within CEDSS, changes in goal-frame occur only once per time step (monthly in the runs reported here). It would be possible to alter the model code to allow switches of goal-frame within a time step, but it is not clear that this would actually improve model performance. Intuitively, it seems likely that there are fluctuations on multiple timescales in the proportion of the time each of the three overarching goals is focal, depending on multiple factors, including the influence of social contacts [9], and habit [6]-[8], as currently implemented in CEDSS; but also factors which do not affect the choice of goal-frame in CEDSS, such as household financial situation (which does nevertheless affect purchasing decisions when the goal-frame is hedonic – this can be seen as an example of the influence of non-focal goals referred to above), and exposure to advertising, news items and publicity campaigns, which are not currently modelled.

Returning to empirical constraints on CEDSS, while the survey data has been essential to our modelling work, in order to implement a model that could plausibly tell us something about the future, we needed to be able to model the recent past, and change over that period; and in order to do that, we needed a wide range of quantitative data about the recent past: energy prices, household incomes, heating systems, insulation measures, the prices and properties of household appliances. This information is not readily available in convenient forms and formats, and we needed to make more assumptions than we would have liked. Where we were unable to access any relevant data – as in the case of the influence of social contacts on purchase decisions – we have been obliged to experiment with different parameter settings to calibrate those aspects of our model. The fact that we were nevertheless able to construct a version of the model that reproduced trends known from national datasets, and produced outcomes in the present that were quite close to those indicated by the survey, we regard as a vindication of the agent-based modelling approach. The main results from the future scenarios reported in the preceding section appear plausible.

Nevertheless, the model does show some anomalous or questionable behaviours. Some of these have been mentioned in the results section. The predominance of hedonism in most scenario runs is another, for which further investigation is planned. If this outcome is the result of the small initial imbalance mentioned, it could indicate that our value strength adjustment algorithms, which are admittedly not empirically based, are too sensitive to initial conditions; if it is due to some other cause, we need to understand it. Another anomaly uncovered in the scenario output is that the households tend to accumulate too many televisions, while seldom replacing other non-essential items such as dishwashers and dryers. The calibration and validation procedures could also be criticized as insufficiently thorough, since they did not detect these anomalies.

Our future work on CEDSS will involve a survey of the model's behaviour over its parameter space that is both broader and more detailed (measuring more aspects of the output from runs) than that briefly described here; and the selection of a range of model variants rather than a single variant for use in future scenarios, thus allowing us to determine which parameters make the most difference to outcomes, and to provide policy-makers with appropriately qualified forecasts of likely direct domestic energy demand under a range of assumptions both about exogenous influences (economic conditions and policy decisions, which we have already begun to explore as described), and also about intra-household and intra-community dynamics, and sociocultural trends, such as external influences on the strength of biospheric values, which we have not.

It is difficult to envisage domestic energy use being reduced as much as emission reduction targets require over the period of the CEDSS scenarios, without considerable behavioural change. Here, goal-framing theory can help us to devise appropriate scenarios, and where necessary, extensions to CEDSS itself. In goal-framing theory terms, such behavioural change would require increasing the proportion of decisions for which the normative goal-frame is focal, and [5] discusses possible ways in which this could come or be brought about: strengthening of the underlying normative (and specifically biospheric) values by "moralization" (in this context; explicit social disapproval of excessive energy use), exposure to good examples both of directly relevant behaviour ([24] showed that learning that neighbours used less energy than themselves prompted people to reduce their own energy use), and of prosocial behaviour in general [25]; and increasing capacity for "self-regulation". This is the ability people have to increase the likelihood they will act in ways they wish to act in order to satisfy long-term goals, despite temptations not to do so. In the context of encouraging proenvironmental behaviour, self-regulation capacity can be augmented by improving feedback, reducing conflict of the normative goals with hedonic and egoistic goals, and communicating concrete, low-level norms (specific behavioural rules) that are clearly linked to the targeted higher-level norm – in this case, reducing domestic energy use. We intend to explore ways to implement these mechanisms within CEDSS. "Moralization" can be explored by providing exogenous boosts to the strength of households' biospheric values, representing government publicity campaigns; the effect of good examples by providing households with information about the average energy use in their neighbourhood; and making self-regulation easier by providing more detailed information about the household's own energy use, as can be done in the real world using smart metering. Finally, we also intend to implement the demographic functions of the model, and extend it to deal with travel and food consumption, once we have adequate data.

Acknowledgment

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Informing agent based models with discrete choice analysis: diffusion of solar PV in the Netherlands

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I. Introduction

Discrete choice models (DCM) are well known in econometric literature and widely applied since the 1970s. These models are used to predict market shares of products or to estimate demand for services and transport or to assess people's compliance to certain policies. DCM provide statistical estimates of people's preferences and behaviour. However, DCM come with limitations that they provide *static* account of preferences. In reality, preferences change as consumers interact with one another or in response to market fluctuations [1], [2]. Simulation models, on the other hand provide *dynamic* representation of affairs. More specifically, agent based models (ABM) simulate interactions and dynamic behaviour of people, and capture emergent patterns [3]. Putting the two approaches together, one can first use DCM to obtain information on current tastes and preferences of individuals, and then use the analysis provided by DCM to create ABM,thereby, introducing dynamics in preferences to assess the outcomes of potential measures or scenarios on people's behaviour [1], [4], [5].

Dia [6] and Vag [1] proposed that ABM can provide better understanding of consumer behaviour, if people's preferences and attitudes are supplied by conventional surveys. Moreover, the interaction of demographic variables (e.g. age, income and education) with people's choices [7] and also influence of social networks [8] can provide even more insights to behavioural aspect. However, these studies do not provide a structured path to describe how data from empirical experiments, such as discrete choice, can be incorporated into ABM.

This paper aims to provide a methodological framework in which combining these two modelling approaches can be realized. Furthermore, we apply these concepts, on the case of large scale adoption of solar photovoltaic (PV) panels by Dutch home-owners.

II. Methodological Framework

In this study, we introduce a methodological framework, which provides a path on how to incorporate outcomes of discrete choice experiments in agent based models. Figure 1 displays this framework.

In the first part our framework (left side of figure 1), a discrete choice experiment is shown. As an input to this type of experiments, domain related information, attributes and influential characteristics of the product or service under study are gathered by the researcher(s). At this stage, norms (i.e. social norms, which according to Ostrom (2009) are informal rules in society that are accepted and complied with by individuals [9]) can already be included in discrete choice experiments [10]. Besides these, interaction of demographic and attitudinal variables with respondents' preferences can be captured through DCM [11].

When a discrete choice experiment is performed, respondents are asked to select among alternatives offered by a survey, and thereby reveal their preferences based on attributes that are featured in alternatives. DCM estimate coefficients for product attributes, which displays the weight attached to them by respondents. These coefficient are then included in the decision making process of agents in ABM.

In the second part of our framework (right side of figure 1), the agent based model is conceptualised. Agents are assigned with properties [12] based on demographics obtained from respondents. Agents are also populated with the attitudes of respondents. These attitudes concern respondents' general approaches and beliefs, in wider perspective, concerning the implication of consuming a product or using a service under study. These are assigned to agents as personal values [12]. These properties and personal values, together, define agent's state [13].

Staying with the ABM part of the framework, we refer to the environment box. The environment, in which agents interact, provides some physical and social components that resemble the real world. For instance the agents have only limited access to solar PV market and the PV systems can only supply a certain amount of power to each house. The social components refer to the influence of society on individual's behaviour; for instance the level of uptake of solar PV technology in a neighbourhood/social network may influence the owners of a house to install panels. These components are investigated at initial stages of the choice experiment and presented in similar form in ABM to provide consistency between the two modelling approaches.

Finally, the agent behaviour box is the heart of decision making and processing part of the ABM. This box includes the decision making process of agents and the weights they assign to attributes, which together enable an agent to choose the most suitable alternative based on its characteristics. The choice behaviour of respondents and the variance of their preferences are taken from the DCM and applied in this module of the ABM. As well as preferences, the agents' state (i.e. properties and personal values) and environmental aspects are included

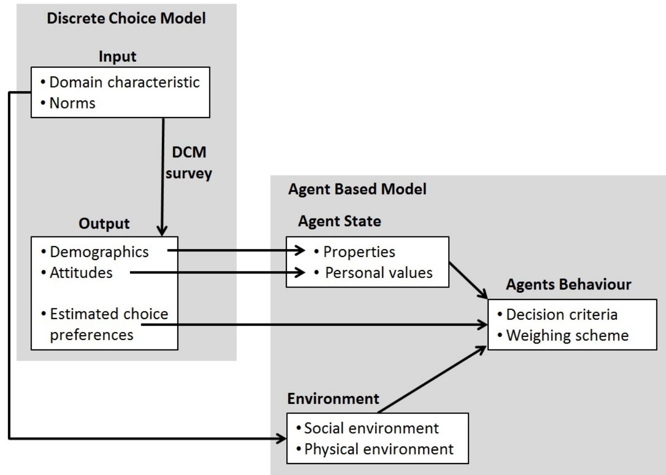

Figure 1. A methodological framework to combine discrete choice experiments with agent based models

in the decision making process. Putting all this information together, agents are equipped to choose the alternatives, which are similar to the products at the market.

Agents obtain a certain amount of utility from each product (i.e. solar PV systems) based on the values of product attributes. If the utility obtained from an alternative meets the threshold utility of an agent, then that agent will buy the product or adopt the innovation or use the service. If the threshold limit is not met by any alternative, then agents leave the process of decision making and wait for the next round of decision making (i.e. next tick). In the next round some changes may occur at the market (e.g. new prices or new product attributes) and also to agent himself (e.g. age, income, or disposable allowance to spend on the alternatives or changes in social network).

III. The case of Solar PVs in the Netherlands

We use the case of large scale diffusion of solar PVs in the Dutch houses as a platform to describe the functionality of our framework. Solar photovoltaic panels are popular technologies for domestic use, with an installed capacity of 51 GW in Europe as of 2011 [14]. The market for these panels is still expanding, despite the financial crisis between years 2008 and 2012. The Netherlands is currently ranked 13th in installed capacity, while its neighbouring countries, Germany and Belgium, are 1st and 6th respectively. The installed capacity of solar PV in the Netherlands is expected to grow, calling for more analysis on consumer behaviours and attitudes with respect to sustainable energy supply. Previous studies have described some common characteristics in the demographic variables of the majority of ”early adopters” of PV systems in Groningen [15]. Other studies have developed ABMs of adoption of solar PVs [16]. At each time-step, agents assess the relative attractiveness of the comparable technologies which then allows them to decide whether to continue using current technology (obtaining electricity from the grid) or to adopt a new power supply (decentralized generation).

Veneman [17] reviewed number of ABM on distributed generation technologies, emphasizing that models developed to study diffusion of decentralized technologies are mostly ”theoretical”, and there is a need to ”combine empirical methods with agent-based modelling” . This is where our proposed framework becomes relevant.

IV. Framework implementation on the PV case and model narrative

The survey on Dutch households is not yet completed, therefore we used a data set from another choice experiment, with a comparable product, as our synthetic data set. The main aim in this paper is to develop an ABM based on discrete choice data and use DCM analysis as the basis of decision making process of the agents.

In the DCM part of the framework, the preferences of respondents is estimated for four attributes of solar panels: initial investment (in euro/Wp), recyclable parts used in PV (after its life time)[in %] , free maintenance support (in monthes) and efficiency of the PV system (in index system). With the data gathered and processed in the DCM part, we calculate the utility derived from PV alternatives by each respondent and record these in a data file for ABM.

Additionally, instead of using a single set of (averaged) coefficients for everybody, we used latent class analysis to categorize our respondents into 3 latent segments that have congruent choice behaviour or preferences within each segment. Latent class models are applied in DCM to estimate segment specific coefficients [18]. These coefficients are then included in agents' decision making processes in our ABM. This allows for consideration of heterogeneity in preferences and choice behaviour among home-owners.

Next, we shift to the ABM part of framework. For this part, an agent based model has been developed using Netlogo platform. For each respondent in the survey there is an agent in the model with its demographic characteristics and coefficients (preferences) - according to the latent class the respondent belongs to.The model is initialized by creating a social network

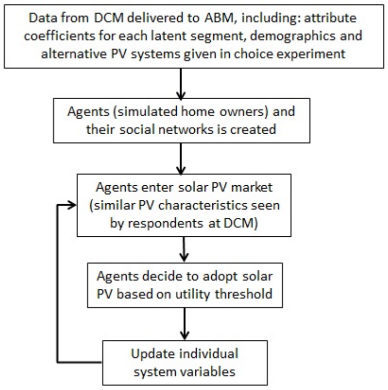

Figure 2. Flow map of ABM for solar PV diffusion in Dutch households

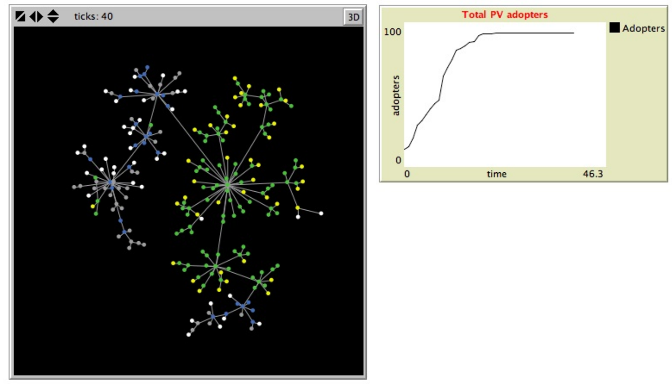

Figure 3. Screenshot of ABM for diffusion of PV systems in Dutch houses

of 238 agents representing this number of respondents from the survey.

Figure 2 shows a conceptual flow map of the ABM model for solar PV diffusion. During the model run, agents decide to enter the solar PV market or not. The decision to enter the market happens when agents have the "intention" to adopt a PV system. Agents' intention are directly influenced by percentage of PV owners in their social network, who own PV system. When a certain percentage of agents (determined by the modeller at set-up stage) have adopted a PV systems then the individual agent in a given social network has the intention to enter the market. In the next step, the agent assesses some random number of PV systems in the market and calculates the utility it derives from each alternative PV system. These alternatives have similar attributes as the ones offered at the discrete choice survey, so that agents face the same situation as respondents in the market.

The decision to adopt one of the solar PV systems is based on the utility maximization mechanism. The alternatives can have a different utility value for different agents, since it depends on their coefficients. Agents have segments specific set of coefficients by which they give weight to the four attributes of the PV system. These coefficient sets are taken from latent class analysis in DCM data, which was explained earlier. Thus, when agents from different segments consider the alternatives, they derive different utilities. Next step in the agent based model, agents compare the utility of their selected PV with their "threshold Utility". If the utility of chosen PV system passes the threshold then agents adopt the candidate PV, otherwise the agents do not adopt and leave the market. The "threshold" is calculated as the highest estimated utility from the DCM data set.

V. Results

A screen shot of the ABM is displayed in figure 3. In this particular netlogo model run, there were 5% initial adopters, 15% PV owners in network required for "intention", and no change in the original threshold utility. Home-owner agents are represented by dots and are connected in a social network via the grey lines. Initially, agents in different latent classes have different colors (grey, blue, white). Agents turn yellow when they enter the market, and eventually turn green if they adopt. The graph on the right side of figure 3 shows the PV adoption curve.

After running the model over 2420 runs and processing the ABM outputs with R [19], we arrived to results displayed in three consecutive figures 4,5,6, showing the total number of agents adopting solar PV systems in different circumstances. Figure 4 shows the impact of initial PV owners on eventual diffusion of PV systems. As the initial adopters increase from 1% to 15% of agents, one can see that final number of adopters also increases. This indicates the rate of diffusion of solar PV has a strong dependence on the current population of PV owners.

As mentioned earlier, agents decide to enter the PV market only when they have intention. This intention is linked to the minimum number of adopters, in each agent's social network. In figure 5, when the minimum number of PV owners (required to trigger agents' intention) increase, the final aggregate number of adopters decline. This implies that, if agents require many peers to adopt before deciding to enter the market, then the diffusion rate would be low.

Finally, the utility threshold of agents are varied (accordingly) to higher or lower levels of original thresholds in figure 6. When the threshold is lowered, agents became less stringent in their selection procedures and adoption rates increase. Conversely, when the threshold levels are increased, indicating captious agents, the adoption rates stay low and almost constant to some specific number of agents.

VI. Conclusion

The proposed framework provides an empirical foundation for developing ABM. Furthermore, the behaviour of agents and those of "real life" respondents can be compared using base case scenarios, where alternatives and environmental factors of the survey and the ABM are similar. In this way, the initial outputs of the ABM can be validated. ABM simulate dynamic choice situations and different scenarios can be exercised. This can be insightful to study emerging patterns from changing market and environmental situations.

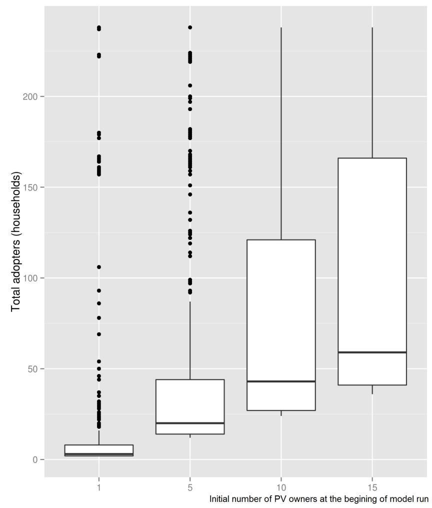

Figure 4. Diffusion of solar PV when the initial PV owners are increased

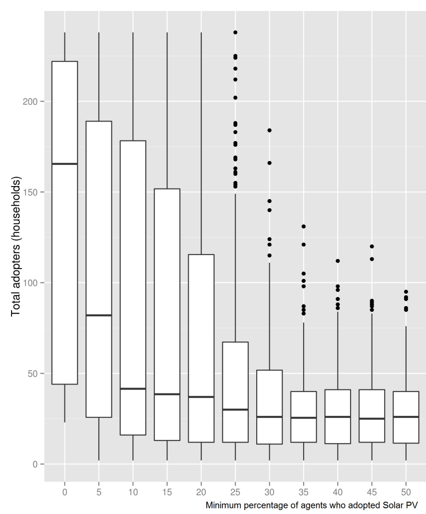

Figure 5. Diffusion of solar PV when minimum required percentage of PV owners in agents' social network is varied

This is a benefit of ABM that can not be easily achieved by conventional discrete choice experiments.

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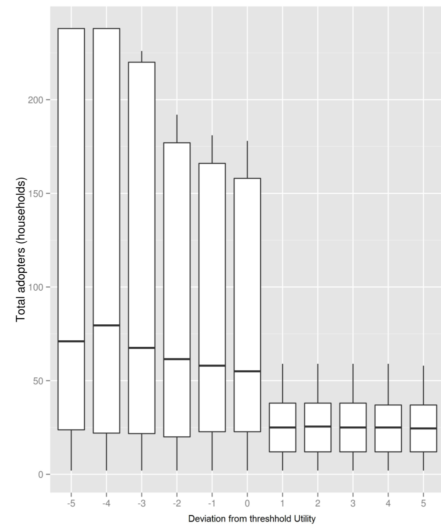

Figure 6. Diffusion of solar PV when agents' utility threshold is varied

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The Internet As a Catalyst for Social Movements: A Simulation of Social Media Mechanisms in the Context of the Arab Spring and Occupy Movements

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***Abstract*—Over the last few years protest movements such as the Arab Spring and Occupy, have cascaded through much of the world. All of these were regularly portrayed as 'Internet Revolutions' in the media, but among sociologists there is strong doubt about whether they actually could have been accelerated by the communicative capabilities of the Internet. In the research that will be presented Illustrative agent-based modeling shall be used to examine whether the Internet could have had anything to do with them, and if so, through what possible social mechanisms.**

I. Introduction

OVER the last few years protest movements such as the Arab Spring, the Spanish Indignados movement, and the Occupy protests, have cascaded through the Middle East and the rest of the world. All of these were portrayed as 'Internet Revolutions', or at least as having been accelerated by the communicative capabilities of the Internet [1, 2]. Did the Internet and social media actually have anything to do with them, and can we expect more Internet-enabled protests soon? Opinions are divided in the scholarly literature; mostly along the lines of the ongoing debate between so-called Internet-optimists and pessimists.

A. Background

Notable scholars in the pessimist camp are Bart Cammaerts, Matthew Hindman and Evgeny Morozov. Cammaerts argues that commodification and appropriation by elites makes the Internet less deliberative than it is often thought to be. Hindman argues that the Internet is barely used for politics and agrees with Cammaerts that it leads to more centralisation; for example into large — larger than any mortar and brick — companies, such as Amazon and Google [3, 4]. In the case of Google this led to censorship under pressure of the Chinese state [5]. Morozov proposes that on-line activism is really slacktivism; a convenient distraction from actual street protests. Gladwell argues in addition that slacktivism can only foster ties that are too weak to sustain the sacrifices that protests require in the real world [6, 7].

On the other hand, optimists such as Yochai Benkler and Howard Rheingold argue that the cheap many-to-many communication afforded by the Internet fundamentally changes how easily people can express and organize themselves, leading to greater empowerment and a more egalitarian cultural sphere [8, 9]. More specific to recent protests, Philip Howard and Lee Rainie noted that on-line activity preceded protests on the ground, and that people who were most active on social media were much more likely to show up at protests than those who do not [10, 11, 12].

While the explanations and findings offered by both optimists and pessimists sound plausible, they do not come close to answering the question of what the impact of the Internet likely has been, or is. This is simply because the social processes they describe (if any), need not be mutually exclusive. They could work both ways, and do not warrant blanket predictions. My DPhil (Phd) research attempts to improve upon this both by explicating and disentangling these, and other social processes relevant to the formation of protest movements, and then by carefully evaluating how various Internet platforms may have changed the media-landscape to affect each of them. Dissecting the Internet into different communication platforms, and 'impact' into a set of counter-acting social processes that each may play out differently, should move insight beyond blanket predictions, and help clarify how anomalous it would be if something as multifaceted as the Internet were *not* to have any impact on collective action initiation [2].

While it is unlikely that Internet platforms were a sufficient cause for recent protests, they are expected to be a contributory cause at least, because collective action is fundamentally communicative: for it to come about at the very least a common interest has to be identified and communicated, and contributions then have to be coordinated between many people [13]. Besides, the initiation of social movements often crucially involves private, potentially high-risk communication to identify other possible initiators. Other central processes heavily relying on communication are: opening up hidden transcripts (people communicating discontent among similarly oppressed friends), overcoming falsified preferences (people adjusting preferences to what seems possible), and communicating new identities and framings of the situation [14, 15, 16].

B. Social mechanisms

In the research that will be presented, social mechanisms of mobilisation and collective action initiation that may have been affected by the Internet are analysed. Social mechanisms are micro-level descriptions of social interactions, and are central to the Analytic tradition in sociology, allowing for abstract, action-based explanations of recurring social interactions and their outcomes [17]. The four mechanisms that will be analysed are:

- Communicative acceleration: Faster and cheaper communication leading to more communicative opportunities and lower costs, which should accelerate various mechanisms, such as the spread of information about protest events, and the coordinating of contributions, even within large groups [18, 8, 19, 20, 21].
- Secluded spheres and enclaves for the progressive: Homophily in Facebook friendship networks may make it easier for movements to reach likely protesters (even more so if social incentives are added) [22, 23, 24, 25, 26, 27].
- Grievance exposure: Increased unintentional exposure of hidden transcripts may happen between activists and non-activist friends and family mingling on extended Facebook networks and help cross communicative boundaries and expose hidden transcripts to widening circles [14, 28, 29, 30].
- Micro-contributions: People can gradually become more active, starting from small, incremental contributions. The first step to activism can be as small as a ‘like’ on Facebook, similar to how Wikipedia gained success by making the first step to contribution as easy as correcting a spelling-mistake [31, 32, 7].

C. Agent-based models

For each of these mechanisms an illustrative Agent-Based Model is created. They each are based on Epsteins model of collective action, and are extended with the affordances provided by the following internet platforms: email, web-forums, and Facebook [33]. Epstein models the essence of Granovetter’s well-known threshold model. According to it, individuals won’t join a protest until their threshold (k) is met, for the number of others that need to be protesting before they dare to join. People’s thresholds vary. Whether a protest happens then depends on whether enough people with low enough ks are nearby: leading to a riot if a hundred people with ks 0 to 99 are present, and only two rabble-rousers (k = 0 & 1) amidst 99 solid citizens, if the next k is missing (if $k = 2$ is missing, then $k = 3$ and further won’t be joining in, breaking the chain) [17, 34]. The output of the agent-based models has been tentatively analysed, and full results, as well as code, will be provided in the presentation.

Agent based modelling is well-suited as a method for illustrating social mechanisms, and for maintaining the micro-macro link that constitutes emergent behaviour [35, 36, 37]; which is a crucial phenomenon here. Even though changes in the affordances offered by media platforms only affect individuals’ communicative environments in various small ways, communication is repeated, recursively, with every ‘round’ of interactions building upon earlier differences. Thus small, individual-level changes may cascade into large, emergent shifts in macro outcomes over time [38, 39, 40, 31, 41, 42, 43, 44, 45, 46]. Being able to trace such change — even if only in a model — allows for a clarification of how historically momentous outcomes, such as the ignition of social movements could hypothetically arise in absence of any large or spectacular causes.

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Information Technology and the Topologies of Transmission: a Research Area for Historical Simulation

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***Abstract*—This paper surveys possibilities for applying the methods of agent-based simulation to the study of historical transitions in communication technology.**

Introduction

HISTORY, in one sense, begins with the invention and adoption of a particular information technology: writing. Initially appearing in Mesopotamia some 5,000 years ago, it has spread (mainly by diffusion, but with some probable cases of independent invention) to cover effectively the whole world. Other key communication technologies have done the same. How does the adoption of such technologies alter social dynamics? How do they interact with economic and political structures, with other technologies, and with the human relationship with the non-human environment? Are there any general principles that can be extracted from the many historical examples available? How can simulation, and in particular agent-based modeling, contribute to advancing understanding in this area of research?

I. Communication Technologies Before Writing

The earliest communication technologies, in the broadest sense, date from perhaps as much as 250,000 in the form of use of pigments and personal ornamentation [1] that may have been used to convey information about social status; or even as much as 700,000 years if the speculation in [2] that some Late Acheulean hand-axes were prestige objects rather than practical tools, is correct. If we regard the modification of natural objects to communicate status information as communication technology, of course, it is not unique to human beings – bower birds provide an obvious non-human example. There have been many agent-based models of the effects of reputation, often with intended practical application in online marketplaces [3], and some of the role of cultural markers in social interactions [4], but the role of prestige objects does not appear to have been explored. Abstract models of the dynamics of small-scale societies in which such objects play a role should be easy to design. Prestige objects must be comparatively rare, and easily recognized, so their effect on social contacts of the owner could be graded both by their sensory qualities, and by how often similar objects have been seen. They can be acquired in three ways: by being found, perhaps with subsequent modification, traded (within or outwith the social group), or stolen; and all these methods could be included in a fairly simple model. Possession of such objects could increase the probability that other individuals will cooperate with the owner – but also the possibility that they will attack the owner to acquire the object. Outcomes of such models (the distribution of prestige objects, peaceful or violent transfers of possession, survival of their possessors, effects on trade between groups) could be compared with archaeological and anthropological findings.

Another very early form of communication technology may have been the use of waymarkers, allowing members of a social group to lay a trail for fellow-members to follow, although small-scale markers are unlikely to last long, while it is difficult to be certain whether more permanent environmental modifications, such as cairns and standing stones, were used in this way. In both these cases, agent-based models could be used to elucidate what effects the technologies could have had on social groups, and hence, possibly, to suggest what archaeologists and anthropologists should look for, or whether their interpretation of the function what has already been found is plausible. Many nonliterate cultures have produced maps and other navigational teaching aids [5], [6], although incorporating these into agent-based models would seem to demand agents of considerable cognitive sophistication.

II. Writing

Writing is the first communication technology generally agreed to have had radical effects on social organization. Although some states of significant size, such as Great Zimbabwe [7] appear to have managed without writing, or even any record-keeping system able to fulfill some of the same purposes such as the knotted string records of the Incas (“quipu”) and other native American and Pacific societies [8], this is certainly unusual and may require special conditions (in the case of Great Zimbabwe, control of a rich source of gold). The oldest known writing system, in 4th millennium BCE Sumeria, seems to have arisen from the accounting and administrative needs produced by increasing socio-political complexity [8], [9].

Reference [10] argues that innovations in linguistic communication technologies, beginning with writing, and changes in the breadth of access to such technologies, are an important factor in determining how hierarchical and authoritarian societies are. When first invented, [10] suggests that writing greatly increased the power of rulers, along with a small scribal caste; but as forms of writing were developed that made literacy easier to achieve, culminating in alphabetic scripts, the result was the emergence of the first democracies, in classical Greece. One might question both the extent of ancient Greek democracy, which excluded women and rested on the extreme exploitation of a large slave class, and the importance of increasing literacy (the proportion of literate individuals is in any case difficult to determine) relative to changes in military technology which underpinned a "citizen army", and indeed to the very presence of a slave class, which allowed citizens to gather in the city to pursue drama, philosophy and politics while the slaves tilled the land [11] and mined the silver which made Athens rich; and [12] (p.165) denies that there is any connection between alphabetic scripts and democracy, noting that while such scripts may aid the development of widespread literacy they are not essential to it, and that the latter is quite compatible with a lack of democracy.

This controversy might be illuminated by agent-based modeling, without requiring the detailed simulation of communication in different writing systems, by examining the effect of changing the costs of acquiring the ability to "read" and "write" messages on differences in inequalities in "wealth" and "influence". However, such a project would require modeling societies of considerable complexity, probably involving thousands of agents, demographic processes, an agricultural economy (capable of generating a surplus sufficient to support non-agriculturalists), an elite exercising coercion (using specialist enforcer agents) to extract that surplus, craft-workers, trade in everyday and prestige goods, and conflict between neighbouring polities.

Assuming that such a model can be designed and implemented satisfactorily, we can list some requirements needed to incorporate the invention of writing and its possible effects. Even the attempt to do so raises interesting issues.

- Modeling writing requires specifying a set of messages – presumably recording which households or villages have and have not paid their taxes – and how much they are required to pay. This raises the question of how, without such a system, preliterate rulers organized tax collection, as opposed to simple looting, which risks missing some targets and taking so much from others that they starve and hence can produce no more. Possibly such rulers operated by giving each taxpayer (village or household) a "receipt" of some kind – so this could be modeled as a stage on the way to writing.
- Even once tax records of amounts paid were kept, rulers would need to associate each taxpayer with a payment record. This would require some unique token to be associated both with the taxpayer and the payment record. Historically, this has been done with personal seals, or with a "split-tally": a broad, flat stick, marked with notches to indicate an amount paid, then broken across the notches, with payer and receiver each keeping half; because of the irregular break, payers could identify themselves as such. The model would not, of course, need to specify the exact method used.
- A model of the effects of writing would also require a distinction between literate and illiterate individuals. In the simplest case, all those (or all males?) born into literate households would become literate.
- Initially, literacy would be restricted to members of the elite. However, if the size of the elite was limited (absolutely or in relation to total population), then the model would need to incorporate recruitment to the elite when there were spare places – and expulsion from the elite when too numerous.

If literate parents had some chance of passing on their literacy, there might emerge a significant non-elite but literate population. This still does not suggest any specific mechanism for increased literacy to reduce hierarchy as suggested by [10]. That might require a more general model of social change. But it seems feasible that the literate might be able to access additional sources of income – acting as scribes to send messages to contacts in other villages, or as traders, who also need to keep records once their activities grow beyond a certain scale. So this does suggest the possible growth of a "middle class", which might then be able to wring concessions from the elite, perhaps in alliance with the masses.

III. Preindustrial Distance Communication

In non-literate societies without some substitute for writing such as knotted string records [8], communication can only occur when communicator and receiver are in the same place at the same time, with the exception of waymarking and other forms of environmental modification, and of more limited forms of message-passing such as signal beacons, which can convey a simple message specified in advance. A partial exception is provided by the "talking drums" of west Africa [12], [13], which were used to convey messages of some complexity over distances of several kilometers, although requiring considerable redundancy, and being dependent on the tonal nature of local languages. Drums producing two distinct tones reproduced the tonal aspects of phonemes – and only those. To overcome the resulting ambiguity, both standardized phrases, and repetition and elaboration of the message in different words could be used. In effect, messages were sent by a whole village to all the surrounding villages; they could not be directed to a specific person or settlement. One can imagine that this system gave its users considerable advantages in summoning help, sending warnings, and arranging meetings, but whether sufficient detail of how the drums were employed remains to inform a useful agent-based model is doubtful.

A more feasible target for modeling might be military and naval flag signaling, especially as there is a body of expertise in simulating battles as part of the computer gaming industry, and detailed records of, for example, the standard British and American naval flag signals at various times. A partial bibliography focused on the US Navy is available at [14].

It is puzzling that visual methods for conveying detailed messages rapidly across long distances, did not develop earlier than they did. Late 18th century Revolutionary France pioneered the development of the optical telegraph, a system of towers, each surmounted by two movable metal arms mounted on a rotating bar, which could be used to signal letters and numerals [15]. The idea spread to much of western Europe, but nothing about the technology should have been impossible to produce centuries or even millennia earlier, and could surely have been useful to the rulers of earlier states, which did put considerable resources into maintaining corps of royal messengers and their horses. Possibly a detailed agent-based model of the optical telegraph as it was finally developed and used would cast light on this question.

IV. Paper, Printing and Public Opinion

As [10] notes, profound changes in transmission topologies were produced by innovations building on the development of writing, including simpler writing systems (for example, alphabetic scripts), the introduction of different writing materials (notably parchment and paper) which brought down the cost of producing written materials, and movable type printing. Positive feedbacks operated between increases in the number of literate people, rising demand for texts for them to read, and reduced costs of producing them.

The movable type printing press in particular, invented by Gutenberg around 1440, has frequently been identified as a key innovation, making mass literacy possible, and setting Europe on the road to modern science and technology, and consequent global predominance. The European printing press spread rapidly - by the end of the fifteenth century there were printing presses in nearly 300 European cities [16], over a thousand in Germany alone [17].

The effects of this innovation look like an obvious target for agent-based modeling. With printing, it becomes possible for a large number of works to be accurately reproduced in large numbers, and many more individuals and groups can circulate their ideas – although they do need access to printing technology and distribution networks. Only those who are literate can be directly influenced – so they form an intermediating group between the producers of texts and the illiterate, and something reasonably described as "public opinion" can form. These changes in the topologies of transmission could be expected to have profound and widespread consequences.

However, two considerable caveats are necessary. First, Gutenberg's invention was only feasible and useful because of a series of earlier European innovations, and imports from elsewhere: paper manufacture, from China via the Muslim world [18] and the application of water-power to reduce its cost, metallurgical discoveries that made Gutenberg's press workable, alphabetic script itself (movable type printing was first developed in 11th century China, but the techniques are different enough to make independent European invention probable [19], and the nature of Chinese script made it much more difficult to exploit), improvements in the readability of books due to the medieval schoolmen [20], and the development of universities which had already raised the demand for multiple copies of a range of texts [18]. Second, printing technology itself did not propel all societies with access to it toward modernity. Reference [21] notes that by some estimates, even by 1800 more material had been written and printed in Chinese than in all other languages together, while [22] notes that the Ottoman Empire's capital, Istanbul, acquired a printing press in 1726, but by 1815 only 63 titles had been printed there. The complex interactions between technological innovations and social processes, rather than the effects of a single "key" innovation, would therefore need to be the target of modeling.

V. Electrical Networks: from Telegraph to Internet

The 1860s saw the most radical change in the speed of long-distance communication ever – and one that will never be surpassed, unless current physics is fundamentally wrong. In 1864 and 1865, the first successful intercontinental telegraph cables were laid, from Britain to India and to the USA [15]. The latter cut the time to send messages between the old and new centres of capitalist development from over a week to a few minutes. Those who made extensive use of telegraphs were always a small minority – primarily they were a tool of governments, and businesses large enough to need rapid long-distance communication. According to [10], this should have favoured an increase in hierarchy and authoritarianism, but in fact telegraphy's spread coincided with the growth of democratic and pluralist ideas and institutions in the industrializing countries building telegraph infrastructure – although also of European imperialism and militaristic nationalism, culminating in World War 1. The agents in any agent-based model of the spread of the telegraph would probably need to be states or corporations, not individuals.

Between the spread of the telegraph and the advent of the Internet, there have been several waves of innovation in electrical or electromagnetic communication technologies, notably telephone, radio and television. The existing agent-based simulation work most relevant to these innovations is the extensive literature on simulations of opinion dynamics [23-25]; but this has almost all been highly abstract, dealing with a single, unspecified issue on which a population of cognitively very simple agents holds either one of two discrete opinions or a continuous range of opinions represented numerically, and often with a fixed network of contacts between agents. This abstraction has been criticized for its failure to relate to significant issues in social science [26]. A recent attempt to increase the realism of opinion dynamics simulations by modeling some features of argumentation is described in [27]; this approach is perhaps more likely than most opinion dynamics studies to be relevant to assessing the effects of historical changes in communications technology.

Reference [28] extends the usual paradigm of opinion dynamics agent-based simulations by adding either one or two "mass media" sources of opinion to the usual binary exchanges between agents, finding different regimes according to how willing the agents are to move closer to opinions different from their own, and whether there is one mass medium propagating a "central" opinion, or two propagating opposing "extreme" opinions.. There does not appear to have been significant subsequent work in this area.

Finally, the internet and social media have made many-to-many communication available to very numerous people. There is a large literature on internet social networks, but little simulation work on their broader effects: exceptions include [29], which introduces a distinction between agents who are and are not internet-connected but is otherwise a standard opinion dynamics abstract treatment; and [30], which examines the claim that the internet and related recent innovations in communications technology make organizing protest movements easier, finding that whether they do so depends on cultural and political factors.

VI. Conclusions

This extended abstract has covered a lot of ground in a rather superficial survey, the intent being to argue that there is an important set of related historical topics related to communication technologies, that form a suitable set of targets for agent-based modeling. These topics range from prehistoric small-scale societies to the twenty-first century, and together constitute a novel approach to the project of constructing a "re-unified historical social science" [31].

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Rise and decline process of online communities: Modeling social balance of participants.

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***Abstract*—Some online communities like Friendster had declined, and some of the others are said to be declining. Recent research has revealed the mechanism of decline as well as that of rise in each community. However, no comprehensive research has yet revealed the difference in declining mechanisms of each communities. We considered the online communities as networks of users and topics and defined behavior of users using Heider's balance theory. Users in our model are in a dilemma, stuck between topic preference and the balance between neighboring users. How the user behaves in the dilemma, his/her strategy, disseminates to other users. We simulate online communities using the model and observe the rise and decline of different kinds of communities. As a result, we found that two types of communities tend to develop with many users: communities in which the topic changes dynamically (FreeTopic-type) and communities in which the topic changes gradually (Topic-type). However, the property of each community and behavior of users are different. We found by simulation that the collaborative behavior of users happens very frequently in the FreeTopic-type community, in which users consider the balance between each other rather than their topic preference. As a result, the FreeTopic-type communities do not often crash (i.e. quickly lose users). In addition, we confirmed that the postings about a topic are either negative or positive in the FreeTopic-type community. On the other hand, in the Topic-type community, simulation results indicate that users prioritize their preference for a topic. This causes the community to crash very frequently. However, users in such a community are found to obtain more benefits than in FreeTopic-type communities. It can be said that, after crashes occur, the community is still relatively beneficial for some users who remain.**

I. Introduction

ONLINE communities and SNS services have become very popular. For example, in the USA, 67% of internet users use Facebook and more than 10% users use twitter and Pinterest [1]. Online communities demand the new kinds of media that can allow users to give each other the information they need [2]. However many communities, even large ones such as Friendster, have declined [3]. The number of users of Myspace has been decreasing [4], and some researchers argue that Facebook, which has more than one-billion active users, is also declining [5]. It is essential to reveal the mechanism of the declining process of online communities to stabilize them because they are of increasing social importance.

Online communities decline in various ways. The declining processes of Friendster and Myspace have been slower than their developing processes [5]. However, some content-oriented communities, such as small communities on YouTube, decline even more faster [6][7].

To reveal the declining process and estimate future trends, many models of online communities has been proposed. Most recently, Cannarella and Spechler have predicted the decline of Facebook using an irSIR model (recovery SIR model) [5]. They consider the entrance/stay/exit process of an SNS in the same way as the suspect/infect/recover process of the SIR model and calculate the probability of transitioning between states using the actual data. However, many critics, including a researcher working with Facebook, have argued against their conclusions because the research does not reveal the relationship between user behavior and the mechanism of decline. Other researchers have made a more detailed model of SNS. Liu et al. classified the users of SNS into four states: New Joining, Active, Active&Inactive, and Quiet)[8]. They estimate the property of bidirectional transition between each state and predict the number of users in the community. Furthermore, other researchers have focused on the developing process [9][10][11] and declining process [3] by investigating relationships in the macroscopic evolution of communities.

As shown above, researchers have revealed macroscopic dynamics of communities. However, the relationship between such collective dynamics and behavior of users is not clear. Furthermore, each research is ad-hoc and does not give a comprehensive interpretation of online communities. Online communities are very different in scale, network structure, range of topics, and so on. We thus propose a comprehensive model that can explain the evolution of a wide variety of communities and simulate the developing and declining processes.

In the model, we focus on the psychological state of users in a community. For example, researchers say Facebook users become tired of clicking the Like button, which expresses approval of other users' postings [12]. Even if your friend posts something that does not interest you, you sometimes push the Like button. In this case, the user is caught in a dilemma between their lack of interest in a friend's posting and the relationship with the friend. When you do not like your friend's posts, there are three solutions: going along with your friend, being silent, or giving your opposing opinion.

Such a situation is explained with Heider's balance theory [13]. In this theory, the psychological stability between three objects can estimated in a simple equation so that the three objects can behave more stably. In the online community, the three objects are a user, a user's friend, and a topic. Heider's balance theory has been verified in experiments [14] and improved with some small extensions [15]. Owing to the simplicity and correctness of model, the theory is used for describing the mechanism of group formation [16][17], predicting likes or dislikes between two users in a community [18], and investigating the process of forming opinions [19]. Thus, we use Heider's balance theory for describing user behavior in an online community.

In addition, we take into account the polarization of opinion in online communities. Cass Sunstein has claimed online communities cannot avoid this polarization without appropriate rules [20][21]. You can feel a unique atmosphere in online communities. For example, people talk only positively about things or only discuss in a serious manner. There are questions about how user interaction forms the atmosphere, what kind of conditions impact the formation of an atmosphere, and what kind of atmosphere is possessed by communities that do not decline.

We propose a comprehensive agent based model of an online community that can explain the developing and declining processes. Using the model, we first investigate what kinds of communities are likely to develop. Second, we investigate the mechanism of polarization of postings. Finally, we classify declining processes and estimate the probability of each process in different conditions (range of topics and affiliation of opinion).

II. Model

We describe the model of online communities using the network of the users and topics.

Balance theory, which was proposed by Heider in 1956 [13], is the generalization of an equilibrium between a person and surrounding objects. This theory considers the likes and dislikes of three objects. The objects can be three people or two people and a subject. The two attitudes, like or dislike, are represented by signs of + or - [(Fig.1). Shown in this figure, when the multiplication of the signs is +, the triangle is stable and people in the triangle also feel stable. For example, as shown in the upper half of [Fig.1], triangles composed of a three "likes" or two "dislikes" and one "like" are stable. The latter situation means you do not like what your rival likes. On the other hand, as shown in the lower half of Fig.1, when the multiplication of the signs is -, the triangle is unstable. For example, you like what your friend dislikes.

A. User Dilemma in Online Communities

In online communities, users behave in accordance with the balance of Heider's triangles and with preferences for different topics. If these preferences are different, the user is caught in a dilemma. We make a model that can illustrate this situation.

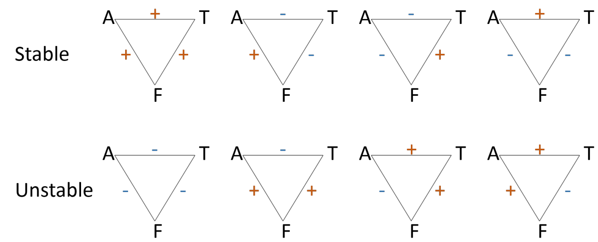


Fig. 1. Heider's balance theory. The model is composed of A (Person A), F (Friend), and T (Topic). The upper and lower rows show stable and unstable situations.

The balance theory is suitable for online communities because they are composed of users and topics. Online communities can be described as networks composed of topics and users (Fig. 2). In this figure, the three topics and seven users are connected. The edges between users can be described as the value of + or -. The edges between a user and a topic mean the user is a participant of the topic and may take the value of P (post positive), N (post negative), or S (silent).

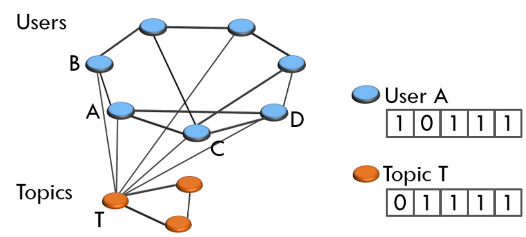


Fig. 2. Network structure of online community.

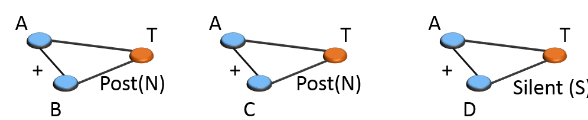


Fig. 3. Example of Heider's triangles related to User A.

A user recognizes all triangles to which he/she belongs. In Fig.2, user A recognizes the three triangles in the network. The networks are shown in Fig. 3. User A calculates the balance of his/her postings, the friend's posting, and the relationship with the friend. Thus, if the friend does not post about the topic, user A does not calculate the balance (right triangle in Fig.3). User A estimates that he/she can obtain better balance in the two triangles, P (post positive) or N (Post negative). In this case, N is the solution in both triangles, so users tend to post N.

However, a user also considers his/her preference to the topic. The user's interest and content of the topic are defined by L-length bits. A user's interest and content of topics are the same length. To represent the conversation in real communities, the L-length bits of a topic change at each step. The similarity of both L-length bits means the user's preference to a topic. This is defined in Eq.1 using the Kronecker productδ in the range -1 to 1.

$$pr(A,T) = \frac{\sum_{i=1}^{L} \delta_{I_A I_T}}{L} * 2 - 1 \quad (1)$$

In Fig.2, user A's preference to topic T is $pr = 0.2(> 0)$. Therefore, user A is satisfied when he/she posts positive (P). However, user A is under pressure to post negative (N) in the balance of triangles, so he/she is caught in a dilemma. In this case, he/she has three solutions: post positive (P) to prioritize the preference to the topic, stay silent (S), or post negative (N) to prioritize the preference to balance.

B. Strategy in the Dilemma

To generalize the dilemma discussed above, agents are placed in four states, considering the balance of Heider's triangle and preference to topics (in the status section in Table I). The former is described as + or - corresponding to the preference to the topic defined in Eq.1. If $pr > 0$, the state is + and - in the opposite case. The latter is also described as + or -. This means which is a better balance in Heider's triangles. If P (Post Positive) is better than N (Post Negative), the state is +. Each user has a strategy corresponding to the four states. In each state, a user can behave in three ways: P, S, or N. Therefore, the number of combinations of the strategy is $3^4 = 81$. The strategies are shown in Table I. For example, when status = 3, the agent with the NNSP strategy selects (S).

TABLE I
STATUSES (#1-#4) AND EXAMPLES OF STRATEGY.

	#		1	2	3	4
Status	Preference to topic		-	-	+	+
	Balance of Triangle		-	+	-	+
Strategy	NNPP	Self	N	N	P	P
	NSPP	Self	N	S	P	P
	SSPP	Self	S	S	P	P
	NNNP	Coll	N	N	N	P
	NSNS	Coll	N	S	N	S
	NSNP	Coll	N	S	N	P
	NSSS	Coll	N	S	S	S
	NSSP	Coll	N	S	S	P
	NPNP	Coll	N	P	N	P
	NPSP	Coll	N	P	S	P
	NPPP	Coll	N	P	P	P
	SSSS	Coll	S	S	S	S
	SPPP	Coll	S	P	P	P
	NNSN	Irra	N	N	S	N
	NNPN	Irra	N	N	P	N
	NNPS	Irra	N	N	P	S
	NSNN	Irra	N	S	N	N

The 81 strategies are classified into three groups: selfish (Self), collaborative (Coll), and irrational (Irra). The agent with a Coll strategy prioritizes the balance rather than its topic preference. For example, an agent with an NPNP strategy posts Positive when it recognizes balanced triangle, even if the agent has a negative opinion. On the other hand, the agent with a Self strategy such as NNPP prioritizes its topic preference. For example, the agent who has an NNPP strategy behaves only on the basis of its preference to topics. However, a PPNN strategy is irrational, because the agent with a PPNN strategy will post (P) in state #1 but post (N) in state #3. These strategies are classified below.

First, we describe the determination method of a Coll strategy. The order of this strategy is assumed to be $N < S < P$. If the strategy of #1 is larger than that of #2 and #3 and that of #4 is less than that of #2 and #3, the strategy is irrational (Irra).

Furthermore, the strategies other then $Irra$ are divided into $Self$ or $Coll$ in the following ways. We define the distance between two strategy strings as the sum of the distance between corresponding strings of each state #1 - #4. We assume the distances of N - S and S - P are 1 and that of N - P is 2. In addition, we assume the most selfish strategy is NNPP and the most collaborative one is NPNP. The strategy that is further from NNPP and closer than to NPNP is the $Self$ strategy.

The $Irra$ strategy seems to be rare in real communities. However, we use all 81 strategies to confirm that an Irra strategy is not suitable for any kind of community and that it will be eliminated within the process of community development. In the model, agents update the strategy in each step, and the strategy of an agent who gains many benefits tends to spread. For example, if the agent who has a $Coll$ strategy gains many benefits, the $Coll$ strategy will spread and the atmosphere of the community will be collaborative.

C. Steps

The flow of the model is shown in algorithm 1. First, a network with agents and topics is constructed. Subsequently, in each step, agents post, calculate benefit, exit, and update strategy in a random order. The steps of the model are described in detail in Algorithm 1.

Algorithm 1 Online communities

```
{Initialization} Making network of topic and agent
while NumberofAgent >= 10 do
  for Each Agents by random order do
    {Step 1} Posting by strategy
    {Step 2} Calculate benefit B
    if B < 0 then
      {Step 3} Exit Agent
    else
      {Step 4} Update strategy
    end if
  end for
  {Step 5} Entrance of Agent
  {Step 6} Update Topic
end while
```

1) Initialization: At first, a perfect network with 10 agents and one topic is constructed. All have strong connections to each other at the beginning of the community. In this paper, we consider only one topic and all relationships between agents are good (+) for analyzing the fundamental behavior of the community.

The strategy of an agent is chosen randomly from the 81 strategies in Table I. Each L-length bit of a topic is 0 and that of an agent is defined as below. Interests of each user are determined completely at random if deviation is low ($dev = 0$) and permanently fixed if deviation is high ($dev = 1$). Initially, all bit sequences of all users are 0. Then, all bits of all users are changed to 1 in probability $(1 - dev)/2$.

2) Step 01 - Posting by Strategy: As defined in Section II-B, an agent recognizes state #1 - #4 by the topic preference and the balance of Heider's triangle and decides its behavior by its strategy. The behavior is post negative (N), silent (S), or post positive (P).

3) Step 02 - Calculate Benefit: Agents in a dilemma between topic preference and balance of Heider's triangle cannot gain much benefit. To express the benefit of such situation, we defined the utility function as below. When an agent posts N or P, the benefit for the agent is the sum of the benefit from its posting B_{po} and the benefit from its preference B_{pr} after subtracting the cost of writing C_{po} (Eq.2). If the agent is silent (S), the benefit is B_{pr}. Thus, the benefits B for the agent's behavior are shown as follows:

$$B = \begin{cases} B_{po} + B_{pr} - C_{po} & \text{(if agent posts (N or P))} \\ B_{pr} & \text{(if agent silents (S))} \end{cases} \quad (2)$$

B_{po} means the external balance of agent, friend, and topic. If the agent's post achieves a balanced triangle, B_{po} becomes higher. First, we describe the definition of $Po(A,T)$, $R(A,F)$, and N_t. $Po(A,T)$ take the values of -1 (when agent A posts positive (P) to topic (T)), 0 (when agent is silent (S)) and 1 (when agent posts positive (P)). $R(A,F)$ take the values of -1 (when A and F have a bad relationship) and 1 (when A and F have a good relationship). In addition, N_t is the number of triangles to which the agent belongs. B_{po} of agent A is the average of each Heider's triangle's balance, which is a multiplication of posting to the topic $Po(A,T)$, the relationship $R(A,F)$, and $Po(F,T)$ (Eq.). For example, if A belongs to one triangle, in which A posts positive (P) to T ($Po(A,T) = 1$) , A and F have a bad relationship and F posts positive (P) to T ($Po(F,T) = -1$). The benefit of A B_{po} is $1 \times 1 \times -1 = -1$.

$$B_{po} = \frac{\sum_{triangle} Po(A,T) \times R(A,F) \times Po(F,T)}{N_t} \quad (3)$$

B_{pr} means the internal balance of agent, friend, and topic (Eq.4). In this case, an agent considers his preference (Eq.1) for calculating his benefit. In the situation in which the agent posts negative (N) to a topic which it prefers, we assume that the agent obtains no benefits except for the cost of writing $-C_{po}$ on average. For this assumption, it is necessary to set $B_{po} + B_{pr} = 0$ on average. We assume the B_{pr} is doubled in Eq.4. This is because the average preference for topic ($E(Pr(A,T)) = 0.5$) in Eq.4 is half of the ($P(A,T) = 1$) in Eq.3 when comparing Eq.4 and Eq.3.

$$B_{pr} = \frac{\sum_{triangle} Pr(A,T) \times R(A,F) \times Po(F,T)}{N_t} \times 2 \quad (4)$$

As stated above, if an agent posts P or N, the benefit is the sum of the external balance calculated from its posting B_{po} and internal balance calculated from its preference B_{pr} from subtracting the cost of writing C_{po}. If an agent stays silent (S), the benefit comes from internal balance B_{pr}.

4) Step 03 - Exit Agent: The agent exits from the community when the benefit of past steps B_{tot} (Eq.5) is less than 0. B_{tot} is not a simple totaling of B. The agent will forget the benefit of past steps by a constant factor of d. In Eq.5, $B(i)$ is the benefit in the i step and $step$ is the current step.

$$B_{tot} = \sum_{i=0}^{step} B(i) \times d^{step-i} \quad (5)$$

When an agent exits, the edge that contains the agent and the triangle to which the agent belongs will disappear from the model.

5) Step 04 - Update Strategy: Each agent updates its strategy to make it similar to that of users who obtain large benefits. An agent chooses one agent with a probability proportional to the past benefit (B_{tot}) and imitates its strategy. The previous strategy is crossed with the strategy of a chosen agent in accordance with the genetic algorithm (GA). In addition, a strategy changes 1 bit randomly with a probability of P_m. This probability means sensitivity to exogenous effects.

6) Step 05 - Entrance of Agent: In this model, agents enter the community at each step. At every step, four new users enter the community. All new joiners are connected to the topic. To reproduce the heavily linked node in the real communities, they connect to A_d friends in accordance with the BA [23] model. Users choose A_d agents with a probability proportional to the number of links that the existing agents already have.

7) Step 06 - Change Topics: If people do not lost interest in the same topic, the communities will continue for a very long time. However, the topic is changed by internal and external effects. To describe this phenomenon in the model, the L-length bits of a topic will be changed by T bits at each step. All randomly selected T bits of a topic will change the probability of 0.5. If T is not the integer, the selected number of bits of a topic is the sum of the number of T and 1 at the probability of a fraction less than one. With this, the model reproduces the dynamics, the balance collapses due to the transition of topics, and the balance is reconstructed by an agent's adaptation of its behavior and strategy.

III. Simulation and Verification

IN this section, we simulate the community using the model for examining whether it exhibits the same behavior of real online communities.

A. Parameters and Simulation Conditions

To simulate various types of communities, we observe the evolution of a community by changing the parameter of changeable bits of topics at each step T. If T takes a lower value, the topic changes gradually. Thus, we name this a Topic-type community. On the other hand, if T takes a higher value, the topic of the community changes greatly at each step. This means the agents of a community change the topic easily, so we name this a FreeTopic-type community.

In this paper, for studying basic behavior of the model, the number of topics is set at one. Other parameters are shown in Table II.

The deviation of user interest dev is set to 0.1 considering online communities in the real world. This is because users in the real online communities such as LinkedIn, Facebook, and Myspace specify their age, nationality, and academic qualifications in addition to their interests. [24].

TABLE II
FIXED PARAMETERS OF SIMULATION

Parameter		Value
T	Transition of topics (Changable bits of topic at each step)	Variable(1-15)
dev	Deviation of user interest	0.125
A_{degree}	Average connecting ratio	12
C_w	Cost of Writting	0.07
U_{add}	Number of users added at step	4
d	Decay ratio of past benefit	0.75
$P_{mutation}$	Mutation ratio of strategy	0.01

B. Example of Simulation Results

We simulate the model under the conditions defined above and observe the process of rise and decline of communities. The simulation results are shown in Figs.4 and 5, where the horizontal axis shows the step from the start and the vertical axis is the number of agents.

As shown in Figs.4 and 5, the rise and decline of a community is observed under the conditions of $T = 1$ and $T = 15$. In addition, the number of agents under the condition of $T = 1$ (Topic-type) seems to have larger variations than that of $T = 15$ (FreeTopic-type). We will verify their mechanisms in the next section.

The distribution of the number of posts is shown in Figs.6($T = 1$) and 7($T = 15$). The horizontal axis indicates the number of postings and the vertical axis indicates the number of corresponding users. The distributions of the posting counts follow power-low distribution, which is observed in real online communities [25].

C. Elimination of Irrational Strategy

Users who have an irrational strategy (Irra), defined in Table I, are considered to be uncommon in real communities. We confirm that an irrational strategy (Irra) is not suitable for a community by the following simulation. We observe the ratio of an agent that has an irrational strategy (Irra) through the entire step as the topics T transition from 1 to 15 by 0.5. In the results, the average ratio of an Irra strategy is $34 - 38\%$.

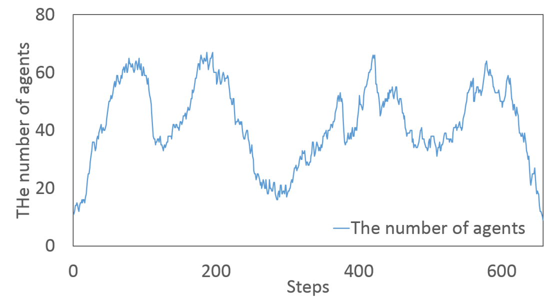


Fig. 4. The evolution of online community under the condition of $T = 1$ (Topic-type)

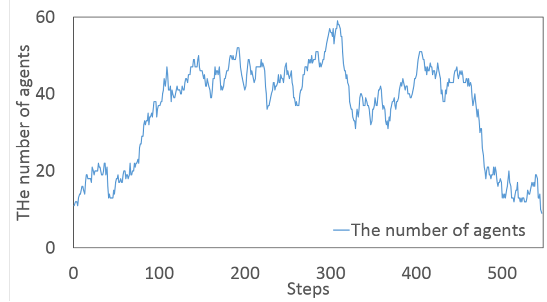


Fig. 5. The evolution of online community under the condition of $T = 15$ (FreeTopic-type)

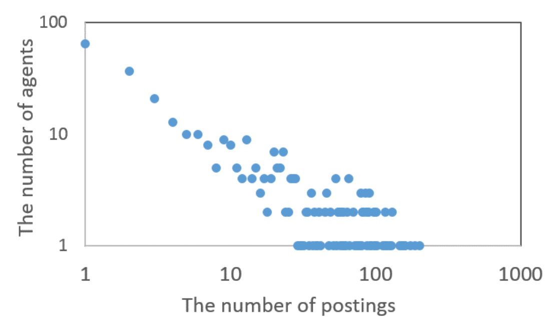


Fig. 6. Distribution of the number of postings of agents under the condition of $T = 1$ (Topic-Type)

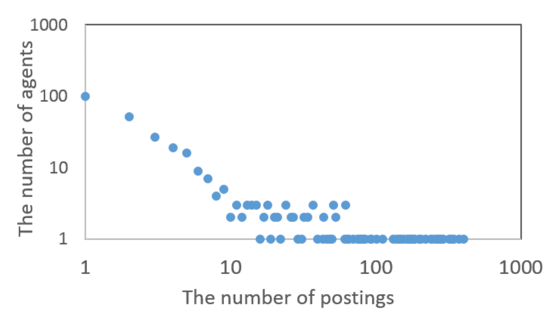


Fig. 7. Distribution of the number of postings of agents under the condition of $T = 15$ (FreeTopic-type).

The ratio of an Irra strategy is relatively low considering the percentage of the Irra strategy, $61/81 = 75\%$, in the initial users and users added at each step.

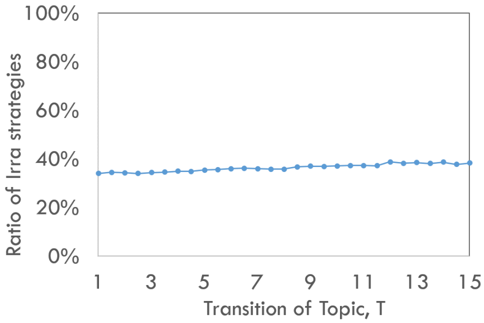


Fig. 8. Ratio of Irra strategy agents to all strategy agents

The users of Irra are considered to change their strategy or exit, since they cannot gain much benefit. In the real world, the proportion of the people who use such a strategy cannot be high. Thus, the model can illustrate the selection process of eccentric users.

According to the results above, this model based on balance theory reproduces the rise and decline of communities without cessation of adding new users or the explicit mechanism of losing interest. Power distribution of the number of users and the elimination of irrational strategy are characteristics of a real community.

IV. Rise and Decline of Community

To investigate the development and decline in different types of communities, we observe the communities' evolution process through changing the transition of topics T. The lower value T is a Topic-type community, such as a bulletin-board system for an exclusive community, and the higher value of T means a FreeTopic-type community, such as Facebook and Myspace.

In this chapter, we simulate the evolution process of communities through the entire step by changing the transition of topics T from 1 to 15 by 0.5. We did not simulate under the condition of $T = 0$, because the topics is not fixed to a specific one in real communities.

A. Average Number of Users and Duration of Community

First, we observe the average number of users and the duration of a community in a single simulation by changing the transition of topics T from 1 to 15 by 0.5. The duration is the number of steps between the first and final steps. The first step is defined as the step in which there are more than 10 users. A single simulation is finished when there are fewer than 10 users. The results are shown in Fig.9. In this figure, the horizontal axis indicates transition of topics T, and the vertical axes indicate duration (left) and the number of users (right).

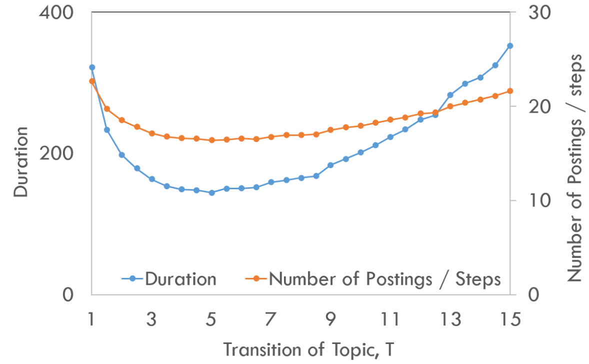


Fig. 9. Duration of communities and average number of postings per step. T is set from 1 to 15

When the transition of topics is high ($T = 15$) or low ($T = 1$), the duration of community becomes long and the average number of postings becomes high (Fig.9). The results show that there are two different conditions for growth of a community. This means the Topic-type ($T = 1$) and FreeTopic-type ($T = 15$) communities tend to exist over a long period.

B. Decline of Community

Subsequently, we observe the decline of a community with changes in the parameters of transition of topic T. In the preceding analysis, the two types of community, Topic-type or FreeTopic-type, both have a chance to grow large. We investigate the decline process of both types below. To investigate the decline process, we use two indexes: the ratio of the number of postings after / before peak and the probability of a crash. The peak is defined as the step that has the highest number of topics through all steps. When there are more than two steps that have the highest number of topics, the peak step is the last one.

1) Continuity of Community After Peak: We observe the ratio of the number of postings after and before the peak with changes in the transition of topics T from 1 to 15 by 0.5. The results are shown in Fig. 10, where the horizontal axis indicates the transition of topics T, and the vertical axis indicates the ratio of postings after and before the peak.

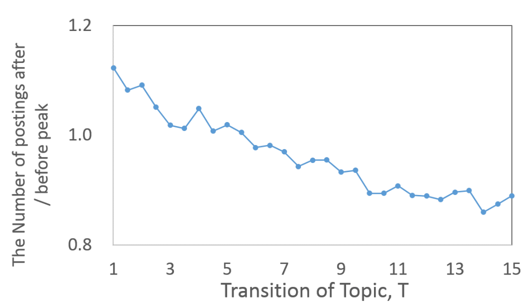


Fig. 10. Ratio of postings after / before peak

As shown in Fig.10, as the transition of topic T becomes larger, the ratio of postings after and before the peak becomes smaller. This means the Topic-type communities last longer than FreeTopic-type communities.

2) Probability of Crashes: Online communities occasionally lose many users in a short period. The causes are exogenous factors, such as server errors and holiday periods [26], and endogenous factors. We investigate the probability of endogenous factors of crashes by changing the transition of topic T.

A crash is defined as the number of users decreasing to less than half or 70% within 10 or 20 steps. We investigate the probability of crash in one simulation step by changing parameter T from 1 to 15 (Fig.11).

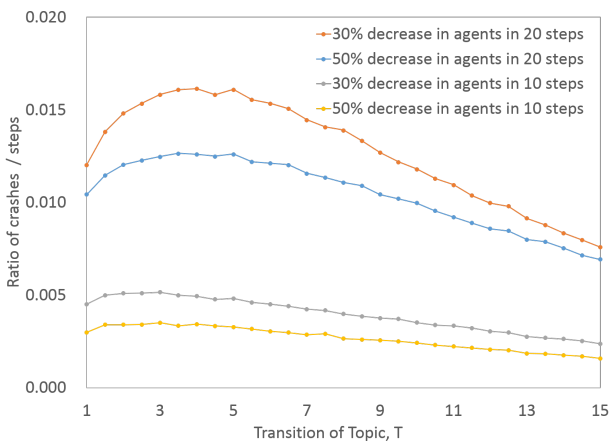


Fig. 11. Probability of crashes

As shown in Fig.11, in each four definitions of probability of a crash, the community with lower T (Topic-type) suffers crashes with high frequency. As the T becomes larger, probability of crash mostly becomes smaller under the condition of $T = 3$.

The above analysis clarifies that the Topic-type community and FreeTopic-type community both have a chance to grow large. However, the processes of decline are different. The Topic-type community has large amount of postings after a peak in spite of highly frequent crashes. Two questions remain in the results: 1) Why do the Topic-type and FreeTopic-type communities have different decline processes? 2) Why do topic-type communities continue long after a peak in spite of frequent crashes? In the next section, we analyze the mechanism of evolution of these communities.

V. The Mechanism of Rise and Decline of Topic-type and FreeTopic-type Communities

To investigate the difference between the decline processes of Topic-type and FreeTopic-type communities, we compare the distribution, selection of strategy, and the average benefit of agents of the Coll, Self, and Irra strategies.

As a result, in FreeTopic-type communities, the concentration of strategies occurs and agents stably gain benefits from the community. This lead to infrequent crashes. Furthermore, the average benefits of agents are larger in Topic-type communities than in FreeTopic-type communities, leading to the longer life of Topic-type communities in spite of their highly frequent crashes.

A. Concentration of Strategy and Stability of Community

In the model, the agent chooses its behavior by its strategy in the dilemma of the balance of Heider's triangles and topic preference. There are 81 strategies divided into three types: selfish (Self), collaborative (Coll), and irrational (Irra). We investigate the distribution of these three strategy types by the transition of topics T. The ratio of Self strategies to Self and Coll strategies is plotted in Fig.12.

Under the condition of less transition of topic T, the ratio of agents who have Self strategies is relatively higher (Fig.12). Agents with a Self strategy, which means they choose their behavior on the basis of topic preference, are eliminated under the condition of a larger transition of topic T. It is considered that the neighbor's postings dynamically change step by step and the balance of Heider's triangle is easily broken at each step. On the other hand, in the Topic-type community, the balance of Heider's triangle of agents who have a Self strategy is not easily broken.

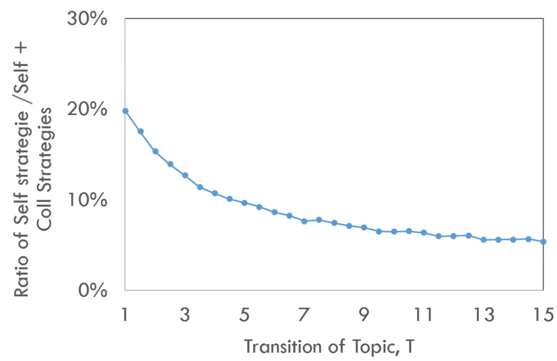


Fig. 12. Ratio of Self strategies to Self and Coll strategies

Subsequently, we investigate the concentration of strategies. The ratio of the top five selected strategies among all 81 strategies that have a higher ratio for the entire term is calculated by changing the transition of topic $T = 1, 8, 15$. In Fig.13, the vertical axis shows the ratio of top N strategies among all 81 strategies.

As shown in Fig.12, in the FreeTopic-type community (larger transition of topic T), the certain strategies tend to predominate. In the community with middle-level transition of topic $T = 8$, the ratio of the concentration of strategies is also relatively high.

To summarize the analysis above, the ratio of selfish strategies (Self) is relatively higher in the Topic-type community, though diverse types of strategies remain. On the other hand, in the FreeTopic-type community, the agents are selected that use certain strategies but not Self strategies. It could be said that, in the FreeTopic-type community, agents collaborate by

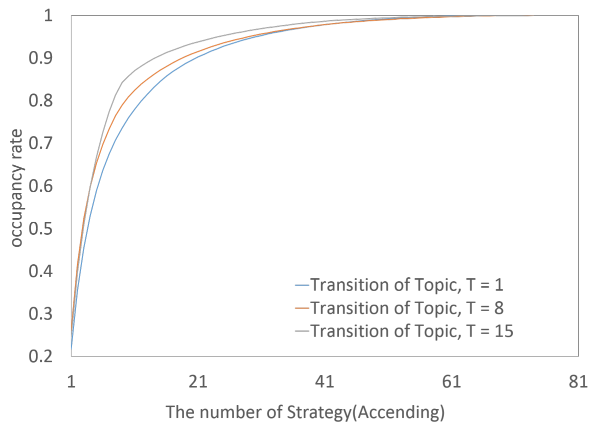


Fig. 13. The ratio of top N strategies among all strategies in a single simulation

considering the balance of Hider's triangle with their neighbors. This represents the process of a real online community in which the users cooperate with others and maintain their relationships by withholding what they want to post or offering an opinion they do not actually hold.

The benefits of agents are considered to be stable in the FreeTopic-type communities because certain strategies make up most selected strategies. In such situations, larger amounts of agents prioritize collaboration while neglecting their topic preference. Accordingly, they do not frequently change their posting behavior to the community and the frequency of crashes is low.

B. Average Benefits for Agents

We compare the average benefits of agents in Topic-type and FreeTopic-type communities or the entire period by changing the transition of topic T. The results are shown in the Fig.15, where the horizontal axis indicates the transition of topic T and the vertical axis indicates the average benefit of agents through the entire period.

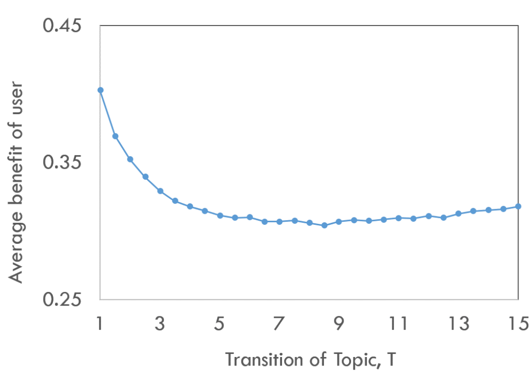


Fig. 15. Average benefit of agents

As shown in Fig.15, as the transition of topics T becomes larger, the average benefit becomes smaller. In Topic-type communities, the ratio of selfish users is relatively high (Fig.12). It is considered that agents tend to post considering their preference and that the positive/negative tendencies of neighborhood postings do not change dynamically due to low transition of topics. Thus, the agent obtains many benefits from its posting B_{po} and the benefit from its preference B_{pr}.

The results in the preceding section show the Topic-type community continues for a relatively long period after the peak in spite of highly frequent crashes. This long life is considered to be due to the many benefits for agents (Fig.15) and the diversity of strategies (Fig.13). Even if communities crash and neighborhoods exit from communities, some agents obtain more benefits and remain. This tendency can be observed in Fig.4. As shown in Fig.4, in the Topic-type community, some agents remain after a crash and the community rises again.

On the other hand, in a FreeTopic-type community, agents obtain relatively fewer benefits (Fig.15) and certain strategies predominate. The low ratio of postings after the peak (Fig.10) can be explained as follows: if some agents exit the community, a large number of neighborhood agents, which have the same strategies, lose the benefit of the balance of Heider's triangle. Therefore, the neighborhood agents are likely to exit subsequently.

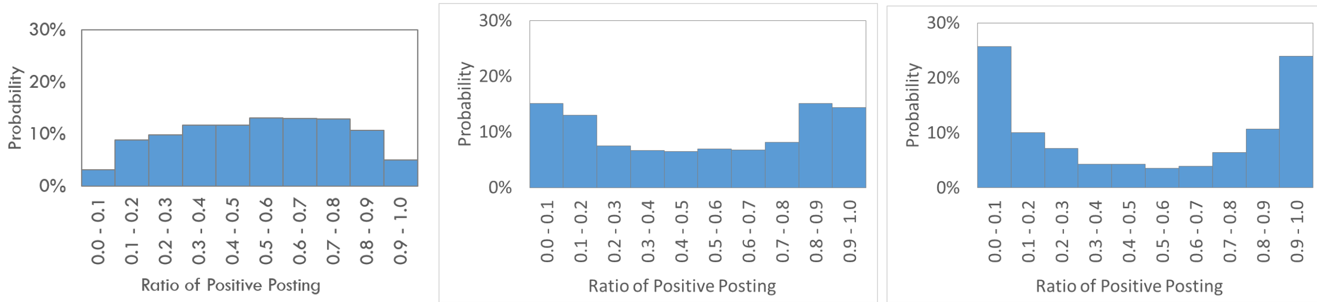
The reason for relatively fewer benefits in FreeTopic-type communities is conflict between agent's topic preference and the balance of Heider's triangles. There is a large cluster of certain strategies, and agents behave considering the balance of Heider's triangles rather than their topic preference. Therefore, the agent obtains benefits from its posting B_{po} in spite of the few benefits from its preference B_{pr}

VI. Deviation of Posting for the Topic

THE above analysis reveals that the mechanism of the rise and fall of a community differs between the Topic-type and FreeTopic-type communities. In this section, we investigate agents' posts in the community, especially focusing on the deviation towards negative/positive postings. In real online communities, participants' posts sometimes deviate towards negative/positive. The reason for the deviation is considered to be that the strategy to post only negative/positive is spread or that many users who only post negative/positive stay in the community.

To investigate the probability of the occurrence of the deviation of posting, we observe the ratio of positive posts in a single simulation by changing the transition of topics $T = 1, 8, 15$ (Fig. 14). In Fig.14, the vertical axis indicates the ratio of positive posts and horizontal axis indicates transition of topic T.

As shown in Fig.14(a), the ratio of positive posting is close to 0.5 under the condition of $T = 1$. In such a community, agents post the same amount of negative and positive postings in a single simulation. On the other hand, as the transition of topics T becomes larger, the ratio of positive postings inclines



(a) Transition of topics $T = 1$ (b) Transition of topics $T = 8$ (c) Transition of topics $T = 15$

Fig. 14. Distribution of the ratio of positive posts through a single simulation under the condition of transition of topics $T = 1, 8, 15$

to 0 or 1. This means the FreeTopic-type community tends to be composed of only positive/negative posts for the topic.

The reason for deviation towards positive postings is that the strategy by which agents tend to post positive things spreads in the community. In this situation, the agents post only positive posts and the benefit from their postings B_{po} (Eq.2) remains stable. The same explanation is suitable for cases of the deviation towards negative postings.

The reason for large deviation of postings under the condition of large T can be considered to be the result of group adaptation. In such situations, the benefit from an agent's preference B_{pr} is unstable because the topic changes dynamically. The strong cluster of agents, who only post positive/negative things, stably benefit from their postings B_{po}. This is considered to the best way to survive in such situations.

According to the above results, the deviation towards negative/positive postings is more likely to occur in the FreeTopic-type community. In such a community, going along with neighborhoods is a good method for staying in the community. As a result, postings for the topic deviate towards negative/-positive. The model shows that peer pressure tends to spread widely in the FreeTopic-type community.

VII. Conclusion

We proposed a model on the basis of balance theory that reproduced the rise and fall of online communities and that clarified their general characteristics, such as the power distribution of postings and the elimination of irrational strategies.

The simulation results indicate two types of communities that will grow large: Topic-type and FreeTopic-type. However, both types of communities have different decline processes. Topic-type communities continue for a long time after they peak, even though they crash relatively frequently. We also investigated the evolution mechanism of Topic-type and FreeTopic-type communities.

The Topic-type communities contain many agents who have selfish strategies. Also, the opinions in postings are not disproportionately positive or negative. In such communities, the ratio of selfish strategies is higher than in FreeTopic-type community. This causes the highly frequent crashes. However, despite these crashes, there is a continuously large number of postings after the peak (Fig.10). In such communities, agents gain many benefits on average (Fig.15) and strategies are highly diverse (Fig.13). After a crash occurs, a relatively large number of agents gain benefits from the community.

On the other hand, FreeTopic-type communities contain a strong cluster of agents who share the same strategy. In this situation, even though the topic changes at each step dynamically, the opinions in postings are disproportionately positive or negative. The mechanism of this phenomenon can be explained by group adaptation to a community in a situation in which topic dynamically changes at each step. In such a community, the opinion of the post deviates towards being either positive of negative. Therefore, agents gain benefits stably. Accordingly, the community does not often crash. However, in such communities, the average benefit for an agent is low, because agents greatly consider the balance between each other rather than their topic preferences.

The simulation results can explain some phenomena that appear in real online communities. For example, on Facebook, the topics change dynamically and positive postings are more likely than negative posts to spread [12]. The simulation results indicated that such a community can be composed of negative postings. The Like button of Facebook could be considered to lead the user to positive postings. It is still doubtful whether Facebook would be composed of negative posting even if there were a ”Don't Like” button.

In this research, we clarified the mechanism of the rise and fall of online communities, especially focusing on the transition of topic. We found how communities decline and what conditions will decrease the probability of crash. However, we still do not know what conditions are sufficient for a crash, and these conditions are required to formulate indicators of an online community's decline. We plan to analyze this in the future.

Furthermore, the model we proposed is suitable for evaluating resilience under some different condition because the model can treat the relationship between users. For example, estimating the effect of the users who attack the community is important for considering how to improve the resilience of a community. In addition to this, the following factors are expected to be significant for estimating the rise and fall of communities.

- Setting the number of topics above two
- Setting the link between the agents to negative.
- Changing the initial conditions of distribution of user strategy
- Introducing stubbornness to each agent
- Introducing the symmetry bias of positive and negative postings to each agent

The final goal of this work is to provide the foundations for analyzing and predicting the behavior of agents in each kind of online community. We will simulate the online communities with the above extensions and confirm their consistency with data of real online communities.

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Testing the resilience of agro-pastoralists communities in arid margins through ABM

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***Abstract*—This paper presents the latest model developed within Case Study 1 (hereafter CS1) of the SimulPast project: *Hunter-Gatherer persistence in arid margins. The case of North Gujarat (India)*. The aim of this model is to test the resilience of agro-pastoralists (AP) communities in semi-arid ecosystems. We created a simple Agent Based Model in which agents relied on a pure subsistence strategy based on domesticated plants and animals. We tested our model against previously published climatic record for the area and concluded that a pure agro-pastoral strategy was not enough to sustain the population in conditions of high climatic variability. Further tests were performed to check the climatic conditions in which this type of subsistence strategy is self-sustained in order to extrapolate the model to areas with different specificities than the one under-study.**

I. Introduction

The prevailing archaeological narrative on the dynamics of human occupation of North Gujarat during the Holocene, states that hunter-gatherer communities (HG) have occupied the territory for a long time span [1]. During part of this period, HG strategies have coexisted in close contact with incipient and more advanced AP societies. CS1 was devised to explore the causes behind the resilience of HG in this area, considering two possible factors that could perturb the system: a) climate variability and change, and b) indirect competition with groups relying on different subsistence strategies. Thus the model was split in several stages to understand the role of each of these factors and to tune the model according to the following steps:

1) The resilience of HG group is tested against climate [2]
2) The resilience of AP groups is tested against climate (this paper)
3) The two groups interacting in the same environment (next step)

A. North Gujarat: the role of Monsoon climate on human groups

North Gujarat is an ecotone in a semi-arid zone, characterised by monsoon dynamics, where small climatic shifts can have great repercussions on the environment and the availability of resources. Previous explorations have shown that strong seasonality is coherent with HG resilience and that yearly rainfall variability in these conditions has a greater effect on population dynamics than average yearly rainfall [2]. In other terms, HG populations are more affected by the uncertainty of rainfall quantity from one year to the next than from long-term climatic change.

II. The AP model

The present ABM explores the role of climate, agricultural production and surplus, and animal availability on the resilience of AP communities on a simplified version of the environment used for the previous simulations (for more details see the ODD protocol in [2]). The model was created based on ethnographic and historic data on AP societies of North Gujarat and calibrated with ecological data of small millets, the primary local crop that is still the basis of self-sustained agriculture in this area [3], [4]. The model was implemented in Python, using the Pandora framework [5] and following a number of software development practices known as eXtreme Programming (particularly Test-Driven Development and pair programming, see [6]).

A. Ground and Climatic engine

The world where the agents move is a 50x50-cells raster where cells are divided in three randomly distributed types (*dune*, *interdune* and *water*). The rainfall generated by the system follows the same distribution and data published in [2]. The environment state is tracked by the entity World, which takes care of generating the rain, updating the biomass quantity of the cells (depending on their state and type) and keeping track of the years in which each cell has been in a certain state.

1) Resources: Interdune type cells can be in one of three states: *wild*, *crop* and *fallow*. The agents derive their caloric intake form *crop* cells. The relationship rain-biomass-crop-calories is derived by ethnographic and ecological sources [7], [8] and it is based on species of small-millets. This is considered to be one of the first domesticated species in the area and it is the best adapted to the semi-arid environment of

North Gujarat. All the data considered regard rain-fed, manual agriculture, which is believed to be the closest to incipient cultivation systems. We use a single parameter for computing calories that are in fact a combination of both plant and animal-derived products (i.e. milk). We calculated that the calories that could be derived from animal by-products yearly correspond c. with the quantity of crops that are loss in each harvest [9], [10]. Thus, by not calculating crop loss we include animal by-products in a single parameter.

B. The AP agent

The agent is modelled as a couple with possible offsprings and the demography tracked yearly, based on the number of days in the year when the agent does not meet her caloric needs (starvation rate).

1) Agent creation and demography: Agent creation and demographic tracking follow the same model as presented in [2]. Each agent is composed of two individual, which, at the age of 15 look for a possible partner, defined as a individual of a different agent who is also older than 15. If any such individual is found, the two ”leave” their respective agent to form a new one. Agents have each year a stochastic probability *x* of generating new individuals.

2) Agent behaviour: Agent behaviour is focused on resource management. For this reason it includes 3 types of actions:

1) Search a suitable place where to settle: defined as a dune cell that has in the home range the number of plots needed for the agent to survive. The required quantity of plots (being each plot a cell) is based on yearly rainfall and the number of individuals that form the agent.
2) Manage farm activities: harvest the calories from the plots. *Wild* cells can be transformed in *crop* once the agents select them as their potential plot, they are maintained and used as *crop* for two years (if needed) and then abandoned at which point they turn into *fallow* for one year before converting back to wild and be available as plot.
3) Manage animals: in those cases when the agents do not meet their caloric intake with the crops they can use the calories provided by the meat of the animals in their herd.

III. Experiments

We run experiments to test the following parameters:

1) Agents mobility: how much the agents are willing to move in the landscape to find a suitable place to settle (as defined above). We evaluated whether the number of tries that the agents were allowed to look for a suitable place to settle and any influence on the population survival.
2) Climate uncertainty and storage: the effect of climate prediction and the possibility to store surplus. We tested the importance of short-term storage strategies to deal with high variability in rainfall patterns.

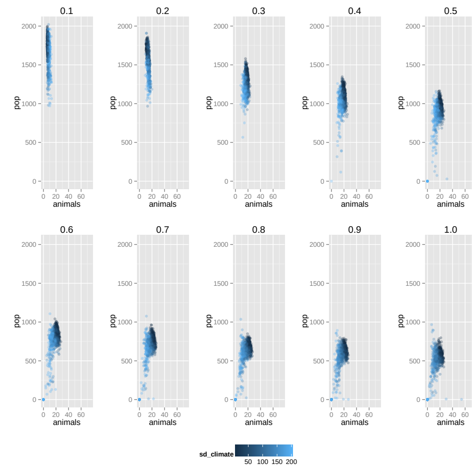

Fig. 1. Average population and quantity of animals depending on climate and how pure the AP strategy is. The lighter colour indicates sd of rainfall closer to the real; reliability on the strategies goes from 0.1 (only 10% of the needed calories are obtained form the AP strategy) to 1 (the entire caloric need in covered by a pure AP strategy

3) Reliability of a pure AP subsistence strategy: the amount of calories that need to be provided by sources other than the AP strategy in order for the population to survive. We investigated the limits of reliability of a pure AP strategy in the face of high rainfall variability and the climatic conditions needed for this threshold to increase/decrease.

For each experiment 100 simulations were run for 5000 time steps (5000 years) with an initial population of 100 agents.

IV. Results

Results of the experiments showed that:

- Mobility is not an issue. Agents do not have difficulties in find a suitable place to settle and when they are allowed to try it twice, the population soon reaches the carrying capacity of the system.
- It is fundamental for the agent, in order to cope with the climatic variability of this system, to be able to store part of their harvest for at least one year. The simulations were tuned so that the agents were aiming at achieving 0.5 more than their requirements each year so that, in case of a ”bad” year they could survive.
- Notwithstanding this, for their survival agents could relay approximately only on getting 0.6 of their needed calories form the AP strategy (including both plants and animals). The remaining 0.4 calories needed to come form another source, different form their own cultivated plants or domesticated animals (Fig. 1).

V. Discussion

The present model is based on very simple agropastoral communities that practice a pure subsistence strategy and do not interact. The aim was to model a very incipient stage of agriculture and test its sustainability in an environment with very high climatic variability. The study-area chosen is and was in te past characterised by monsoon rainfall and is subjected to some of the widest extremes in terms of annual rainfall quantity, being at the same time very prone to droughts and flooding [2]. The inter-annual climatic variability is such that the probability for the AP agents to incur in two or more consecutive years whereby the rainfall amount falls outside the limits for plant growing is extremely high [2]. The logical consequence is that the population cannot survive based solely on a pure incipient agropastoralist strategy (as defined by the current model). It is to be noticed that in our model we used very tolerant values for the parametrisation of both plant ecological requirements as well as agents needs and workload capacity. Based on the results of our experiments, in order for the population to survive, at least 0.4 of the caloric intake need to come from a source different from the cultivated plants/domestic animals (e.g, trade, exchange, hunting and gathering etc). The archaeobotanical record has provided hints of possible exchange in the form of small quantities of wheat and barley grains recovered from some of the settlements excavated in this area (see [11] and bibliography therein).This has important implications for the historical interpretation of the dynamics of occupation of North Gujarat during the Holocene. Indeed, if we hypothesise that small farming communities that based their survival on the plants and animals most adapted to the area cannot rely completely on a pure AP strategy, large and complex settlements in this area had to rely on imports of food form outside probably much greater than what can be expected form the archaeobotanical record.

VI. Conclusions and Future Developments

The model presented testifies the importance of tackling the issue of subsistence strategy reliability when constructing narratives about past societies. Indeed, our work shows that in semi-arid areas with highly variable climatic regimes, a pure agropastoralist subsistence strategy was not sustainable. The next step in the exploration of this model will include testing the interaction between agents with different subsistence strategies and introducing mechanisms of interactions amongst agents. This will enlighten what are the most resilient strategies to cope with resource and climatic uncertainty as well as inform of what are the conditions in which pure strategies are most effective.

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Tackling Model Selection and Validation: an Information Theoretic Criterion

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***Abstract*—Simulated economies suffer intrinsically from validation and comparison problems. The choice of a suitable indicator quantifying the distance between the model and the data is pivotal to model selection. However, how to validate and discriminate between models are still open problems calling for further investigation, especially in light of the increasing use of simulations in social sciences. In this paper I present a new information theoretic criterion to measure how close models' synthetic output replicates the properties of observable time series without the need to resort to any likelihood function or to impose stationarity requirements. This indicator is sufficiently general to be applied to any kind of model able to simulate or predict time series data, from simple univariate models such as Auto Regressive Moving Average (ARMA) and Markov processes to more complex objects including agent-based or dynamic stochastic general equilibrium models. More specifically, I use a simple function of the L-divergence computed at different block lengths in order to select the model that is better able to reproduce the distributions of time changes in the data. To evaluate the L-divergence, probabilities are estimated across frequencies including a correction for the systematic bias. Finally, using a known data generating process, I show how this indicator can be used to validate and discriminate between different univariate models providing a precise measure of the distance of each model from the data.**

I. Introduction

The use of simulations as a tool to investigate real phenomena has increased steadily in the last two decades, covering almost every field of the social sciences (see [1]). Acknowledging this trend, one fundamental issue has become to establish what a good simulation is. According to [2] the answer to this question must be: a good simulation is one that achieves its aim. But just what the aim or goal of a simulation might be is not obvious. Simulations might be used to explain a phenomenon, to predict its behaviour or to explore the internal structure of the phenomenon itself. Moreover, the aim of the simulation depends largely both on the modeller and the model. In [3] two kinds of models are recognized: *demonstration models*, essentially existence proofs for phenomena of interest, and *descriptive models*, that attempt to track dynamic historical phenomena. Most early simulation models are considered as demonstrative and a nice example could be the well known Schelling ([4])'s segregation model. Despite these models are extremely useful tools for explorative analysis and "as if" stories, policy analysis requires descriptive, validated models. The argument is simple: if you wanted to advise a policy maker on the basis of results from your model, you should be able, at least, to show that your model can replicate the behaviour of observed data. When this does not happen, it would be difficult for the policy maker to trust your advice or, at least, it should. Hence, for a descriptive model, offering good simulations means these simulations can be successfully validated against historical data.

How to validate a model is still an open issue for simulation studies[1] (see [9], [10] and more recently [11]). Finding appropriate tools to so is crucial both for the scientific debate and for policy analysis; the academia needs to develop theories whose implications fits with empirical evidence and policy makers needs information coming from reliable models. Establishing the fit of different models with empirical data is exactly what I am doing in this paper where I introduce, discuss and estimate a new information theoretic criterion.

Mason ([12]) distinguishes between *output validation* and *structural validation*. The latter asks how well the simulation model represents the (prior) conceptual model of the real-world system; the former asks how successfully the simulations' output exhibits the historical behaviours of the real-world target system. Output validation can be directly related to what Leombruni et al. ([13]) define as *empirical validity* of a model, i.e. validity of the empirically occurring true value relative to its indicator. Leombruni et. al introduce other four validity concepts that theory- and data-based simulation studies must consider: theory (the validity of the theory relative to the simuland), model (the validity of the model relative to the theory), program (the validity of the simulating program relative to the model), operational (the validity of the theoretical concept to its indicator or measurement). Any-time simulations exhibit lacks with respect to one or more of these validities, empirical validity is in turn affected and thereby reduced.
Following [14], it is useful to think of two parallel unfoldings: the evolution of the real economy (or market or whatever) and the evolution of the model of this real-world phenomenon. If the model is properly specified and calibrated, then its

[1] In what follows I refer to the Agent Based literature, where simulations are at the very core of the scientific inquiry process (see [5]); however, validation is crucial also for more standard approaches, especially in economics (see [6]), which would certainly benefit from reading and confronting with the literature I am referring to (see [7]). On the latter theme see also [8]

evolution should mirror the historical evolution of the real-world phenomenon: we could observe the evolution of the model or the real-world evolution and both should reveal similar behaviour of the variables of interest.

In this paper I focus on establishing whether and the extent to a simulation is able to reproduce and predict the behaviour of a phenomenon. This procedure is carried out by defining and computing an information theoretic criterion, based on a simple function of the L-divergence ([15]), which measures the distance between the actual, observed data and the synthetic series generated by different, competing models. This criterion, named *Generalized Subtracted L -divergence*, shortly *GSL-div*, allows to validate the output of a model by capturing its ability to reproduce the distributions of time-changes (that is, changes in the process' values from time to time) in the real-world observed process, without the need to resort to any likelihood function or to impose stationarity requirements. In turns, the procedure I am going to describe allows for direct model selection, identifying a precise measure which expresses empirical validity and selecting the model which exhibits the highest value with respect to this metric. The approach is in line with [3] and, as the State Similarity Measure (SSM) proposed therein, it tackles the fourth issue raised in [9]: validating agent based models using historical data. It is to be noticed that, in this paper, I use the *GSL-div* to compare univariate time series; however the approach can be extended to multivariate data structures.

II. Measuring the distance between time series: the GSL-div

As well explained in [3], using the glasses of information theory rather than statistics, the observed data contain information, and the (descriptive) models we develop (from our theoretical understanding of the underlying processes generating the observed data) can be seen of as attempts to reproduce the highest possible fraction of these information, in the most compact way. When several models referring to the same phenomenon are available, empirical validation should be able to point out the "best" model, that is the model whose output lose the least amount of information with respect to the real-world data.

The *GSL-div* measures the distance between the real and model's time series. The former is the unique realization of the unknown data generating process, the latter are taken to be M series generated by the same model, with the same (post-calibration) parameters' value. The use of an ensemble of replicated series provides a double advantage: it allows to correct for the systematic bias in the estimation of information theoretic quantities (see below) and it captures the behaviour of the model washing away the effects of particular realizations. The approach used to develop this criterion could be thought as the result of an extension of the work provided in [16].

Distance or divergence measures are widely used in a number of theoretical and applied statistical inference and data processing problems, including estimation, detection, compression and model selection ([17]). Most of them rely largely on the concept of Shannon's entropy ([18]), which expresses the amount of uncertainty associated with a random variable. Among these measures, one of the best known is the Kullback-Leibner divergenge (*KL-div*) between two distributions, $D(\mathbf{p}||\mathbf{q})$, or *relative entropy* ([19]). It is a measure of the inefficiency of assuming that the distribution is $\mathbf{q}$ when the true one is $\mathbf{p}$. The following discussion will be limited to discrete probability distributions, but results can be generalized to probability density functions.
Let X be a discrete random variable with support indicated by X and probability mass function $p(x)$, $x \in X$. If $q(x)$ is another probability mass function defined on the same support X, the *KL-div* is defined as

$$D_{KL}(\mathbf{p}||\mathbf{q}) = \sum_{x\in X} p(x)\log\left(\frac{p(x)}{q(x)}\right), \tag{1}$$

where the logarithm is, usually, in base 2. Throughout the paper the following conventions will be used: $0\log(0/0) = 0$ and, on the basis of continuity arguments, $0\log(0/q) = 0$, independently of the logarithm's base. It is immediate to see that if there exist any symbol $x \in X$ such that $p(x) > 0$ and $q(x) = 0$ then, $D_{KL}(\mathbf{p}||\mathbf{q})$ is undefined. This means that distribution $\mathbf{p}$ has to be absolutely continuous with respect to $\mathbf{q}$ for the *KL-div* to be defined [20]. In addition, the $D_{KL}(\mathbf{p}||\mathbf{q})$ is non-negative, additive but not symmetric. In order to overcome these problems Lin defined a new symmetric measure, called L-divergenge, shortly *L-div*:

$$D_L(\mathbf{p}||\mathbf{q}) = D_{KL}(\mathbf{p}||\mathbf{m}) + D_{KL}(\mathbf{q}||\mathbf{m}), \tag{2}$$

where $\mathbf{m} = (\mathbf{p}+\mathbf{q})/2$ is the "mean" probability mass function. As the names suggest the $L-div$ is the basic building block I will use to construct the *GSL-div*.
It is immediate to see that $D_L(\mathbf{p}||\mathbf{q})$ vanishes only if $\mathbf{p} = \mathbf{q}$ and that the L-divergence is bounded above by 2. This is more evident when expressing the L-divergence in terms of the Shannon entropy, that is

$$D_L(\mathbf{p}||\mathbf{q}) = 2H\left(\frac{\mathbf{p}+\mathbf{q}}{2}\right) - H(\mathbf{p}) - H(\mathbf{q}), \tag{3}$$

i.e. the difference between twice the mean distribution and the sum of the entropies of $\mathbf{p}$ and $\mathbf{q}$. The generalization of the *L-div* is the Jensen-Shannon divergence (see [15]), defined as

$$Div_{JS}(\mathbf{p},\mathbf{q}) = H(\pi_1\mathbf{p} + \pi_2\mathbf{q}) - \pi_1 H(\mathbf{p}) - \pi_2 H(\mathbf{q}), \tag{4}$$

where the weights π_1 and π_2 must satisfy $\pi_1, \pi_2 \geq 0$ and $\pi_1 + \pi_2 = 1$. It is straightforward that $D_L(\mathbf{p}||\mathbf{q}) = 2Div_{JS}(\mathbf{p},\mathbf{q})$ for $\pi_1 = \pi_2 = 1/2$. It is to be noticed that the *KL-div*, and consequently the *L-div*, does not satisfy the triangle inequality, and hence cannot be considered a proper

metric.[2]
With reference to the use of these measures as quantities for model validation and selection Marks ([3]) outlines their inadequacy due to the previous problem. However, if models' data-distributions (say **q**) are always compared directly with the real data-distribution (say **p**), and not among themselves, model selection does not need a metric satisfying triangle inequality. Moreover, Endres et al. ([22]) found that the square root of the *L-div* is a metric and they called this new information metric the Jensen-Shannon distance.

In this paper I use the *L-div* as a measure that captures the distance between the distributions of time-changes in the real-world process and those generated by the synthetic output of simulated, competing models. Time-windows of different lengths are taken into consideration for the generation of the state space, which is represented by the set of values the series might take at each instant of time. The *L-div* is estimated for each length of the time-window and results are finally aggregated into a single information criterion, the Generalized Subtracted L-divergence (shortly *GSL-div*). It is worth noticing that this new measure is designed to capture similarities in the behaviour of the time series, and not in their levels. This reflects the opinion that is not relevant for a simulation to mirror the same values of the real data but to display the same behaviour in terms of trends, variabilities, trajectories and their shape. These elements are captured by the *GSL-div*. Furthermore, given two series sharing the same behaviour but different levels, it is sufficient to change initial conditions to notice they are in effect identical, and this would amount to add or subtract a drift to one of the two. Finally, levels depend largely on the unit of measure used by different models, while series' behaviour does not.

A. The GSL-divergence

Consider a random variable x taking values from the set $\mathbf{x} = (x_1, ..., x_k)$ with probabilities $\mathbf{p} = (p_1, ..., p_k)$. Assume we observe real-world or simulated time series both of length N; from $x(t)$, $t = 1, ..., N$ it is possible to build an histogram $\mathbf{n} = (n_1, ..., n_k)$, where n_i is the number of times the outcome was x_i. The frequency vector $\mathbf{f} = (f_1, ..., f_k) = (n_1/N, ..., n_k/N)$ is an estimator of the probability distribution **p**.
Within this framework it is important to notice that I consider a discretization of the state space: time series are assumed to take only a finite set of values. How to conduct this procedure is crucial. In particular, for each time series $\{x(t)\}_{t=1}^{N}$, I take the original, real interval $[x_{min}; x_{max}]$ and I partition it in $b \in \mathbf{N}_0$ subintervals, each of equal length. These intervals are numbered increasingly from 1 to b, with 1 assigned to $[x_{min}; x_{min} + \frac{(x_{max}-x_{min})}{b})$. The time series is then symbolized straightforwardly: each observation is mapped into the number assigned to the interval it falls within. The parameter b controls for the precision of the symbolization: for $b = 1$ the symbolized series takes one and only one value (namely 1) while for $b \rightarrow \infty$ we are back to the (scaled) real-valued process. The symbolization is simple and works as follows: each $\{x(t)\}_{t=1}^{N}$ is mapped into the natural number corresponding to the partition interval where it falls.
For example, consider the following realization of the stochastic process $x(t)$ with $t = 3$: $\{0; 0.65; 1\}$. Choosing $b = 2$, the symbolized series will be $x^s(t) = \{1, 2, 2\}$, while choosing $b = 10$ the symbolized series becomes $x^s(t) = \{1, 7, 10\}$. It is immediate to see that increasing b the information loss about the behaviour of the stochastic process due to the symbolization becomes smaller and smaller. However, as it typically happens, increasing the precision of the symbolization has a cost: higher b translates also in higher size of the alphabet, that is the total number of words that could be created using symbols $\{1, ..., b\}$. The size of the alphabet corresponds to the cardinality of the state space and increasing it might require larger time series to conveniently estimate probability distributions. However, as will be shown, the *GSL-div* does not suffer from the use of low values of b. Additionally, it is important to notice that using high precision of the symbolization procedure is not a problem when a large amount of data are available, for example in high frequency models of financial markets (see, among others, these recent contributions [23] and [24][3]). A detailed discussion about the partitioning of the state space when dealing with information theoretic functional is provided in [25].

Once the time series are properly symbolized, they are subdivided in successive blocks of equal length l; this operation is recursive for $l = 1, ..., L$, where L is the maximum block's length (time-window) considered. Since there are N observations for each series, N/l blocks will be obtained for each value of l. L represents the maximum length of the windows which are used to compare the behaviour of the real data with the synthetic ones. It has to be chosen considering both (i) the nature of the phenomenon of interest and (ii) the size of the available real-world time series which can be used to validate the models. The first criterion, (i), reflects the time-horizon one considers when analysing a given phenomenon. For example, if the focus is centred on business cycles, data will be typically quarterly and the time-window around eight or twelve periods; conversely, in case one considers economic growth in the long run, data will be annual and the window considerably enlarged. The second criterion, (ii), puts a constraint on the comparability of real v.s. simulated data: when a real-world time series of length N is the only available source of information about the phenomenon under study, it makes a non-sense to compare it with a double-length simulated series. On the other hand it could be perfectly reasonable to take an ensemble of replicated series each of length N, both to wash away across-simulation variability and to solve the small sample problem ([26]). Using symbolized

[2]A metric is a distance function which must satisfy non-negativity, symmetry, coincidence and triangle inequality (see [21]).

[3]Here the methodology described in the paper is directly applicable to the time series of stock prices.

series, $l = 1, ..., L$ represents also the length of the words which compose the corresponding alphabet.

For each value of l, a subtracted version of the *L-div* is estimated from the data. It provides a measure of how close the behaviour the synthetic data replicates the real one when the series are studied along windows of length l. The *GSL-div* aggregates subtracted *L-div* values using weights increasing in l. In such a way it integrates the distances between the distributions of two time series for multiple (namely L) time-windows. Greater weights are assigned to values of the *L-div* considering longer windows.
Let $\{x(t)\}_{t=1}^{N}$ and $\{y(t)\}_{t=1}^{N}$ be two time series of total length N and indicate with $x^s(t)$ and $y^s(t)$ their symbolized version according to the procedure described above. It is important the precision level b chosen in the symbolization procedure to be the same for the two time series to be comparable.
The *GSL-div* takes the following functional form:

$$\begin{aligned} D_{GSL}(x(t)||y(t)) &= \sum_{i=1}^{L} w_i[-2\sum_{x\in X_i} m_i(x)\log_{a_i} m_i(x) \\ &\quad + \sum_{x\in X_i} q_i(x)\log_{a_i} q_i(x)] \qquad (5) \\ &= \sum_{i=1}^{L} w_i\left(2H^{X_i}(m_i) - H^{X_i}(q_i)\right) \qquad (6) \end{aligned}$$

where the symbol $H^{X_i}(\cdot)$ indicates the Shannon entropy of a distribution over the state space X_i.
On the right hand side of the first line of (5) the big square brackets contain the subtracted L-divergence computed at different block lengths l. In particular I take the *L-div* ([15]) and I subtract the entropy for the time series $\{x(t)\}_{i=1}^{N}$. This can be justified in two ways. On the one hand it is due to the fact that $x(t)$ is always taken to be the real-world time series and it can be observed only once. This means it is not possible to replicate this series and create an ensemble, as it will be done for the time series produced by models. As a consequence, it cannot be corrected for the systematic bias stemming from the fact that its entropy is computed using an estimator (the frequency over the state space) and not the true probabilistic structure (see [27] and [26]). On the other hand, being the *GSL-div* always applied to real data against models' output, when one compares the distance of different simulated data with respect to the real counterpart the entropy of the latter will always be washed away.

The logarithm is always in base a_i with $i = 1, ..., L$, which corresponds to the cardinality of the alphabet available at length $l = i$.
Consider for example the following symbolized time series of length 8 obtained selecting $b = 4$:

$$\{x(t)\}_{t=1}^{8} = \{0, 2, 1, 2, 1, 3, 4, 0\}.$$

When $l = 1$ the time-window corresponds to one period, the series is sub-divided into 8 blocks and each of them is associated to one out of four symbols, namely $1, 2, 3$ or 4. When $l = 2$, $N/l = 8/2 = 4$ blocks are obtained and each is mapped to one of the following 2^4 symbols: $\{(11); (12); (13); ...; (43); (44)\}$. The mapping between blocks and corresponding symbols is straightforward: the series' first block of length 2 is $\{0, 2\}$ and it is associated to the symbol (02); the second block, $\{1, 2\}$, is associated to (12) and so on. The cardinality of the alphabet available when the selected time-window has length l corresponds to the number of different symbols the series' blocks might be associated to. Hence

$$a_i = 2^{X_i} = b^l,\ \forall l = 1, ..., L \qquad (7)$$

where b is, as usual, the precision level used in the symbolization.
It is worth recalling that, in equation (5), $m_i(x)$ indicates the "mean"distribution of $p_i(x)$ and $q_i(x)$:

$$m_i(x) = \frac{p_i(x) + q_i(x)}{2}, \qquad (8)$$

where $p_i(x)$ is the estimated probability (frequency) assigned by the real-world process to the symbol x, while q_i is the counterpart assigned by (one series of) the simulated process to the same symbol.

As introduced above, each of the subtracted L-divergences entering the *GSL-div* is assigned an increasing weight. This reflects the grater importance assigned to the ability of the simulated data to match the behaviour of the real process over a longer time-window and, additionally, it compensates for the increasing value of the logarithm basis a_i. In particular, weights are chosen to guarantee that their first differences are constant; that is, the weight assigned at a given length of the time window is equal to the one assigned at the previous length plus a constant term. As usual, the normalization condition must hold, $\sum_{i=1}^{L} w_i = 1$. The following weights are obtained[4]:

$$w_i = w_{i-1} + \frac{2}{L(L+1)} \qquad i = 1, ..., L \qquad (9)$$

where $w_0 = 0$. As will be shown, the choice of the weights is robust to changes and even assuming equal weights across the length of the time-windows results are unaffected.

B. The systematic bias

When an information theoretic function is computed without knowing the exact probability of each symbol, a systematic error might arise. In particular this the case when the true probabilistic structure of a process has to be estimated from a finite sequence of observations (see [27], [26], [28], [29], [30]).
Even knowing the true distribution **p** of a time series $x(t)$ over a state space *X*, when one computes any of the *KL-div*, *JS-div*,

[4]proof omitted here both for sake of brevity and its simplicity.

L-div or *GSL-div* between **p** and **q** estimated from $\{x(t)\}_{t=1}^{N}$ with $N < \infty$, the result would be larger than zero. Obviously, the bias is also present when computing the distance between two frequency vectors that are estimated from two realizations of the same stochastic process.

The concept of systematic bias for the numerical values of information theoretic functional is well known in the literature and it follows directly from Jensen inequality (see [31]). In particular, the bias is identified with the expectation value $E[f(\mathbf{f})]$ being lower than $f(\mathbf{p})$ where **f** is an estimator of the true probability distribution **p**. Applying this result to the Shannon entropy one obtains

$$E[H(\mathbf{f})] \leq H(\mathbf{p}), \tag{10}$$

where the expectation is defined over the ensemble of finite-length i.i.d sequences generated by the probability distribution **p**.
Following [32] it can be shown that the expected value of the observed entropy is systematically biased downwards from the true entropy:

$$E[H(\mathbf{f})] = H(\mathbf{p}) - \frac{B-1}{2N} + O(N^{-2}), \tag{11}$$

where N is the length of each time series and B is the number of states $x \in X$ such that $f(x) > 0$. This result was originally obtained by Basharin ([27]) and Herzel ([26]) who found also that, up to the first order $O(N^{-1})$, the bias is independent of the actual distribution **p**. The term $O(N^{-2})$ contains unknown probabilities **p** and cannot be estimated in general (see [28], [29], [32]).

Dealing with a model it is always possible to generate an ensemble of time series; conversely, it becomes impossible with the unknown real data generating process, which produces an unique observable series for each phenomenon. This help justify the fact I subtract the entropy of the real series when I define the *GSL-div*.
Applying the previous correction of the systematic bias to the *GSL-div* one obtain the following expression

$$\begin{aligned} D_{GSL}(x(t)||y(t)) = \sum_{i=1}^{L} w_i [&-2 \sum_{x \in X_i} m_i(x) \log_{a_i} m_i(x) \\ &+ \sum_{x \in X_i} q_i(x) \log_{a_i} q_i(x)] \\ &+ \sum_{i=1}^{L} w_i \left(\frac{B_i^m - 1}{N_i} - \frac{B_i^q - 1}{2N_i} \right) \end{aligned} \tag{12}$$

where the second line captures the correction terms for the systematic bias.

Finally it is important to recall that the *GSL-div* is bounded both from above and below. In particular it is possible to show that

$$0 \leq D_{GSL} \leq 2. \tag{13}$$

However, due to the subtraction with respect to the *L-div*, this is not the case in practice, and the lower bound for the *GSL-div* is the unknown entropy of the real-world time series, which is, apart from special cases, positive. However, this is not a problem for model selection and validation and the only thing which matters is to have an upper bound for the criterion, which can be used as a comparison term. To the purposes of model selection lower the *GSL-div* the better the ability of the model to reproduce the behaviour of the observed real data.

III. A SIMPLE EXAMPLE

In this section I show the performance and the precision of the *GSL-div* criterion in distinguishing between three ad hoc created time series. $x(t)$ is chosen to be the observed series while $x_A(t)$ and $x_B(t)$ are to be intended as the output of two models (A and B respectively) trying to simulate $x(t)$. These series are consciously chosen to have $x_A(t)$ much more close to the behaviour of $x(t)$ with respect to $x_B(t)$. Their plot is reported in figure 1.

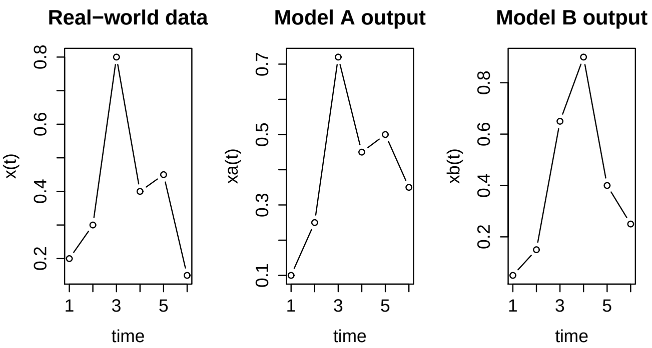

Fig. 1. Behaviour of three selected time series

I expect the *GSL-div* criterion to show a lower distance between the observed time series coming from the unknown data generating process and model A's output.
Before showing the results I present the symbolization process. The three series take values in the real interval $[0, 1]$ and a very small sample consisting of six observations is chosen:

$$x(t) = \{0.2; 0.3; 0.8; 0.4; 0.45; 0.15\},$$
$$x_A(t) = \{0.1; 0.25; 0.72; 0.45; 0.5; 0.35\},$$
$$x_B(t) = \{0.05; 0.15; 0.65; 0.9; 0.4; 0, 25\}.$$

The precision of the symbolization is set to $b = 3$; this choice leads to the following partition of the original state space: $[0; 0.33)$; $[0.33; 0.66)$; $[0.66; 1]$. Despite the choice of b is arbitrary results are robust to changes in the value of this parameter. The use of a low b can be justified here by the fact that the time series are very short; in addition, representing it the the precision of the symbolization process, the use of a low value for b makes it more difficult to distinguish between the series. The ability of the *GSL-div* to recognize the most similar even when the symbolization is relatively imprecise would confirm the power of this new criterion.

According to the chosen parametrization, the three symbolized time series are:

$$x(t) = \{1, 1, 3, 2, 2, 1\},$$

$$x_A(t) = \{1, 1, 3, 2, 2, 2\},$$

$$x_B(t) = \{1, 1, 2, 3, 2, 1\}.$$

By inspection it is possible to notice that x_A is much more closer to x than x_B: while the former exhibits the same behaviour of the real data apart form the very last period, the latter displays twice the opposite one (it increases from $t = 3$ to $t = 4$ when $x(t)$ is decreasing and vice-versa in the following period).

Given the use of short time series, the maximum value of the time-window's length along which the three processes are compared cannot be set above $L = 3$; otherwise one and only one block would be available, the probability distribution over the alphabet would appear constant and its entropy pushed to zero. Hence, I am considering blocks and corresponding alphabets for $l = 1, 2, 3$. Respectively, six, three and two observations are obtained and used to estimate the frequencies. As it is obvious, these are very rough estimates of the probabilities the three process assign to symbols $x \in X_l$.
Notwithstanding this limitation the performance of the *GSL-div* in selecting model A and validating its output against real data is excellent. Table 1 (with progressive weights) and Table 2 (with uniform weights) provide evidence of this result.

TABLE I
GSL-DIV FOR $x(t)$ AND BOTH $x_A(t)$ AND $x_B(t)$ WITH PROGRESSIVE WEIGHTS

	block length	weights	Subtracted L-div model A	model B
	1	0.17	0.948161	0.920620
	2	0.33	0.710310	0.710310
	3	0.50	0.420620	0.630930
GSL-div			**0.605900**	**0.706373**

TABLE II
GSL-DIV FOR $x(t)$ AND BOTH $x_A(t)$ AND $x_B(t)$ WITH UNIFORM WEIGHTS

	block length	weights	Subtracted L-div model A	model B
	1	0.33	0.948161	0.920620
	2	0.33	0.710310	0.710310
	3	0.33	0.420620	0.630930
GSL-div			**0.693030**	**0.753953**

Two observations deserve attention. First, the subtracted L-divergence at blocks' length equal to one is lower for model B's than for model A's series. This is driven by the fact that $x_B(t)$ and $x(t)$ have been chosen to exhibit the same frequency distribution over the alphabet available for $l = 1$, $X_1 = \{1, 2, 3\}$, while $x_A(t)$ has not. This means that it becomes relatively more difficult to recognise $x_A(t)$ as the series most similar to $x(t)$. However, the distribution of time-changes is completely different between $x(t)$ and $x_B(t)$. The result is that when one move to $l = 2, 3$, corresponding to capture longer trends and trajectories, $x_A(t)$ equals and overcome $x_B(t)$'s performance in simulating the behaviour of $x(t)$. In addition, this justifies the choice of using progressive weights in the definition of the *GSL-div*: a model matching the distribution of changes for a longer time window should always be preferred and selected.
Secondly, the three time series have been selected ad hoc to show the performance of the *GSL-div*. Not having a proper model it is not possible to replicate simulations and correct for the systematic bias[5].
In the next section I move away from this example and I show the precision of the *GSL-div* in validating and selecting the most appropriate among 9 univariate stochastic models; the correction term for the systematic bias is added to the estimation of the criterion.

IV. SELECTING AND VALIDATING ARMA MODELS

A set of 9 Auto Regressive Moving Average (ARMA) models is analysed. The *GSL-div* is used to select the model which minimizes the distance with respect to the distribution of time changes in the real data. Real data are assumed to be a realization of a Gaussian $AR(1)$ process with autoregressive order-one parameter $\phi_1 = 0.1$. Figure 2 provides a plot of this process. It is obviously stationary, causal and invertible[6].

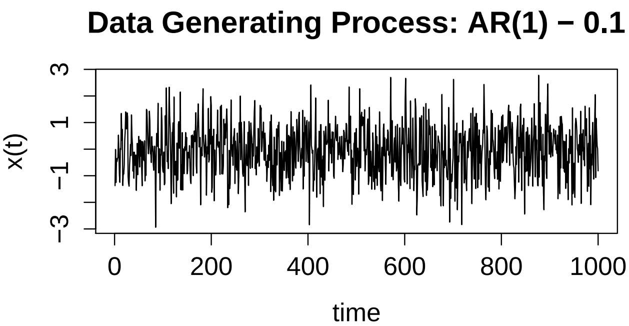

Fig. 2. The real-world time series

Table 3 summarizes the main features of the models which are considered for replicating the behaviour of the real data.

[5]The only meaningless solution would be assuming deterministic models producing always the same realization.
[6]see [33] for a definition of these properties

All of them are Gaussian $N(0,1)$ ARMAs and are used to produce an ensemble of $M = 1000$ Monte Carlo replications, each of length $N = 1000$. These series are symbolized using precision $b = 5$.

TABLE III
MAIN FEATURES OF THE NINE MODELS CONSIDERED

		parameters		properties	
	model	ϕ	θ	stationary	invertible
1	AR(1)	0.1	0	yes	yes
2	AR(1)	0.2	0	yes	yes
3	AR(1)	0.5	0	yes	yes
4	AR(1)	0.01	0	yes	yes
5	AR(1)	0.9	0	yes	yes
6	ARMA(1,1)	0.2	0.9	yes	yes
7	ARMA(1,1)	0.5	2	yes	no
8	AR(1)	1	0	no	yes
9	AR(1)	2	0	no	yes

The majority of the models considered are stationary and, even if not reported directly, they are also causal. In addition, most of them are invertible. This allows to conclude that six out of nine are unique, meaning that there is a one-to-one correspondence between the family of the finite dimensional distributions of the process and its finite parametric representation (see [33]). This applies also to the Data Generating Process (*DGP*).

The *GSL-div* is expected to recognize the model which is most similar to the *DGP*: model 1 exhibits exactly the same parametric representation of the data generating process from which $x(t)$ is taken. In addition one should ask the *GSL-div* to identify models producing series completely inconsistent with the real world data $x(t)$: model 9 is strongly non-stationary and exhibits an explosive behaviour. Therefore, within the class of models considered here, I expect the *GSL-div* to reach a minimum when model 1 and $x(t)$ are evaluated and a maximum when model 9 is compared to observed data.
Figures 3 and 4 provide a plot of a realization for model 1 and 9 respectively.

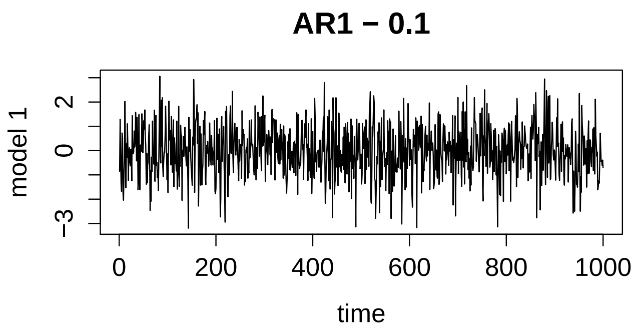

Fig. 3. A realization of model 1

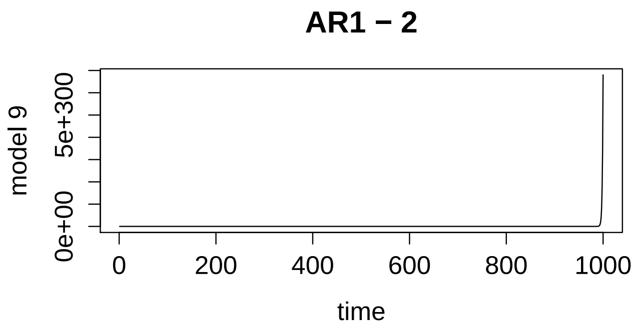

Fig. 4. A realization of model 9

Tables 4 and 5 (in the next page) show the performance of the *GSL-div* in evaluating the distance between the distributions of the real-world time-series and different models, after correcting for the systematic bias. The maximum length of the time-window (or block-length) is chosen to be six. Numbers in bold indicate the estimated *GSL-div* while those in plain represent its partial values, that is subtracted L-divergences.

Expectations are perfectly confirmed: model 1 turns out be the closest to the real data while model 9 the most distant. In general the *GSL-div* is shown to distinguish clearly among models: non-stationary processes are the most distant from the real data and when a Moving Average component is added to the process the distance from the real data increases. This is true especially when the MA part is non-invertible (model 7). Moreover, among the same class of processes (AR(1)) the criterion is able to recognize those having a parametric representation which is closer to the *DGP*.
It is worth noticing that results are robust to the choice of the weights in the functional representation (12) of the *GSL-div*. Finally, the correction term for the systematic bias is, in absolute value, considerably low with respect to the estimated value of the *GSL-div* criterion, and it becomes even smaller the longer the time series. In particular, the correction never affects results and the ordering of models' distance from $x(t)$.

V. CONCLUSIONS

Validation of simulated models is still an open issue. One way of tackling this problem is via the identification of a measure of the distance between simulated and real-world data. This paper provides an information theoretic criterion, the *GSL-div*, which captures this distance without any requirement of stationarity nor the need to resort to any likelihood function. This constitutes a direct advantage with respect to other approaches aimed at characterizing times series and their behaviour.

TABLE IV
GSL-div FOR $x(t)$ AND NINE ARMA MODELS WITH PROGRESSIVE WEIGHTS

block length	*weights*	*AR1 - 0.1*	*AR1 - 0.2*	*AR1 - 0.01*
1	0.047619	0.035086	0.035110	0.035135
2	0.095238	0.069981	0.070112	0.070133
3	0.142857	0.104996	0.105102	0.105244
4	0.190476	0.140687	0.140874	0.140918
5	0.238095	0.173118	0.172980	0.173164
6	0.285714	0.194703	0.195057	0.195459
GSL-div		**0.718571**	**0.719235**	**0.720053**

block length	*weights*	*AR1 - 0.5*	*AR1 - 0.2 MA1 - 0.9*	*AR1 - 0.5 MA1 - 2*
1	0.047619	0.035154	0.035147	0.035203
2	0.095238	0.071077	0.071422	0.073134
3	0.142857	0.106422	0.106308	0.109892
4	0.190476	0.142626	0.144963	0.146516
5	0.238095	0.173115	0.174841	0.175495
6	0.285714	0.194625	0.195291	0.195260
GSL-div		**0.723019**	**0.727973**	**0.735501**

block length	*weights*	*AR1 - 0.9*	*AR1 - 1*	*AR1 - 2*
1	0.047619	0.035500	0.040350	0.072301
2	0.095238	0.077123	0.087890	0.109458
3	0.142857	0.114550	0.126863	0.143475
4	0.190476	0.151631	0.163332	0.174783
5	0.238095	0.178279	0.188724	0.196458
6	0.285714	0.196556	0.202831	0.207266
GSL-div		**0.753639**	**0.809990**	**0.903741**

TABLE V
GSL-div FOR $x(t)$ AND NINE ARMA MODELS WITH UNIFORM WEIGHTS

block length	*weights*	*AR1 - 0.1*	*AR1 - 0.2*	*AR1 - 0.01*
1	0.17	0.122801	0.122884	0.122972
2	0.17	0.122467	0.122696	0.122733
3	0.17	0.122495	0.122619	0.122784
4	0.17	0.123101	0.123265	0.123303
5	0.17	0.121183	0.121086	0.121215
6	0.17	0.113577	0.113784	0.114018
GSL-div		**0.725624**	**0.726333**	**0.727025**

block length	*weights*	*AR1 - 0.5*	*AR1 - 0.2 MA1 - 0.9*	*AR1 - 0.5 MA1 - 2*
1	0.17	0.123037	0.123015	0.123211
2	0.17	0.124385	0.124989	0.127985
3	0.17	0.124159	0.124026	0.128208
4	0.17	0.124798	0.126843	0.128202
5	0.17	0.121181	0.122389	0.122846
6	0.17	0.113531	0.113920	0.113902
GSL-div		**0.731091**	**0.735181**	**0.744353**

block length	*weights*	*AR1 - 0.9*	*AR1 - 1*	*AR1 - 2*
1	0.17	0.124250	0.141225	0.253055
2	0.17	0.134965	0.153807	0.191552
3	0.17	0.133642	0.148007	0.167387
4	0.17	0.132677	0.142915	0.152935
5	0.17	0.124795	0.132107	0.137521
6	0.17	0.114658	0.118318	0.120905
GSL-div		**0.764987**	**0.836380**	**1.023355**

My approach leaves two free parameters: the precision of the symbolization process, namely b, and the maximum length of the time-window used to identify blocks of the time series, namely l. Both can be increased when the size of real time series against which models are evaluated is large; however, I showed that using relatively low parameters' values ($b = 5$, $l = 6$) the *GSL-div* is extremely precise in selecting and ordering the models which are better able to reproduce the distributions of time-changes observed in the real data.
In this paper the *GSL-div* is applied to univariate models. Extensions to multivariate settings are possible. There, I explicitly account for the fact that a multivariate model which perfectly matches one real time series but poorly replicates the others should not, in general, be better than one which decently simulates the behaviour of all the considered series.

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Simulating land use of prehistoric wetland settlements: did excessive resource use necessitate a highly dynamic settlement system?

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***Abstract*—In the European circumalpine region, remains of wetland settlements that were constructed on lake shores and in peat-bogs have been investigated for more than 150 years. Interdisciplinary research provides detailed evidence on many facets of prehistoric subsistence. This project aims at some fundamental questions related to the land-use and the settlement system, that are today either controversially debated or unclear. To this aim, an agent-based simulation model of an idealized, hypothetical settlement located in the alpine forelands in the 4th Millennium BC is set up: WELASSIMO (Wetland Settlement Simulator). The main problems to tackle are: I) to assess the sustainability of the land-use system, II) to investigate the systemic effects of neolithic subsistence on the environment and III) to identify potential limiting factors for the system. The observer is enabled to investigate the close connection and the relevance of the subsystems for the whole system.**

I. Introduction

FROM the archaeological investigation of findings in peat-bog and lake-shore sediments in the North-Western pre-alpine forelands, it is known that people built their wooden houses in these locations from the 4th to the first Millennium BC [1]. In more than 150 years of interdisciplinary research, detailed knowledge has been gained from the excavations and analysis of the oxygen-depleted layers and remains of wooden house piles. However, a striking gap exists between highly resolved knowledge on certain issues, and some very fundamental, yet unsolved questions. Thus, it is known exactly which plant and animal species have been consumed [2], but the husbandry and land use methods are contradictory discussed [3], [4]. Evidence is for a highly dynamic settlement system and a short occupation time of many sites, yet the reasons are as unclear as the feedback mechanisms inside of the system [5]. This project aims at these questions using a systemic approach. My assumption is, that intensive resource use and degrading ecosystem services were the key factors determining the high mobility of the wetland settlements. Accordingly, my approach is to test whether the reconstructed land-use system could have been sustainable for a prolonged period.

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II. Regional and Archaeological Setting

WELASSIMO is simulating a hypothetical, idealized settlement, but I used data from several sites that have been excavated to a significant extent as a reference. Fig. 1 shows the three main sites that were used to this aim. All sites are located in South-Western Germany in the vicinity of Lake Constance. The physical landscape is largely influenced by the Würmian glaciation, as documented by numerous lakes of various sizes, kettle-hole peat-bogs, drumlin fields and wide areas of relatively fertile soils on glacial till. The subcontinental climatic conditions are locally favorable with relatively mild winters and mostly warm and humid summers. The site Ho1A (Hornstaad-Hörnle, 3918 - ca. 3905 BC) is located near the outlet of Lake Constance into the River Rhine. It was fully excavated, and a large body of evidence is published on archaeological and ecological questions, e.g. [6], [7], [8]. Up to 45 houses were inhabited contemporaneously, each of which is interpreted by the authors as an individual economic unit. I use their interpretation for the sake of simplicity, despite new studies that demonstrate how the social system is likely to have been more complex than the equation House = household = nuclear family [9]. At the site Si (Sipplingen-Osthafen), up to 15 anthropogenic debris layers bear witness of frequent settlement activities. Dendrotypological studies on the wooden house posts yield evidence of forest management systems, such as the use of primeval forest, the existence of coppiced forests, or intensive forest thinning [10]. For this project, I refer to the layers Si1 and Si2 (3919-3904 BC). The third settlement is De1A (Degersee), which was constructed at the shores of a small lake in the beginning of the 39th century BC and inhabited for a few years only. It was partially excavated recently, and only preliminary results are published until now, e.g [11].

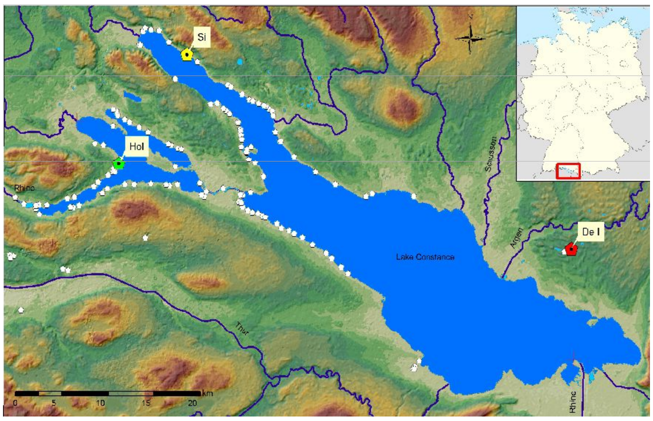

Fig 1. Distribution of pile-dwellings and peat bog sites near Lake Constance in SW-Germany and NE-Switzerland (not complete). Ho I:Hornstaad-Hoernle 1. Si: Sipplingen-Osthafen. De I: Degersee 1. Figure taken from [11]

III. The economic System: data and Hypotheses

The general properties of the system have been described by various authors in relative consistency, e.g. [1], [2], [12] and can thus be described as follows. The inhabitants of the wetland settlements lived on a mixed diet comprising of products from crop and livestock husbandry, hunting, gathering and fishing. They built elevated houses in close proximity to or directly in shallow lake areas or in peat bog. The mean lifespan of the houses was only several years [5], and accordingly, the occupation time of many of the sites was short. The interpretation of published data by the individual authors with respect to the internal functioning of the subsystems, however, is not consistent [3], [4]. This is especially true for the crop husbandry system. The major hypotheses on land-use related subsystems are:

A. Shifting Cultivation (SC)

The main arguments for this hypothesis on crop husbandry is evidence of frequent large-scale fires and for an anthropogenic increase in shrub-land vegetation at the beginning of the 4th Millennium BC. Several authors interpret these phenomena as a result of a land-use system that is based on ash fertilization of the crop fields, e.g. [3]. Massive nutrient input allows for high yields, while the need for fuel wood and very intense weed growth soon after the fire would require an annually shifting of the fields. Based on experimental reconstruction of this system, I assume annually varying yields with a long-term average of 3000 kg/ha for shifting cultivation. Annual variation of the yield due to weather is accounted for in all husbandry systems.

B. Intensive Garden Cultivation (IGC)

Well-preserved crop stores have been analyzed using the FIBS-approach [13]. The ecological properties of the plants are interpreted as evidence for a crop husbandry regime, that is - in contrast to *A* - based on permanent fields, which are cultivated for more than just a couple of years [4]. The analysis of isotope relations of the cereal grains make probable the use of animal dung for manuring of the fields, so that a small-scale, permanent and highly intensive cultivation is reconstructed [14]. Here, I assume an average yield of 2400 kg/ha, also with annual variation due to weather events.

C. Non-Intensive Cultivation (NIC)

This scenario is basically the same as *B*, but with the difference that no manure is applied and thus, yields are markedly lower and soil nutrient depletion may occur after some time. I assume an average yield of 1100 kg/ha.

D. Livestock husbandry regimes

The relative importance of livestock, especially cattle, is debated; while cattle bones with signs of butchery are found frequently, the reconstruction of an approximate number of cattle kept per person varies [15]. This is important not only with respect to the nutritional significance of livestock, but also in relation to the possible amount of manure available for IGC. As forest covered nearly all available land, large areas were possibly needed for forest pasture.

E. Forest management strategies

An ubiquitous and mostly well - preserved element of the wetland sites are the remains of wooden construction piles. The analysis of their tree-ring patterns yields not only an absolute dating for the felling of the trees, but also information on the structural and compositional features of the forest stand they grew in [10]. While coppiced forest or single tree selection dominated in some phases, in others only a few old trees seemed to be available. Likely for the ease of processing, quite young trees with a diameter of 5-20 cm were preferred in the beginning of the 4th Millennium. As these are not necessarily available in adequate numbers in a primeval forest, a suitable stand certainly constituted a valuable resource.

IV. The model

WELASSIMO is an agent-based simulation model of the system “pre-alpine wetland settlement” and its major subsystems, as shown in fig. 2. Agents are units of interest contributing to the system, programmed in specific software environment (here: NETLOGO). Agents in WELASSIMO are: “households”, comprising of an averaged 6 inhabitants; individual heads of livestock; secondary forest patches (age < 50 years); primary forest patches (age > 50 years); cereal field patches. For the formulation of the agent´s internal specifications and the necessary calculations, I reverted mainly on the published palaeoecological and archaeological data on wetland sites in the North-Western pre-alpine forelands of the 4th Millennium BC which I have compiled in [16]. The landscape is represented through grid cells of 25x25 m. Each cell incorporates a set of attributes, which are derived from modern spatial data and are modulated according to paleoenvironmental data on forest cover and soil development. The temporal resolution is one year. The model is driven by the inhabitant´s annual demand in calories and timber.

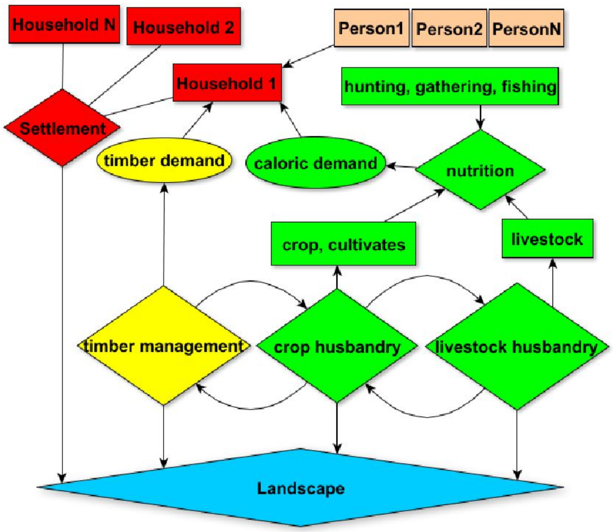

Fig 2. Schema displaying the major elements of the system "prehistoric wetland settlement". Subsystems are drawn as rhombes, the driving forces are drawn in oval shape. Colors are given according to internal relation of the system elements.

The observer has the ability to choose between various options on nutrition strategies and crop husbandry systems, from which a set of different scenarios results. The main discriminating choices are the hypotheses *A. - C.* described in section III, and the diet composition. Either 100%, 85% or 70% of cereals are formulated as an annual aim of the settlers, 15 % of livestock or 30 % summed up livestock + collected plants + game and fish making up for the rest. The cereal proportion aimed at determines the annual field size of one "household", but annual variation in yields due to weather events is incorporated. Thus, in some years the aim will not be met, and shortage occurs. If hunting/fishing/gathering is part of the nutrition strategy, this loss can be accounted for to some extent. For the crop yield determination, quasi-realistic centennial yield series for the 4th Millennium BC have been simulated using a modern agro-ecosystem model [17].
Processes on different timescales occur. Crop yields, fields size, forest pasture area, and number of "households" are updated every year, while houses have to be rebuilt every 7 to 12 years, and forest regeneration from field or clearing to primary forest needs 50 years. Soil nutrient depletion takes place in NIC, beginning 10 years after the initial cultivation of a field on Luvisol soil type. In contrast to the archaeological record, in the model, the "households" remain on their spot and the inhabitants do not change settlement location. Thus, it can be observed whether phenomena occur that necessitate a shift of habitation under a given scenario.

V. Results and Discussion

WELASSIMO can be seen as a tool that generates surplus value with respect to the inputted data. It dynamically thus allowing for an understanding of the spatial and systemic

Fig 3a (above) and 3b (below). Two snapshots of a simulation run of WELASSIMO, depicting the situation in year 10 of the settlement. The different land use patterns are due to different crop husbandry regimes as described in the text. Various shades of green represent natural ecosystems; brown areas are cleared from forest 1-2 years ago, incremental dots of green on the brown showing older patches. A yellow spot indicates a cereal field (25x25m). Black dots are this years areas for livestock forest pasture, red diagonal logs indicate forest patches where no suitable timber is available due to past logging.

implication of certain hypotheses. An example is shown in fig. 3a and 3b, which show a snapshot 10 years after the start of the simulation with the same input parameters (3 initial "households", diet of 70% cereal – 15% livestock meat – 15% hunted/gathered food). The difference is in the crop husbandry system, which is SC in 3a and IGC in 3b. A very different landscape is simulated as a result of the land use strategies. In 3a, a large area of primary forest has been converted by crop husbandry activities and is now in various stages of forest succession. The annual need for new fields and wood for ash-fertilization leads to relatively large distances to the fields of up to 1150 meters. The quite small area needed for livestock fodder is due to low livestock numbers (0.2 per Person) and high quality of leave fodder on secondary growth. In 3b, larger permanent fields due to lower yields and more livestock (0.7 per Person) for manuring reasons are needed. Thus, much more primary forest is conserved, but this is heavily affected by forest pasture and pollarding. Fields may be much closer to the settlement (max. 350 m). The major question behind this project is whether any one subsystem calls for a shift of the settlements after some time and necessitates the highly dynamic settlement system that can be reconstructed by dendrochronological dating. The main resources in question are work force, hunting and gathering grounds, timber forest, suitable soil for crop husbandry, and livestock browse area. The work force related to the scenarios is not simulated in detail; but other authors deal with the question of prehistoric work loads, and I have assured that my assumptions are within their ranges [18], [19]. The three crop husbandry subsystems have different implications. SC may necessitate distant fields. With a settlement size of 18 inhabitants, maximum field distances of 1150 meters occur, with 60 inhabitants up to 1800 meters. Systemic benefits may arise: the highly structured catchment may attract game; the fallowing areas make better livestock browsing areas than primary forest, and hazelnut bushes may grow much better here, providing nuts; secondary or coppiced forest has larger numbers of suitable trees. For a group the size of 18-60 applying SC, there arises no direct need for a shifting of their settlements. Only if one assumes that a maximum distance of 1800 meters may be too distant, there would be a case for this Hypothesis. IGC is facilitated by large numbers of livestock and means to collect the dung such as stables, for both of which in the pre-alpine region, there is no evidence in the beginning of the 4th Millennium. If these were proved, contiguous fields and good yields were to assume for decades. The primary forest might be very close to the settlements, though it would show signs of intensive browsing. So also from this Hypothesis, no necessity for high mobility arises.

NIC calls for somewhat larger fields than IGC, but other than that, there is not much difference.

The demand in timber with the right dimensions is quite high. The size of the area to harvest such trees is highly dependent on the composition of the forest stand. If a primary forest is assumed, the necessary timber for one house could be extracted from 0.5-1 ha. From a coppiced stand of 1 ha, however, a multitude of houses can be constructed [20]. Taking 7-12 years as an average house age, for a group of 10 "households" this may make the difference of extracting wood from 10 Ha of primary forest or from one Ha of coppiced forest. I therefore assume that the major resource governing the decision to shift habitation were suitable timber stands. Refinements of WELASSIMO will elaborate on that, accounting also for settlement density in the landscape and transport on water. The integration of detailed data on forest stand dynamics is not yet realized in WELASSIMO due to missing data on suitable modern analogies for the forest in the 4th Millennium BC; building on publications on Bialowieza National Park (Poland), this will be the next project to integrate in the simulations.

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An Agent-based Concept to Analyze Elite-Athletes' Doping Behavior

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Abstract — **A seemingly endless series of scandals has focused increasing public attention on the issue of doping among elite athletes. But we still do not know how many elite athletes really make use of banned drugs. In addition, we recognize the literature suffers a lack of appropriate game theory models for complex social interactions related to doping. Therefore, we think that an agent-based approach may allow doping behavior patterns in professional sports to be explored and elucidated. We conceptualize an agent-based model on three interacting objectives, namely (i) elite athletes, (ii) anti-doping laboratory and (iii) anti-doping agency. The latter agency announces anti-doping rules and imposes penalties; the anti-doping laboratory executes doping controls and elite athletes compete for income. In particular, we focus on presenting an agent-based concept to analyze elite athletes' doping behavior. Using such an agent-based framework and computational simulations may lead in the future to policy recommendations for the fight against doping.**

I. Introduction

AS LONG as competitive professional sports exist the phenomenon of using illicit methods like doping will remain. However, in modern times doping has gained more and more public attention since the astonishing death of cyclist Knud Jensen at the Olympic Games of 1960. The World Anti-Doping Agency (WADA) has shown the rate of Adverse Analytical Findings is approximately 1% in recent years [1]. But banned substances and methods may not be detectable and effective doping controls may not be feasible, e.g. because of their enormous costs in economic terms. Therefore, we believe, in line with [2]-[3], that [1] underestimates the true extent of doping behavior in elite sports. Recent research activities in this field are based on various methods to approximate the extent of doping but estimates differ widely. To begin with, [4] make use of projection-methods and estimate the extent of doping as approximately 72%. Applying a forensic approach, [5] analyze 7,289 blood samples collected from 2,737 athletes. The authors detect abnormal blood profiles and calculate the extent of blood doping as approximately 14% [5]. In a world wide web survey, [6] ask 448 German elite athletes about their doping behavior, making use of a randomized response technique to ensure that answers are anonymous. The authors present a lower interval limit of 25.8% and an upper limit of 48.1% for the use of banned substances or methods by German elite athletes [6]. Also applying a randomized response technique, [7] conduct a study of 1,394 international top athletes and find the extent of doping is approximately 6.8%. To sum up, we find in the literature estimations for extents of doping in a range of 1% to 72% [1]-[7]. Further investigations also differ in the extent of doping estimated, which supports our notion that identifying the real extent of doping is a complex problem [8]-[13].

To address this problem of complexity in professional sports doping researchers have developed various game theory models based on rational choice theory [14]-[17]. A common feature of these models is to depict doping behavior patterns in professional sports. But we think that these models exhibit a low degree of complexity because of analytical solvability.

Therefore, the main purpose of the paper is to address the complexity problem by presenting an agent-based concept to analyze elite athletes' doping behavior. If we have no clue what the real extent of doping may be how can we provide reliable policy recommendations? An agent-based approach might allow determining detected as well as undetected dopers within populations of elite athletes under varying environmental conditions. We describe below an agent-based framework that may serve in the future as a basis for generating simulation results and follow-up contributions. For instance, we incorporate elite athletes' decisions that affect more than one time period; an issue frequently neglected in the literature and which allows the investigation of lapse-of-time effects.

The paper is organized as follows. The next section presents a brief literature overview of game theory models that describe doping behavior patterns in professional sports, with a focus on strategic and inspection games. The third section proposes an agent-based concept to analyze elite athletes' doping behavior. The final section discusses implications and provides an outlook.

This study was conducted independently of funding from any organization.

II. Literature Overview of Game Theory Models

A. Strategic Games

In this subsection we survey briefly a series of game theory models that make use of strategic interactions based on rational choice theory to elucidate doping behavior patterns in sports. The seminal paper [14] appeared in 1987 and by a simple and simultaneous game theory model similar to a prisoner's dilemma situation describes an athlete's doping decision. The authors' so-called 'doping dilemma' consists of two rational-acting athletes endowed with identical characteristics who have to decide independently from each other to dope or not to dope. To do so, the athletes make use of an expected utility maximization approach as follows. An athlete decides to dope if her expected utility is higher in the case of doping abuse compared to the abandonment of doping. Therefore, athletes take benefits and costs of doping into account. The author concludes that without an anti-doping control, checked in turn by an international inspection procedure, the doping problem cannot be eliminated. In the case such a strategy does not work within a few years the legalization of doping is the only solution.

To our best knowledge [18] implements for the very first time a doping-control-scheme in strategic games to verify if athletes act rule-consistently so that detected doping athletes may be punished. Two interacting athletes make use of a linear expected utility function concerning whether to take banned substances or not. Although the authors invent a novel doping-control-scheme, their focus is on strategic interactions among athletes because of controls conducted at random and not on the basis of a specific decision-making process. The authors find that, beyond the investments made in the dope-testing system, other factors, such as prevention measures, the number of events and the prizes offered, have a non-negligible effect on doping behavior in elite sports.

Contrary to the assumption in both strategic games above, [19] assumes that athletes do not have an identical chance to win a competition. Hence, the author creates two artificial athletes endowed with heterogeneous characteristics and, therefore, having an unequal probability to win a competition even under identical conditions. The result is that ranking-based punishments are less costly and more effective than the regulations announced by the International Olympic Committee. Further, based on [19], 'unpublished' [20] develop an evolutionary doping game considering more than one time period. The authors find situations where, in theory, all athletes either break anti-doping rules or act totally rule-consistently. Furthermore, the authors provide evidence that highly talented athletes are more likely to dope than athletes with a lower degree of talent.

Reference [16] evolves a symmetric strategic game that takes two athletes into account who are endowed with homogeneous characteristica. The author aims to determine the influences of prize-money distributions and likelihoods to detect doping behavior. As an extension, [21] examines up to four athletes and focuses on comparisons between linear and non-linear prize-money distributions. While linear prize-money distributions lead to situations in which all athletes act (non-) rule-compliantly, non-linear prize-money distributions lead to more complex situations. Reference [22] refers to [16] as well as [21] and implements so-called 'fair play norms' like pre-play communication about doping and formal anti-doping agreements, which may induce higher compliance levels with anti-doping rules.

Reference [23] evolves an asymmetric strategic game within athletes' performance that depends on individual talent, or rather, constitution. An athlete may make use of legal activities like training or may resort to banned and illicit substances. In consequence athletes can enhance their performance and thereby improve their competition result. The author examines effective strength of doping substances, doping costs, and income effects with respect to the influence on an athlete's decision to dope or not to dope. The author identifies costs, likelihoods and base-salary effects that deviate athletes from doping abandonment.

Reference 'unpublished' [24] provides an asymmetric strategic game appropriate to consider any desired number of athletes. The author models a 'winner-takes-all' effect, i.e. only the winner of a competition receives prize-money. Such an extreme prize-money distribution seems to be responsible for the finding that incentives to dope decrease if the number of athletes in competition increases. In addition, 'unpublished' [24] deduces an optimal – in the sense of economic costs – quantum of doping controls if athletes are selected at random for testing.

B. Inspection Games

In this subsection we overview briefly inspection games applied to doping behavior, a recent development in game theory that [15] launched in 2002. It is important to distinguish between strategic and inspection games insofar as inspection games feature an institution which conducts doping controls on the basis of specific decision-making processes. After interactions among athletes in competition have taken place, an institution conducts doping controls. Thus, inspection games focus mainly on interactions between athletes and a doping-control institution whereas strategic games illuminate interactions among athletes. In the seminal paper on inspection games [15] shows that increasing fines leads to a higher level of rule-compliance.

Reference 'unpublished' [25] models characteristica very similar to those modeled in [15] and presents an institution that conducts doping controls as facing two kinds of error. On the one hand a doped athlete is not detected despite being tested (error of the first kind) and on the other hand a clean athlete may be erroneously found guilty of taking banned substances (error of the second kind). The author finds that an athlete's optimal choice – with respect to maximization of expected payoffs – depends on the preferences of the institution in terms of how to conduct dope controls and on the quality of those controls.

Reference [17] extends [19] with respect to a doping-control institution that decides subsequently to the competition whether to test the winner or not. Hence, the authors extend a strategic game to obtain an inspection game. Recall that the basic model, i.e. [19], consists of two athletes; a winner and a looser. Among other things, the doping-control institution takes information into account from the losing athlete, the so-called 'whistleblower' [17]. The authors conclude that whistleblowing reduces economic costs of doping controls, since testing athletes is costly.

Reference 'unpublished' [26] provides an extension of an inspection game model. The authors model three steps, which are, (i) competitions among athletes, (ii) doping controls, and (iii) decisions of customers or sponsors. The latter step is innovative and concerns in particular customers or sponsors' point of view with respect to their option to withdraw their financial support after a doping scandal. The authors find that doping controls should be carried out by an independent institution. A doping-control institution that depends on the financial support of customers or sponsors has no incentive to detect doping athletes.

To summarize, we surveyed briefly more than ten contributions to game theory models of doping behavior patterns. We find that the strategic and inspection models above often consider fewer than four athletes; a feature far from reality in professional sports. Reference 'unpublished' [24] is an exception that allows any desired number of athletes to be considered. However, game theory models applied to doping have a low degree of complexity. Therefore, we propose in the following section an agent-based concept to analyze an elite athletes' doping behavior.

III. Agent-based Concept

A. Aims and Basics

In line with the literature we think that agent-based modeling has potential as a 'third way' of doing social science in addition to argumentation and formalization [27]. Reference [28] provides a toolkit for agent-based modeling and computational economics. Reference [29] overviews agent-based modeling applied to economic problems and social dilemmas. Reference [30] presents recent advances in computational econophysics including agent-based econophysics. Making use of agent-based modeling we are able to formalize theories on complex social processes like doping behavior patterns in professional sports. Thus, modeling a high degree of complexity is an essential advantage of an agent-based approach compared to game theory models.

Note that we do not aim to present an agent-based model of doping behavior for the purpose of estimating or predicting the real extent of doping in professional sports. Instead, we intend to model a complex social system to test how parameters – e.g. bans, fines, prize-money distributions and subjective detection probabilities – may influence elite athletes' doping behavior and how policymakers may fight against doping.

Our multi-period agent-based doping concept is based on three interacting objectives, namely, (i) elite athletes, (ii) an anti-doping laboratory, and (iii) an anti-doping agency. The agency announces anti-doping rules and imposes fines as well as bans. Anti-doping laboratory executes doping controls whereby control frequency and efficiency are imperfect, so that not every doped and tested elite athlete is detected as a dope user. In each time period any elite athlete competes for income in a rank-order tournament. We assume that using dope increases an elite athlete's chance of success in rank-order tournaments in the short term but such an illegal practice causes an adverse reaction in the long term. To put it differently, in the long term the harm caused to elite athletes by doping is higher than the benefits. We justify such an adverse reaction to doping in terms of potential health risks. However, in the following subsections we introduce key parameters and explain in detail our three interacting objectives (i) elite athletes, (ii) anti-doping laboratory, and (iii) anti-doping agency.

B. Anti-doping Agency

We create an 'artificial' anti-doping agency within our agent-based concept to reflect the 'real world' institution, i.e. the WADA. The anti-doping agency announces anti-doping rules the elite athletes have to comply with. Hence, the anti-doping agency sets a Complexity of Anti-doping Rules (CAR). Furthermore, the anti-doping agency determines pecuniary levels of FINes (FIN) and states BANs (BAN). Thus, detected dope-taking athletes face a system of punishment that consists of fines paid in Tokens and bans with respect to time periods an elite athlete is forbidden to participate in rank-order tournaments. The maximum number of time periods applied, i.e. the maximum ban (maxban), depends on minimum and maximum age (minage, maxage) within a population of elite athletes. Table I provides characteristica of parameters and attributes used in our agent-based doping concept.

At the end of any time period the anti-doping agency publishes statistics on doping. In particular, we aim at calculating figures like the Share of DEtected elite athletes (SDE), the Share of DOped elite athletes (SDO) and the Share of Detected and Doped elite athletes (SDD).

TABLE I.
AGENT-BASED DOPING MODEL: CHARACTERISTICA OF PARAMETERS AND ATTRIBUTES

Parameter / Attribute	Abbreviation	Characteristica	
Anti-doping Agency			
Complexity of Anti-doping Rules	CAR	[0;1]	Exogenous
FINes	FIN	[0; ∞]	Exogenous
BAN	BAN	[0; maxban]	Exogenous
Anti-doping Laboratory			
Number of Tested elite Athletes	NTA	[0; N]	Exogenous
Number of Preannounced-tested elite Athletes	NPA	[0; N]	Exogenous
Number of Randomly-tested elite Athletes	NRA	NTA-NPA	Exogenous
Control EFficiency	CEF	[0; 1]	Exogenous
Number of Controlled Periods	NCP	[1; ∞]	Exogenous
Share of DEtected elite athletes	SDE	[0; 1]	Endogenous
Share of DOped elite athletes	SDO	[0; 1]	Endogenous
Share of Detected and Doped elite athletes	SDD	[0; 1]	Endogenous
Elite Athletes			
Population of elite athletes	N	[1, ∞]	Exogenous
Identification number	I	[1, N]	Exogenous
AGe	AG	[minage; maxage]	Endogenous
Behavioral-Type	BT	[A; B; C; D]	Exogenous
PErformance	PE	[0, maxperformance]	Endogenous
FItness	FI	[0; 100]	Endogenous
COnstitution	CO	[0; 100]	Endogenous
DIsturbance	DI	[0; 100]	Endogenous
INcome	IN	[-∞; maxprize]	Endogenous
Income due to Detected doping	ID	[-∞; maxprize]	Endogenous
Income due to Undetected doping	IU	[-DC; maxprize]	Endogenous
Doping Decision	DD	[+; -]	Endogenous
Realized Rank in tournament	RR	[0; N]	Endogenous
Doping Costs	DC	[0; ∞]	Exogenous
Doping Efficiency	DE	[0; 1]	Exogenous
Doping Harm	DH	[0; 1]	Exogenous
Prize-Money	PM	[0; maxprize]	Endogenous
Weighting of Fitness	WF	[0; 1]	Exogenous
Weighting of Constitution	WC	[0; 1]	Exogenous
Weighting of Disturbance	WD	[0; 1]	Exogenous
Time index	T	[0; ∞]	Endogenous
Weighting of doping Efficiency	WE	[0; 1]	Exogenous
Weighting of doping Harm	WH	[0; 1]	Exogenous
Expected Utility	EU	[0; 1]	Endogenous
Subjective detection Probability	SP	[0; 1]	Endogenous
Risk Perception	RP	[0; 1]	Endogenous
Size of an elite athletes' social Network	SN	[1; N]	Exogenous
Number of periods an elite athlete has to act Rule-compliant	NR	[0; maxage-minage]	Exogenous

Note: Table I offers an overview of characteristica used within the agent-based concept sorted according to (i) anti-doping agency, (ii) anti-doping laboratory, and (iii) elite athletes. The first column displays the parameters or attributes; the second column shows related abbreviations, and the last column presents characteristica with respect to the domain and whether the parameter or attribute is determined endogenous or exogenous.

C. Anti-doping Laboratory

We suppose an 'artificial' anti-doping laboratory that conducts doping controls according to anti-doping rules announced by the anti-doping agency for the whole population of N elite athletes. In each time period doping controls are carried out as follows. Immediately after a rank-order tournament some participants are selected for testing so that we obtain a Number of Tested elite Athletes (NTA). Note that the number of tested elite athletes is made up of two terms. First, we assume a Number of Preannounced-tested elite Athletes (NPA) in the sense that participants are always tested if they achieve preannounced placements in a rank-order tournament – usually placements near the winner, for instance, winners of medals at the Olympic Games are always tested. Second, we suppose a Number of Randomly-tested elite Athletes (NRA), reflecting doping controls at random to ensure that doped elite athletes face the risk of being caught and punished regardless of their placement in the rank-order tournament. Equation (1) guarantees some randomly tested elite athletes will be selected, since otherwise a feasible strategy for doped participants is to achieve placement NPA +1 so that any risk of being tested and caught is circumvented. Thus, Equation (1) is necessary and sufficient to generate deterrence of the use of banned substances.

$$NRA = NTA - NPA > 0 \tag{1}$$

Numbers of tested and preannounced-tested elite athletes can be freely selected according to Equation (1) before executing the source code to obtain simulation results. Eventually, in analogy with the literature of game theory models, we assume that doped and tested elite athletes will not be detected as doping athletes for sure in this time period because of imperfect Control EFficiency (CEF).

Regarding time periods, we suppose two treatments concerning how to conduct doping controls. First, in the `baseline treatment` we require that elite athletes face doping controls in the actual time period only. Obviously, the Number of Controlled Periods (NCP) then equals one. Further, an objective likelihood of being caught in the baseline treatment depends on control efficiency, placements in rank-order tournaments, and numbers of tested and preannounced-tested elite athletes. Second, in the `back-controlling treatment` we postulate that elite athletes are tested in the actual time period as well as for some time periods in the past. Thus, the number of controlled periods is now greater than one. Further, the objective likelihood of being caught in the back-controlling treatment depends on the number of controlled periods in addition to control efficiency, placements in rank-order tournaments, and numbers of tested and preannounced-tested elite athletes.

Finally, at the end of any time period the anti-doping laboratory and the anti-doping agency exchange information on doping rules, the number of tested elite athletes (i.e. executed doping controls), Share of DEtected elite athletes (SDE), Share of DOped elite athletes (SDO) as well as Share of Detected and Doped elite athletes (SDD). Based on that information the anti-doping agency regularly publishes doping statistics and assigns fines and bans to elite athletes. Among other things, we describe in the following subsection how punishment of detected and doped elite athletes might take place.

D. Elite Athletes

We create 'artificial' elite athletes endowed with heterogeneous attributes to populate our agent-based framework. In particular, among the population of N elite athletes each one has ten attributes at any specific Time index (T), namely Identification number (I), AGe (AG), INcome (IN), Doping Decision (DD), Realized Rank (RR), PErformance (PE), FItness (FI), COnstitution (CO), DIsturbance (DI), and Behavioral-Type (BT).

Identification numbers are allotted in the initial time period and remain constant for all future periods to identify elite athletes in computational simulations. For simplicity, we drop abbreviations I, N, and T whenever possible.

An elite athlete's age is assigned, also in the initial time period, to an integer between minimum and maximum age but in every period the population grows one period older. As a consequence elite athletes retire mandatorily after reaching the maximum age, i.e. their career in professional sports ends. Retired elite athletes are replaced by newcomers at the minimum age. During replacement all other attributes of newcomers are set to the initial values of retired elite athletes. Note that such a procedure of replacement ensures that the distribution of elite athletes' attributes like Behavioral-Type (BT) remains identical over time and, therefore, allows for observing age-effects under `ceteris paribus` conditions.

In each time period elite athletes compete for income in a rank-order tournament [31]. In such a rank-order tournament the income depends on elite athletes' relative performance. Rank externalities in combination with the so-called 'superstar effect' may result in a situation where small variations in performance lead to strong differences in the distribution of income [32]. Thus, we assume a prize-money distribution as follows. Winners of a rank-order tournament get a maximum prize of 1,000 Tokens and the next-highest finishers until rank 99 get a positive amount of Tokens – but less than each finisher's predecessor. If elite athletes realize rank 100 or worse they earn nothing in this time period. Table II presents a non-linear prize-money distribution intended to be used for theoretical considerations and computational simulations. In particular, we make use of this prize-money distribution to provide a numerical example in the course of the paper. Nevertheless, to allow for a higher degree of generality we introduce a parameter for the maximum prize (maxprize) available.

TABLE II.
EXAMPLE: PRIZE-MONEY DISTRIBUTION OF RANK-ORDER TOURNAMENT IN TIME PERIOD T

Realized Rank	Prize-Money in Tokens	Realized Rank	Prize-Money in Tokens	Realized Rank	Prize-Money in Tokens	Realized Rank	Prize-Money in Tokens
1	1,000	**26**	135	**51**	63	**76**	24
2	700	**27**	130	**52**	61	**77**	23
3	500	**28**	125	**53**	59	**78**	22
4	400	**29**	120	**54**	57	**79**	21
5	350	**30**	115	**55**	55	**80**	20
6	310	**31**	112	**56**	53	**81**	19
7	280	**32**	109	**57**	51	**82**	18
8	260	**33**	106	**58**	49	**83**	17
9	250	**34**	103	**59**	47	**84**	16
10	240	**35**	100	**60**	45	**85**	15
11	230	**36**	97	**61**	43	**86**	14
12	220	**37**	94	**62**	41	**87**	13
13	210	**38**	91	**63**	39	**88**	12
14	200	**39**	88	**64**	37	**89**	11
15	190	**40**	85	**65**	35	**90**	10
16	185	**41**	83	**66**	34	**91**	9
17	180	**42**	81	**67**	33	**92**	8
18	175	**43**	79	**68**	32	**93**	7
19	170	**44**	77	**69**	31	**94**	6
20	165	**45**	75	**70**	30	**95**	5
21	160	**46**	73	**71**	29	**96**	4
22	155	**47**	71	**72**	28	**97**	3
23	150	**48**	69	**73**	27	**98**	2
24	145	**49**	67	**74**	26	**99**	1
25	140	**50**	65	**75**	25	**100**	0

Note: Table II shows a regressive non-linear prize-money distribution used within the agent-based concept. We assign each realized rank a specific amount of prize-money in Tokens due to an elite athlete's placement in the rank-order tournament. Note that if elite athletes achieve rank 100 or worse they receive a prize-money of zero.

An elite athlete's income in a time period is calculated as follows. We suppose elite athletes have only one source of earnings, which is prize-money earned from successful competition in rank-order tournaments. Depending on Realized Rank (RR), any participant can earn a non-negative amount of Prize-Money (PM) according to Table II. An elite athlete's spending depends on the individuals' Doping Decision (DD), Doping Costs (DC) and proposed FINe (FIN) in the case of detection. Note that doping decisions are binary. We explain how elite athletes make their doping decision in the behavioral-type paragraph later on in this subsection. However, subscript '+' indicates that an elite athlete uses dope and subscript '–' indicates an elite athlete does not use dope. Thus, we obtain Equation (2) presenting three cases with respect to feasible income.

$$IN = \begin{cases} IU = PM_{+} - DC \\ ID = -DC - FIN \\ PM_{-} \end{cases} \quad (2)$$

First, an elite athlete dopes and remains undetected for whatever reason. Then, she has to pay her doping costs (DC) from her prize-money (PM_+) so that she obtains an Income due to Undetected doping (IU). Second, a doped elite athlete is detected and as a consequence she earns no prize-money and has to pay a fine (FIN) in addition to her doping costs (DC), which leads to a non-positive Income due to Detected doping (ID). Third, an elite athlete does not make use of doping so that she can enjoy her prize-money (PM_-) for certain. Note that we implement an error of the first kind if and only if control efficiency of the anti-doping laboratory is less than one. Further, we do not model an error of the second kind. To put it differently, we may find in our agent-based framework a dope-using elite athlete who is not detected despite being tested but a clean elite athlete cannot erroneously be found guilty of taking banned substances. We adhere to this feature since an accused and innocent elite athlete may go to court and we are confident that she will get justice sooner or later. Moreover, intuition may favor the notion that prize-money is always higher when making use of doping than not. Note that this notion is not true since an elite athlete's placement depends on her performance in

TABLE III.
EXAMPLE: SHORT- AND LONG-TERM EFFECTS OF DOPING IN TIME PERIOD T

Parameter	Weighting of Doping Efficiency (Short-term Effects)	Weighting of Doping Harm (Long-term Effects)
Period T	WE_0=1	WH_0 = 0
Period T+1	WE_1=0.5	WH_1=0.25
Period T+2	WE_2=0.25	WH_2=0.5
Period T+3	WE_3=0	WH_3=0.75
Period T+4	WE_4=0	WH_4=1
Period T+5	WE_5=0	WH_5=0.75
Period T+6	WE_6=0	WH_6=0.5
Period T+7	WE_7=0	WH_7=0.25
Period T+8	WE_8=0	WH_8=0

Note: Table III contrasts doping efficiency and doping harm over time. While doping has a decreasing positive effect over three periods, the negative effect of doping increases from time period T+1 to T+4 and declines afterwards until it becomes zero in time period T+8.

rank-order tournaments and includes randomly allotted disturbance-effects.

In this paragraph we explain an elite athlete's PErformance (PE) used to model rank-order tournaments in the presence of doping behavior. Performance takes into account an individual's FItness (FI), COnstitution (CO), and DIsturbance (DI). In addition, we need to introduce three related figures as real numbers between zero and unity. These numbers are Weighting of Fitness (WF), Constitution (WC), and Disturbance (WD). If a weighting factor is zero, performance is not influenced by the respective attribute. An increase in the weight of a factors leads to higher influence of respective attributes; maximum influence is reached at unity. To ensure that clean elite athletes can get only a preannounced maximum performance (maxperformance) we suppose that weighting factors sum up to unity. Equation (3) formalizes this weighting-condition.

$$WF + WC + WD = 1 \tag{3}$$

Further, we assume Equation (4) represents an elite athlete's performance.

$$PE = WF \cdot FI + WC \cdot CO + WD \cdot DI \tag{4}$$

In the initial time period an individual's FItness (FI), COnstitution (CO), and DIsturbance (DI) are randomly allotted between zero and 100. Thereafter, we suppose that disturbance is calculated each time period randomly, whereas physical fitness and constitution change due only to doping. Thus, a clean elite athlete can reach only a maximum performance of 100. COnstitution reflects an elite athlete's physique in terms of long-term effects. For instance, we assume that Doping Harm (DH) affects constitution as follows. Effects of doping harm increase over time, reach a maximum, and then need some time periods to vanish. Fitness represents an elite athlete's physique regarding short-term effects. Thus, Doping Efficiency (DE) affects fitness as follows. Effects of doping efficiency occur immediately at a high positive level and then need some time periods to vanish (see Table III). Finally, disturbance may reproduce an elite athlete's fortune or misfortune in competition. Realized rank depends on an individual's performance; in each period the highest value of performance wins the rank-order tournament.

To provide an example, we assume that an elite athlete makes use of doping in time period T only. Further doping has positive effects on fitness for three time periods whereas such an illegal practice has negative effects on constitution for seven periods. Regarding strength of effects we introduce two related figures as real numbers between zero and one. These are Weighting of Doping Efficiency (WE), and Doping Harm (WH). Furthermore, we assign in Table III numerical values to these weighting factors. For a sequence of time periods we obtain then Equations (5) and (6), which describe effects on constitution and fitness, respectively, if an elite athlete makes use of doping in time period T

$$CO_{T+at} = CO \cdot \prod_{t=0}^{at} \left(1 - WH_t \cdot DH\right), at \in \{0;...;8\} \tag{5}$$

and

$$FI_{T+at} = FI \cdot \prod_{t=0}^{at} \left(1 + WE_t \cdot DE\right), at \in \{0;...;8\} \tag{6}$$

Of course, we have to adjust Equations (5) and (6) if elite athletes make use of doping in more than one time period to incorporate overlapping-effects. However, in the following paragraph we describe how elite athletes may behave with respect to making their multi-period doping decisions.

We postulate four Behavioral-Types (BT) of elite athletes, namely, (i) rational-acting A-types, (ii) suggestible B-types, (iii) compliant C-types, and (iv) erratic D-types. Rational-acting A-type elite athletes might make use of doping substances with respect to an expected utility maximizing approach. A suggestible B-type elite athlete is influenced strongly by doping behavior committed in her social network. A compliant C-type elite athlete accepts and follows strict announced anti-doping rules. An erratic D-type elite athlete wants to act rule-consistently but may commit doping unintentionally because of her ignorance of announced anti-doping rules or other misbehaviors. Note that these proposed behavioral-types stem originally from agent-based tax evasion models [33]-[39]. For instance, [33] makes use of an exponential utility function to model expected-utility-maximization behavior of rational-acting taxpayers. Thus, we transfer recent advances in tax compliance research to doping behavior patterns.

Rational-acting A-type elite athletes constrain their doping decision based on whether taking banned substances increases their Expected Utility (EU) or not. Thus, we make use of an exponential utility function displayed in Equation (7). Distinguishing the doping use and doping abandonment cases, we aim to model expected-utility-maximization behavior of rational-acting elite athletes, that is

$$EU(IN) = \begin{cases} \mathrm{EU}_{+} = \mathrm{SP}(1-\mathrm{e}^{-\mathrm{RP \cdot ID}}) + (1-\mathrm{SP})(1-\mathrm{e}^{-\mathrm{RP \cdot IU}}) \\ \mathrm{EU}_{-} = \qquad 1-\mathrm{e}^{-\mathrm{RP \cdot PM_{-}}} \end{cases} \quad (7)$$

In order to maximize their expected utility, A-type elite athletes take Income due to Detected doping (ID) and Income due to Undetected doping (IU) into account. Further, we introduce a Subjective detection Probability (SP) that reflects an A-type elite athlete's perception of being caught as a doped participant. In the course of the paper we provide a numerical example of the maximizing procedure. However, note that the subjective detection probability may differ from an objective detection probability given by the anti-doping laboratory and the anti-doping agency. Furthermore, A-type elite athletes are endowed with a subjective Risk Perception (RP) to reflect their attitude to uncertainty. Subjective risk perception takes values between zero and unity whereby risk-seeking athletes have a value close to zero and risk-averse athletes have a value of nearly unity. According to [40] elite athletes become more risk seeking over time because of increasing opportunity costs in the course of their biographical fixation. While young elite athletes have more opportunities to find employment beyond professional sports, older elite athletes have often to persist in the system. A-type elite athletes are assigned to one out of four risk groups appropriate to their age. Table IV provides details with respect to classification of A-type elite athletes in risk perception groups. Risk perception is randomly allotted to elite athletes between the upper and lower threshold of their respective risk group. However, A-type elite athletes make use of doping if expected utility is higher in the case of doping abuse (EU_+) than in the case of anti-doping rule compliance (EU_-).

B-type elite athletes are suggestible and therefore their doping behavior depends on the doping behavior committed in their social networks. Therefore, B-type elite athletes decide to dope if at least one athlete in her social network dopes but none is caught as a doped participant. The size of the elite athletes' Social Network (SN) is equal for all athletes. For simplicity we assume a ring-world structure so that an elite athletes' I social network includes athletes with the identification numbers I+1, …, I+SN. If N is reached the social network includes elite athlete I=1 and so on until SN athletes are chosen. Note that [33] have used such a ring-world structure to investigate tax evasion behavior in a society of heterogeneous agents. Reference [37] examine various social network structures and find that Erdös-Rényi and Power-law-distributed networks influence taxpaying behavior particularly strongly. However, in line with the literature we assume that a convicted B-type elite athlete has to act for a designated Number of periods Rule-compliantly (NR).

Compliant C-type elite athletes act always and deliberately in a rule-compliant manner. That is why C-type elite athletes do not make use of a specific decision-making calculation.

Erratic D-type elite athletes also want to act in compliance with anti-doping rules but may break these rules unintentionally because of a lack of knowledge about anti-doping rules in force. The probability for such misbehavior depends on the Complexity of Anti-doping Rules (CAR) set by the anti-doping agency. For instance, CAR=1 corresponds to anti-doping rules with the highest level of complexity. In this case D-type elite athletes are more likely to act against anti-doping rules. Contrarily, CAR=0 displays anti-doping rules with the lowest level of complexity so that

TABLE IV.
CLASSIFICATION OF RATIONAL-ACTING A-TYPE ELITE ATHLETES IN RISK PERCEPTION GROUPS

Age (AG)	**Subjective Risk Perception (RP)**
minage ≤ AG < minage + (maxage-minage)·0.25	[0.75;1]
minage+ (maxage-minage)·0.25 ≤ AG < minage + (maxage-minage)·0.5	[0.50;0.75]
minage + (maxage-minage)·0.5 ≤ AG < minage + (maxage-minage)·0.75	[0.25;0.50]
minage + (maxage-minage)·0.75 ≤ AG < maxage	[0;0.25]

Note: Table IV displays classification of rational-acting A-type elite athletes into four risk perception groups with equal intervals. The first column illustrates age intervals and the second column is associated with the related subjective risk perception interval.

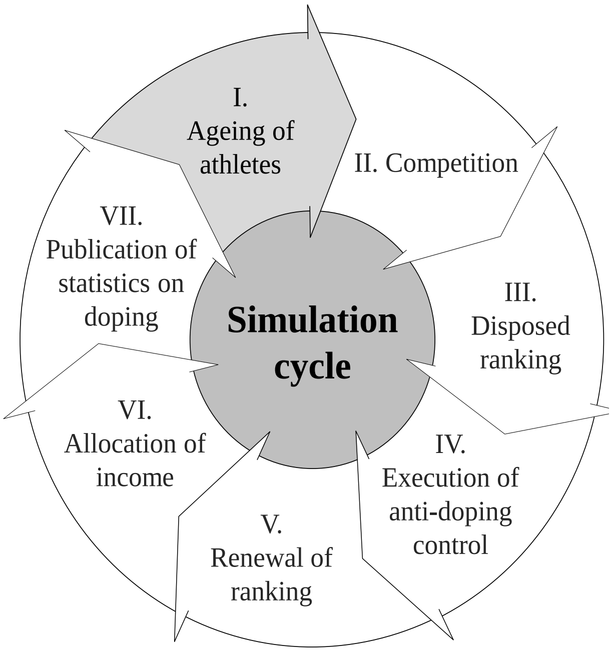

Fig 1. Graphical Illustration of Simulation Process

all D-type elite athletes are able to follow anti-doping rules. In the latter case D-type agents behave like compliant C-type agents.

E. Simulation Process

Above we have described three interacting objects. The aim of this subsection is to depict the simulation process within which these objects interact. After running some initial rounds to create objects and to generate initial information we repeat a simulation cycle as often as required. Fig. 1 illustrates this simulation cycle and its seven steps.

As a first step, in each time period any elite athlete grows one time period older until reaching maximum age (maxage). On reaching maximum age an elite athlete retires and is replaced by an agent at minimum age (minage), all of whose other attributes are set to the initial values of the retired elite athlete to allow for investigations under ceteris paribus conditions.

Subsequently, elite athletes make their doping decision on the basis of their behavioral-type specific decision calculus described above. Using the information concerning doping decisions a rank-order tournament takes place (step II). In the third step, a disposed ranking is drawn up. According to the rank-order tournament, all elite athletes are sorted according to their performance in competition. Both clean and doped elite athletes are listed on this disposed ranking.

Afterwards an anti-doping laboratory executes an anti-doping control (step IV) in which the preannounced-tested elite athletes are chosen on the basis of the disposed ranking and additional athletes are selected at random. Note that since doping test efficiency and frequency is imperfect not every doped athlete will be caught. Convicted dopers are noted and are punished by the anti-doping agency.

In the fifth step, convicted dopers are removed from the disposed ranking and a renewed ranking is created. The next step is to distribute income to clean elite athletes and undetected dopers based on the renewed ranking (step VI). Thus, we make use of the prize-money distribution described in Table II. In the seventh and last step, the anti-doping agency announces detected and undetected extent of doping and other statistics. This information is used in subsequent periods e.g. elite athletes base their doping decisions on them.

F. Illustration of Doping Decision

We describe in this subsection the decision-making calculus of a rational-acting A-type elite athlete in the course of a rank-order tournament as an example. In this example, parameters and attributes are set to values as follows.
N = 100; WF = 0.5; WC = 0.4; WD = 0.1; DC = 100; FIN = 200. Furthermore, let us assume we are considering elite athlete 23 (I = 23) and suppose parameter values in the first period (T = 1) are as follows. $AG_{23;1} = 37$; $FI_{23;1} = 86.4$; $CO_{23;1} = 78.5$; $DI_{23;1} = 95.0$; $RP_{23;1} = 0.01$; $SP_{23;1} = 0.002$. Inserting these values in Equation (4) leads to Equation (8).

$$PE_{23;1} = 0.5 \cdot 86.4 + 0.4 \cdot 78.5 + 0.1 \cdot 95.0 = 84.1 \qquad (8)$$

Moreover, we assume that elite athlete 23 achieves rank eight ($RR_{23;1} = 8$) with respect to her performance ($PE_{23;1} = 84.1$). Using the prize-money distribution described in Table II, she earns 260 Tokens if acting rule-compliantly.

Elite athlete 23 may increase her $FI_{23;1}$ value in the short term by 30 percent (DE = 0.3) through the use of banned substances. In this case her $FI_{23;1}$ may increase to 112.32 and, therefore, her $PE_{23;1}$ to 97.06. If her doping abuse remains undetected, let us assume she achieves second place in the rank-order tournament and earns 700 Tokens, but has to pay 100 Tokens for doping substances, so that 600 Tokens ($IU_{23;1} = 600$) remains. If elite athlete 23 is detected her loss amounts 300 Tokens ($ID_{23;1} = -300$). Inserting $IU_{23;1}$, $ID_{23;1}$, $RP_{23;1}$, and $SP_{23;1}$ in Equation (7) leads to Equation (9).

$$EU_{23;1+} \begin{array}{l} = 0.002\,(1-e^{(-0.01)\cdot(-300)}) + (1-0.002)\,(1-e^{(-0.01)\cdot(600)}) \\ \approx 0.957 \end{array} \qquad (9)$$

In the case of doping abandonment, elite athlete 23 earns 260 Tokens for certain, so that IN = 260 is inserted in Equation (7) leading to Equation (10)

$$EU_{23;1-} = 1 - e^{(-0.01)\cdot(260)} \approx 0.926 \qquad (10)$$

Since elite athlete 23 is rational and an expected-utility-maximizer she decides to dope ($EU_{23;1+} > EU_{23;1-}$).

IV. Discussion and Outlook

To our best knowledge we have proposed in this paper for the very first time an agent-based concept to analyze elite athletes' doping behavior. Varying parameters for various kinds of sport can be selected. Currently the computational simulation is in a preliminary state so that simulation results are not yet available. However, a benefit of such an agent-based modeling approach is that doping behavior patterns may be investigated in a more realistic manner than with other methods like traditional game theory approaches.

In theory we expect our basic concept to show that back-controlling, i.e. doping controls with respect to competitions years ago, influences an elite athlete's decision to dope or not to dope particularly strongly. Note that lapse-of-time effects with respect to doping behavior are frequently neglected in the literature. We think that such an agent-based approach may provide new insights concerning lapse-of-time effects. For instance, deterrence effects that lengthen time spans regarding storage of necessary materials to conduct doping controls, e.g. blood and urine samples of elite athletes, are important. Moreover, interaction processes among elite athletes in competition may influence the effectiveness of lengthening storage time spans depending on behavioral type distributions in artificial populations.

After generating simulation results, the next step in our research project might allow the sensitivity of various anti-doping measures to be determined by varying the latter ceteris paribus. Based on simulation results we may provide policy recommendations to the WADA such as an optimal budget allocation for prevention policies. This will be very useful for future practice of doping prevention. In 2014 a budget of 26 million US Dollar is available to the WADA, but the contributions of several anti-doping measures are still unknown [41]. Using an agent-based modeling approach, their efficiency and effectiveness can be estimated for the first time.

With respect to extensions, we plan to implement a fixed budget for the anti-doping agency that finances various activities, e.g. control (delegated to anti-doping laboratories), education and prevention of doping behavior patterns. Within such an extended framework we can examine economic costs of doping controls and investigate optimal allocations of resources. In addition, several doping substances may be distinguished. The latter feature would lead to different detection probabilities and doping costs. Furthermore, consultants, e.g. team-managers or doctors, with an own advisor utility function could be implemented since consultants seem to play a main role in professional sports. Both outlook and extensions delineate a rather rich agenda for research activities in the future.

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How passenger decides a check-in option in an airport: Self-Service Technology Adoption model in passenger process

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Abstract—**This study intends to propose "Self-Service Technology Adoption Model" by utilizing the knowledge and experiences of front line experts. The Agent-Based Model has a fuzzy inference system to let passengers choose a check-in option: a conventional style check-in position or a self-service kiosk. The experiments are conducted with observed data, which are collected from the airline's Departure Control System (DCS). We tried approximating the experimental space to "the real world" and evaluating the proposed model by measuring how it reproduces the observed self-service usage rate in "the real world". This study also suggests the efficient practice of air–travel passenger handling with self-service kiosks in an international passenger terminal by the simulation of the proposed agent-based model. Through conducting the experiments, the scenario and the key factor are indicated, which may possibly accelerate the self-service usage rate with cost effective way and less impact for customer services.**

I. Introduction

THIS study pursues to clarify how consumers make decision when they face to choose self-service technology to help firms understand how they can best promote cost efficient service alternative. We look over the current circumstances of airline industry in this chapter, and describe the objectives of this study.

A. Background

Currently Full Service Carriers (FSCs) are facing severe competition with new players such as Low Cost Carriers (LCCs) and other foreign carriers, in which the current deregulation policy brings aircraft landing slots in the short-range view of the aviation industry in Japan. The recent statistic clearly shows our society is aging due to better health care and with fewer children; these facts consequently leads airlines to the necessity to enhance their presence in the international service sector rather than the domestic service sector.

The competition in global airline industry will be even more severe for them because emerging countries can provide workforce with a lower wage cost than labor markets of developed countries. Current FSCs need to provide high quality service with lower price in order to keep attracting the loyal frequent flyers.

Huge investments are required to upgrade services as well as renew the aging air fleets and equipment. The automated process has been recognized as one of solutions for cost saving and self-service technologies (SST) have been implemented in various processes. However, though self-service process in the domestic airports is spreading, there is a lot of room for improvement in the international sector.

B. Objective of this study

This paper pursues two objectives. One of them is constructing the SST adoption model to examine the mechanism of how passengers choose their check-in option in the departure lobby of an international airport. We study how recognized waiting time and the degree of self-service options' perceivability affect usage rate of self-service kiosks by modeling the process of cognition and decision-making of passengers, which the queuing theory does not deal with [3]. We conduct series of experiments to ascertain the validity of the proposed agent-based model through calibration and expanding the prototype model. It has a fuzzy inference system, which utilizes the empirical knowledge of front line experts and observed data from airline's DCS.

The other objective of this study is to discuss the best practice of passenger service with self-service kiosks among the prepared scenarios. We also discuss how the frequent self-service users' existence helps increase the usage rate of self-service kiosks.

Knowing how the passengers makes decisions and what contributes to increase self-service usage rate will help firms to plan how they can best promote SST usage improvement.

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II. RELATED WORK

According to Levitt [6], the product of an airline is not only transporting passenger from point A to point B, but "service" itself. As service has characteristic of "intangibility", "inseparability", "heterogeneity", "perishability", air-travel passenger evaluate those services from their travel experience including check-in process in the departure lobby. We reviewed previous studies of self-service technology and diffusion of innovation from three areas.

Convenience has been examined and discussed from mainly two perspectives, one side of them is "waiting time and its management" and other is "what people find their convenience from the consumer point of view" [1]. There are studies for finding factors which influence the usage of SSTs through various surveys by interviews and questionnaires on service site and/or in website etc.

Meuter[7] described that service convenience brought consumers' satisfaction of using SST and the most major reason of using SST when it is "better than alternatives" and they appreciate "time saving" the most. Bitner[2] proposed that "Consumer Readiness" influences the usage of SSTs in "The Model of SST Adoption". Meuter[8] extended their study and found "Technical Anxiety" explained influence of SST adoption even better than the demographics of users.

Rogers[9] described that the designated variables defined the speed of diffusion. More "Relative Advantage", higher "Compatibility", less "Complexity", higher "Trialability" and "Observability" speed up the diffusion of innovation. And how "change-agent" promotes the innovation is one of important variables to fasten the diffusion.

Check-in is mandatory process for air-travel passenger before boarding the aircraft. There are more conventional ways of checking in, however, if passengers discover and accept these new ways of checking in, they are introducing new ideas to increase their convenience. In this regard, how innovation diffuses has implication for self-service usage. Rogers indicated the 5 processes on how people adopt innovation.

Agent-based model is based on the technical instrument, which enables each agent to behave autonomously. Agent-based simulation developed its study field by expanding players in experimental space and approximating the experimental space to facsimile the real world. The social multi-agent system aims to explicate the phenomena in the complex social system [5]. Kawai [4] attempted to build abstract model to explain diffusion of services by the agent-based model.

Those studies are indicating the important factors and/or concepts of diffusion of SST adoption or innovation. However, they did not reproduce the mechanism of consumers' decision making when they face opting the conventional ways or SSTs by utilizing the agent-based model. As Kawai's attempt didn't utilize the observed data, it is difficult to explicate the phenomenon of diffusion and what makes consumers to select an alternative.

III. FEATURES OF SST IN AN AIRPORT

Currently LCCs keep and gain passengers by providing

TABLE 1.
FEATURE OF SELF-SERVICE KIOSK FOR DOMESTIC/INTERNATIONAL AIRPORT

Items	Domestic	International
Feature of domestic/international service context in an airport		
Flight volume per day	Many flights per airline	Less flights per airline
Facility	Does not need any government formality (CIQ) Dedicate (24/7) usage	Needs government formalities Common use
Self-service kiosk (SSK)	Already spreading Long history in market	New product Implemented after 2005
Feature of domestic/international Self-service kiosk		
Ownership	Respective airlines	Airport or AOC
User(s)	Dedicate use	Common use
Features	Same: Color, Shape etc.	Various
Deployment	Consistent	Inconsistent
SSK operations	Simple	Complicated

competitive prices and adopting clear-cut attitude on customer services. Passengers fly with LCCs on the premises of self-service usage through their experience from reservation to boarding and cabin experiences. They opt additional service such as interpersonal check-in, as additional charges are applied.

LCC passengers have a clear intension to save money, so that when they fly with a LCC they take it granted using a self-service kiosk for check-in.

In this section we briefly review the history of self-service deployment in Japanese market and the current context of self-service devices in airports.

A. Brief history of self-service kiosk in the airport

We focus on the FSC passenger using international flights because these passengers' self-service kiosk usage is not as popular as for domestic services.

One of two major reasons why implementation of self-service kiosk for international flights had to wait until the late 2000s was due to ticket media. In Japanese domestic market, Automated Ticket and Boarding pass (ATB) have been deployed since the 1980's and those tickets with magnet stripes are compatible with self-service, as kiosk needs to read encoded information on the tickets. Since there is fewer interline connection passengers in the domestic market, most of the domestic ATB are controlled by the Japanese airlines and issued as machine-readable.

On the other hand, there were many international flight coupons (tickets) with red carbon because various foreign carriers and travel agencies overseas, whom Japanese airlines could not influence, issued those tickets. Even though the ticket had a magnet stripe, the encoding quality was not very consistent. Therefore substantial volumes of flight coupons were not machine-readable. It was an obvious challenge for airlines to introduce self-service kiosks under such circumstances: there were many passengers who could not use self-service kiosk due to their ticket type.

This difficult context was dramatically changed by International Airline Transportation Association (IATA) e-ticket policy announcement in 2004. In 2008 100% e-ticketing policy almost removed the inconsistency of ticket media, and airlines could verify the ticket validity with ticket database by ticket number.

Another aspect of delaying the implementation of self-service in international sector is the complexity of check-in procedure of international flights. The airline check-in agents need to verify the travel document to clarify if it satisfies passengers' disembarking requirement at their destinations. We needed to wait until new technology take place of this skill required procedure.

However, those two major issues have been solved. We see more self-service kiosks in international passenger terminals.

B. Observed passenger behaviors in an airport

Through interviewing the passenger service experts, we focus on a few simple rules, which is mentioned later (IV.B). The more than 16 days of on-site-observation were conducted. It includes 7 days that the airline provides their DCS data. We have learned some interesting passenger behavior in the departure lobby as follows:

- Passengers using self-service kiosk without hesitation
- Passengers using self-service kiosk on a case by case basis after observing the local context
- Passengers paying no attention towards self-service kiosk

We also observed how airline-handling agents (CSR: Customer Service Representative) interact with passengers in front of a self-service kiosk, who promote self-service kiosk usage to passengers. And three types of reaction were observed as listed:

- Passenger accepting the suggestion
- Passenger rejecting the suggestion
- Passenger accepting the suggestion with some conditions (with operational support, ensuring the self-service option is a quicker/easier process than alternatives)

We also observed that CSR's active and positive approach to passengers contributed to increasing self-service usage.

C. Self-service kiosk for domestic/international flights

The implementation of self-service kiosks for international service is fairly new since there are different in context from domestic services as described in the preceding paragraph. And it is rather difficult for international passengers to find a self-service kiosk under current circumstances as Table 1 describes.

IV. Self-Service Adoption model in an airport

This study proposes to reproduce the dynamic decision-making mechanism of passengers in airport departure lobby in experimental space. We mapped a partial departure lobby ("the real world") to experimental space and ran the simulation with observed data which was collected by the airline DCS. In this section we describe the overview of the proposed model.

A. Model Concept

There are experienced airline handling staffs in passenger service, who know the tips to motivate and encourage passenger to use self-service kiosks and optimize their staff and self-service kiosks in the lobby. They know how to streamline the process of their passenger handling, they

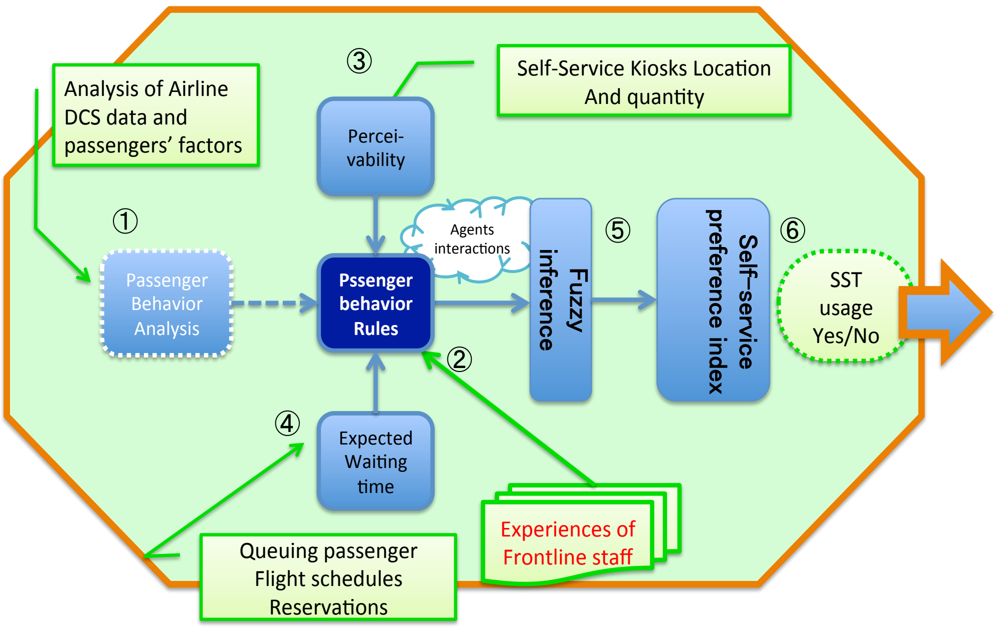

Fig 1. SPI model

know how passenger behave according to their surrounding situation.

We have come up with the self-service adoption model by utilizing the front line experts in passenger services, and that it has a fuzzy inferences system in order to take into consideration of human decisions, as passengers deal with vague information (Fig.1).

The fuzzy rules for inferences are defined through empirical knowledge of passenger service experts. The inputs for calculating membership scores are generated in the agent-based model, which introduce the observed data provided by the airline. By compiling the results of each rule, this model outputs the "Self-service Preference Index (SPI)", which means passenger decision to use or not to use a self-service kiosk for the check-in option.

B. SPI quantification (Defuzzification)

It applies two simple rules as listed in Table 2. The estimate waiting time of queuing in front of the conventional check-in position (Fuzzy membership score "W") and the perceivablity of Self-Service Kiosk (Fuzzy membership score "V") are the key indexes to decide his/her option for check-in.

TABLE 2: FUZZY RULES

Rule-1	IF "W" is short and "V" is low, THEN Self-service Preference is rather negative.
Rule-2	IF "W" is long and "V" is high, THEN Self-service Preference is rather positive.

The respective rules calculate their results by the max-mini inference method and using the simplified centroid method for defuzzification combines these results.

The input value to calculate the membership score "W" is defined as equation (eq.1).

EQT is the waiting-time in a queue at conventional check-in position predicted by the passenger, compared with the waiting time of using the self-service kiosk.

NCCQ stands for the Number of passenger waiting in Conventional Check-in Queue. And CCPs stands for the number of Conventional Check-in Positions. NSSQ stands for the Number passenger waiting in Self-Service Queue. And SSU stands for the number of Self-Service Units.

"*p1*" and "*p2*" are weighting-parameters of each members of equation. How we arrange the weighting parameters will be mentioned later. How we arrange the weighting parameters will be mentioned later.

$$EQT = \frac{NCCP}{CCPs} xp1 - \frac{NSSQ}{SSUs} xp2 \quad (1)$$

Another input value to calculate is the membership score "V" which is the passenger head count in front of self-service kiosks. The membership score "V" is low when no passenger uses self-service kiosk. The more passenger use self-service kiosk, the higher it scores. However once number of passenger exceeds the number of self-service kiosks, it scores lower and lower.

C. Process of experiments and evaluation

In this study, firstly we build a prototype model (Fig.2) and verify the behavior of agents, secondly map existing

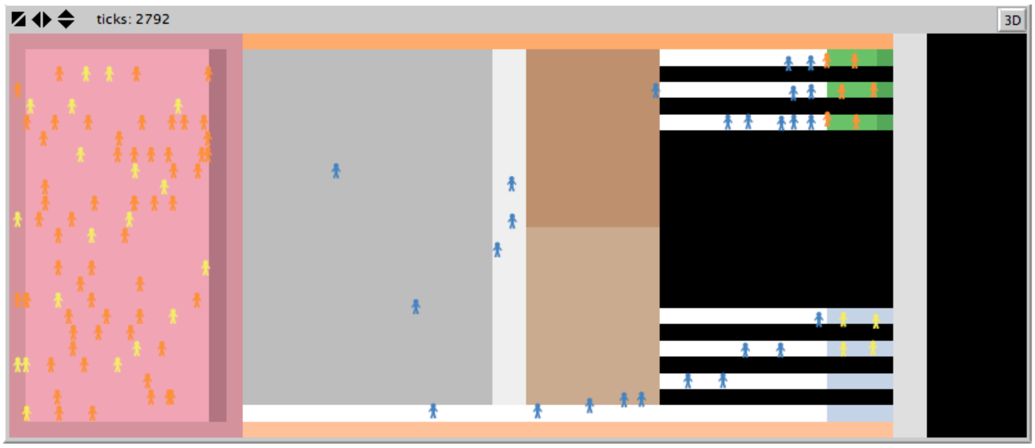

Fig 2. mini-model (Prototype)

observable data of the real world to this model. And after examining the gaps and found subjects, we apply them and expand the model to approximate to the real world.

To evaluate the probability of this model, we focus on the "self-service usage rate" which is the ratio of passengers using self-service kiosk for all check-in passenger. We estimate the best parameter value with the training data, and run the simulation with other experiment data, using the fitted parameter value. We look at the "self-service usage rate" that is the result of the experiment and the observed "self-service usage rate" in the real world to evaluate the probability of the proposed model.

We collect the proxy data of passengers' 60 minutes show-up timing (check-in complete timing) from the airline's DCS for the simulations. Using this data, we generate passenger agents in the experimental space and see reproducibility of this agent-based model.

V. Model Experiments and Discussions

A. Experimental space and parameters

Through the experiments, we verified that the model behaved how we intended to and observed expected output by calibration. However, We find following issues to make it approximate to the real world:

- We need to adjust the productive properties of the proposed model to the same quantity as the observed environment. Passengers using self-service kiosk with baggage consequently stop by "Bag Drop position" to check their baggage. And these positions are utilized like conventional check-in positions when there is no waiting passenger for checking the baggage.
- We need to set the observable parameters to the values observed in the real world.
- We need to estimate the values of unobservable parameters in the real world.
- We need to implement the mechanism of CSR's interaction with passengers. They approach passengers to urge them to try the SST.

B. Summary of imported data and parameters

In consideration of the preceding clause, we correspond raised issues as following:

- We add "Bag Drop position" in addition to the conventional check-in position and self-service kiosk as a check-in option. Those quantities are adjusted to the same amount of the operation date. (See Appended Table 1.)
- We map the observed parameter values to the model, such as "baggage holder ratio", "frequent self-service user ratio", etc. (See Appended Table 2.)
- We estimate the values of unobservable parameters: "*speed-limit*" and "*p1*", the weighting parameter of interpersonal service preference.
- CSR's interaction to passenger will be described later in V.*C.*1) The Concept of "Hesitation model".

C. The expanded model-1: Bag Drop Utilizing (BDU) model

1) Corresponding the raised issues by prototype

We have corresponded the raised issues in "V.*A. Experimental space and parameters*" by setting productive properties just the same as the operation date. Then parameters both observable and unobservable are set and estimated.

Bag Drop is not only the position to check bags but also that CSR can perform check-in similar to the conventional check-in position when there are no passenger queue for checking their baggage.

We select the data (date412) as a training data for this experiment, because we see there is almost no positive approach from CSR to passenger. We calibrate "self-service usage rate" by changing the values of two parameters (firstly "*speed-limit*" and then "*p1*") and finally select the values of those parameters, which bring it almost approximately to the real world.

For fitting the parameter, we changed "*speed-limit*" value from 0.10 to 0.30 by 0.01 and ran 20 simulations and calibrated the self-usage rate for each time. It was observed that RMSE from the real world is smallest when "*speed-limit*" was 0.25 in the experiment.

Next parameter fitting with "*p1*" was done after setting "*speed-limit*" 0.25. We ran 20 simulations and calibrated the self-service usage rate by changing "p1" from 3.0 to 6.0 in every 0.1 value. Through the calibration, it was observed that the experiment results approached closest to the real world with "*speed-limit* = 0.25" and "*p1* = 5.1".

Table 3: Simulation Results with Speed-limit=0.25, *p1*=5.1

Speed-limit *p1*	*0.25* *5.1*	date406	date408	date409	date410	date411	date412	Ave.
Productive	*quantity*	*CC3BD3*	*CC2BD3*	*CC2BD2*	*CC2BD2*	*CC2BD2*	*CC3BD2*	
Usage rate	real data (a)	0.351	0.375	0.364	0.446	0.496	0.272	
	sim ave. (b)	0.303	0.369	0.303	0.377	0.369	0.245	
difference	(c) = (b)−(a)	−0.048	−0.006	−0.061	−0.069	−0.127	−0.027	
RMSE	SQRT(c^2)	0.048	0.006	0.061	0.069	0.127	0.027	0.056
								RMSE Varaiance
								0.0017

SSU : Self-Service User , Usage rate : SSU usage rate

Table 3 and Fig.3 show the simulation results (6 days) of the expanded model, Bag Drop utilizing model. The productive properties are fitted to the observed context. Therefore active check-in positions, Bag Drop positions and self-service kiosk are same in experimental space as the situation of which data was collected. In Table 3, the simulation results are shown below the observed "self-service usage rate" of the real world.

In Fig.3, the bar graph displays the RMSE of simulation results average and observed "self service usage rate", the line graph shows the observed "self-service-rate"(real-data) and simulation result average (CSR=0 means that this model does not include CSR's interaction).

The data "date412" was collected on the day CSR did not positively approach the passengers. Our experiment shows RMSE between the real world and the experimental space becomes 0.027.

This result is within the expectation and feasibility because it means that 100 passengers showed up in departure lobby during the busiest business hour and consequently there were 3 more/less passengers using self-service kiosks than the observed result. Therefore we evaluated this result is approximating to the real world. However other experiment results except using data412 are lower than observed values and the errors from the observed values vary inconsistently.

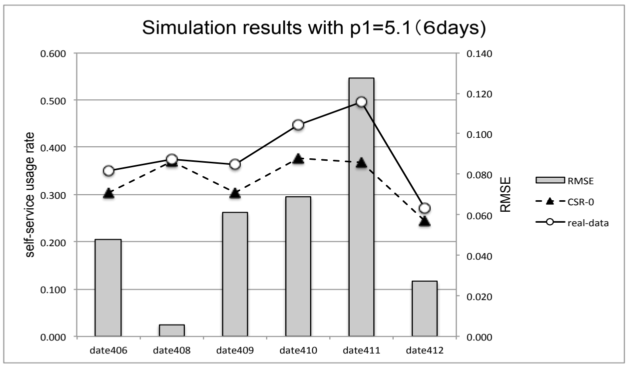

Fig.3: Simulation results with *Speed-limit* =0.25,*p1*=5.1

2) Bag Drop utilizing model experiments and discussion

We analyze that the reason why the experiment results vary and produce the error from the observed data in the real world. Though we recognize that CSRs are approaching passengers to urge them using self-service kiosk in the real world and it appears to work effectively, the "BDU model" doesn't include interactions between CSRs and passengers.

In this sense, output results from this simulation model are predictable as expected, because they come out below the observed result without CSR's interaction, so the effectiveness of CSR's approach depends upon their skills and actual effort of them.

In the next step, we propose to implement the interacting sub-model between CSRs and passengers in order to refine and develop the Bag Drop utilizing model.

D. The expanded model-2: Reducing Hesitation model ("Hesitation model)

1) The Concept of "Hesitation model"

Corresponding the subject in the previous clause, and focusing the influential factor, we introduce "state of mind" into passenger agent to expand the BDU model.

When the experimental space generates passenger agents, it gives each agent a new variable valued randomly, which is equivalent to hesitation of adopting the new way of doing. And the expanded model locates CSR agents in the lobby who approach and urge passenger agents to use the self-service kiosk. (See Fig.4)

CSR agent can reduce the "hesitation" of using self-service for passenger agents when they come into contact. The reducing value depends upon the status of CSR agents. If they contact passenger agent twice in a short period, the first contact will reduce more value of the "hesitation" variable than the second time. If duration after first contact is long enough, the reducing value of second contact will be of the same amount.

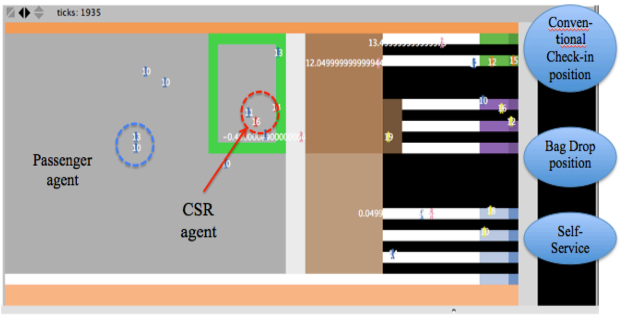

Fig.4: Reducing Hesitation model ("Hesitation model")

2) Result of "Hesitation model" experiments and discussion

We conducted 50 simulations for respective datasets and calibrate the self-service usage rate. The experiment shows that the results approximate to the real world most closely with 2 or 3 CSR agents. The average of RMSE between the experimental result and the observed self-service usage rate is 2.5% (See Table 4).

Table 4: Simulation Results with CSRs

Speed−limit p1	0.25 5.1	date406	date408	date409	date410	date411	date412	Ave.
Productive CSR	quantity quantity	CC3BD3 2	CC2BD3 2	CC2BD2 2	CC2BD2 3	CC2BD2 3	CC3BD2 0	
Usage rate	real data (a)	0.351	0.375	0.364	0.446	0.496	0.272	
	sim ave. (b)	0.361	0.422	0.364	0.452	0.434	0.245	
difference	(c) = (b)−(a)	0.010	0.047	0.000	0.005	−0.062	−0.027	
RMSE	SQRT(c^2)	0.010	0.047	0.000	0.005	0.062	0.027	0.025
							RMSE Varaiance	0.0006

SSU : Self−Service User, CSR : Customer Service Representative
Usage rate : SSU usage rate

It is considered that this model has a fair probability to approximate to the real world as follows:

- The number of CSR located in the real context is equivalent to the number of CSR agents in "Hesitation model".
- The errors between the real data and simulation result average decrease from the "BDU model" experiment. And RMSE of "Hesitation model" becomes about half amount of "BDU model".
- The RMSE variance reduces as 1/3 in comparison with that of "BDU model".
- Fig.5 shows that the experimental result of the proposed model is getting closer to the observed data.

VI. Scenario Analysis

In this chapter we examine two sets of scenario analysis. Firstly we discuss the effective passenger handling by utilizing self-service kiosk through the simulations with the proposed model. Secondly we focus on the passenger who most likely use self-service kiosk to discuss how "frequent self-service user" gives positive influence in terms of increasing self-service kiosk users.

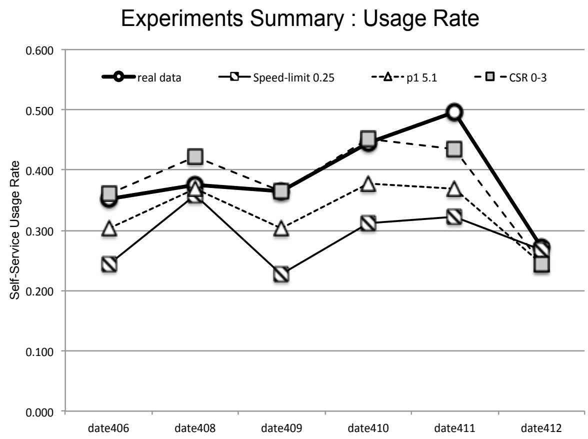

Fig.5: Experiments Summary of "Hesitation Model"

A. Scenario analysis: examining an efficient passenger handling to increase self-service usage rate with cost-effectiveness and low-impact for customer service

1) Experiment scenarios and focus of scenario analysis

There are two perspectives how we set the scenarios.
Firstly, we are looking at the impact which staff reduction makes. Secondly, we examine differences staff relocation makes. We set the reference scenario using the dataset "date406", which we have 3 conventional check-in positions (CC3), three Bag Drop positions (BD3) without CSRs (CSR0): CC3BD3CSR0 (hereafter the combination of productive properties are stated CCnBDnCSRn). Examined scenarios are listed in Table 5.

Table 5: Scenarios for experiments

Scenario	CCK	BD	CSR	SSU	Number of Operating Agents	code
Original plan	3	3	0	4	6	CC3BD3CSR0
Scenario(1)	3	2	0	4	5	CC3BD2CSR0
Scenario(2)	2	3	0	4	5	CC2BD3CSR0
Scenario(3)	2	2	0	4	4	CC2BD2CSR0
Scenario(4)	3	2	1	4	6	CC3BD2CSR1
Scenario(5)	2	3	1	4	6	CC2BD3CSR1
Scenario(6)	2	2	1	4	5	CC2BD2CSR1
Scenario(7)	2	2	2	4	6	CC2BD2CSR2

CCK: Conventional-Checkin , BD: BagDrop , CSR: Lobby Service Agent, SSU: Self-Service Unit

2) Experiments of scenario analysis

We ran the simulations to compare the effectiveness among them from following three perspectives;

a) How does the respective scenario work to increase self-service kiosk users?
b) Is it contributing to cost reduction?

c) Does it result in a significant impact on waiting time?

Each experiment consists of 50 simulations for each scenario. We look at the results with above measures to evaluate the scenario.

3) Experiment results and discussion

Fig.6 displays the results of 6 scenarios with the experiments result including the reference model on the far left (CC3BD3CSR0). The bar graph shows self-service usage rate and line graph shows the largest totals of agents' headcount in simulations, which are making queue in front of productive properties.

As each scenario has 50 simulations, number displayed on the graph is the average totals of the largest headcount of each simulation.

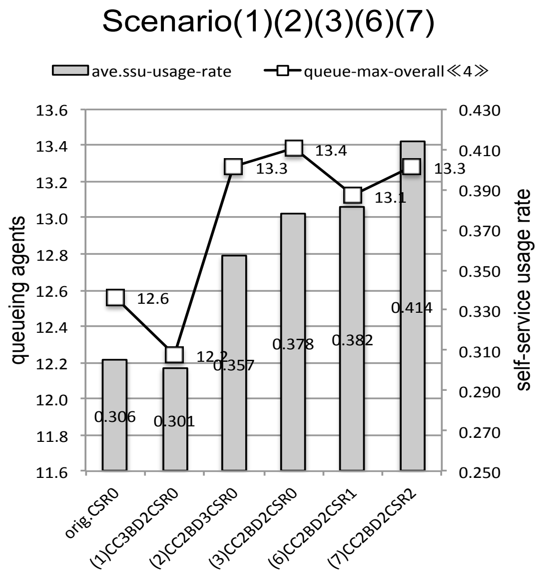

Fig.6: Simulation results

Table 6 displays ranked scenarios according to the respective perspectives. It shows that the most feasible scenario is the Scenario 6, which reduces a conventional check-in position and a Bag Drop position and relocates one operating staff in the lobby to assist and urge passengers to use self-service kiosks.

Focus point	Scenario 3	Scenario 6	Scenario 7
Perspective a)	3	2	1
Perspective b)	1	2	5
Perspective c)	3	1	2

TABLE 6: SCENARIO RANKING FOR EACH PERSPECTIVE

With regard to increasing self-service users, the scenario 7 is the top. However, it does not reduce cost. With regard to cost reduction, the scenario 3 defeat all but it produces the queuing passengers most. The scenario 6 is in second place with regards to increasing self-service users and cost effectiveness, however this scenario does not give a huge impact on waiting time, because it didn't make as long queue as those scenario which took the first and/or second place in perspective a) and b).

Through observing the passenger handling and simulation experiments, this study reaffirms the important principle of on-site management. Knowing the expected result through simulation, the management will be able to locate necessary man resource at the necessary position. It is also important for management to make the man resource function.

We see CSRs' approaching to passenger make difference to increase self-service users. It is important for the acting staff to recognize the role and expected outcome. The agent-based model may be able to give both of them the visible ideas and outcomes of their scenarios.

In the real world, the local managements take prudent steps to try new things, because they can't take a chance, don't like that the new way affect their current service level. We can say that as long as the agent-based model is approximating to the real world, and the local managements understand its limitation, agent-base model with high probability can be some of help for service industry to get a rough idea how new things work.

B. Scenario Analysis: In terms of increasing self-service product users for international air-traveler

1) Experiment scenarios and focus of scenario analysis

We conduct series of simulation in the previous section by changing the productive properties. In this section, we select three scenarios and calibrate the self-service usage rate by changing the ratio of "frequent self-service user".

2) Experiments of scenario analysis

It is observed that the existence of passengers who is using self-service kiosks gives positive influence to passengers who select check-in option in both the real world and the experimental space. In this section we calibrate and examine how the change of "frequent self-service user" will give impact to self-service usage rate.

The proposed agent-base model stochastically gives the property, which is to select self-service kiosk, to generated agents. We select following three scenarios and run 20 simulations for each scenario by changing the parameter of "frequent self-service user" rate into every 0.05 from 0.00 to 0.40. Each scenario has 6 service agents who are located in different ways. We use the same dataset as the previous scenario experiment in VI.*A*: "date406".

- CC3BD3CSR0: "Original plan" which has 3 conventional check-in positions and 3 Bag Drop positions and no lobby service agent
- CC2BD3CSR1: "Scenario 5" which has 2 conventional check-in positions and 3 Bag Drop positions with 1 lobby service agent
- CC2BD2CSR2: "Scenario 7" which has 2 conventional check-in positions and 2 Bag Drop positions with 2 lobby service agent

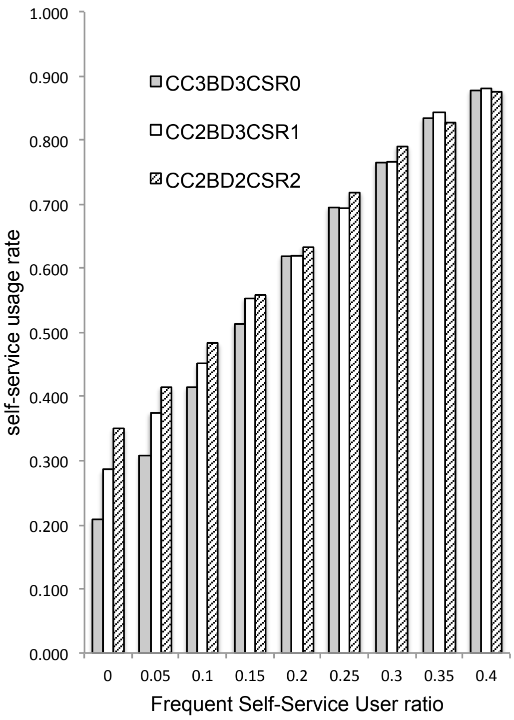

Fig.7: Influence of Frequent Self-service Users

3) Experiment results and discussion

The results of experiments are displayed in Fig.7. It shows that each case increases self-service usage rate in proportion to "frequent self-service user" rate. The experiments with zero "frequent self-service user" rate display that the existence of lobby service agents affects positively to self-service usage rate. More service agent who invites and advises passenger to use self-service kiosks brings higher self-service usage rate.

However, as the rate of "frequent self-service user" gets higher, the difference between three cases becomes closer. Once "frequent self-service user" rate reaches 0.2, the self-service usage rate of the original plan without lobby service agents becomes almost same as the cases with lobby service agents.

The Fig.7 shows that when "frequent self-service user" rate gets more than 0.25, the case without lobby service agent gains even or higher self-service usage rate than other cases with lobby service agents.

This series of experiments indicates that if there are "frequent self-service users" more than 20% of passenger in the departure lobby, who are most likely use self-service kiosk, there is less necessity to locate lobby service agents. In addition, Fig.8 shows the regression line of "frequent self-service user" ratio and self-service usage rate. As the liner equation displays, it is observed that if frequent self-service user rate increases by 0.1 point, self-service usage rate increases by 0.17 point. These results indicate that it is important for the diffusion of international self-service kiosk to increase the "frequent self-service users" rate up to 0.2 as soon as possible.

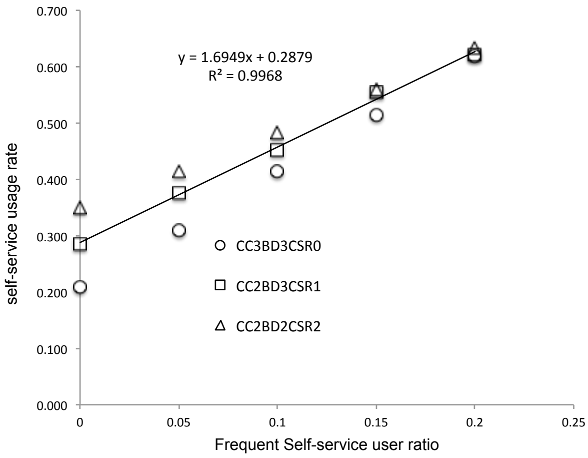

Fig.8: Influence of Frequent Self-service Users

C. Conclusion and subjects

It is common understanding that passenger's travel frequency of international flight is less than the one of domestic flights. Besides that, as mentioned in III.*C,* it is rather difficult for international passengers to find a self-service kiosk under current circumstances. Understanding such contexts, currently Full Service Carriers need to promote self-service product to survive in severer competitions to achieve cost effective operation.

It is necessary for attaining higher cognition of self-service product in airport to appeal the new option in each process of air-travel: travel-planning, booking flights, purchasing flight tickets etc. Because air-travel passengers need to identify themselves to the airline during the travel experience, B to C approach is possible in terms of promoting the self-service product in airport. Instructing the self-service kiosk is available for the international flight which the passenger flies with, and by advising the convenience of them, airlines could reduce "hesitation" of passengers to choose the new way of doing.

The experiments in this section describe that in early stage of international self-service kiosk's diffusion, it is important for local management to locate lobby service agents to urge passenger to use self-service kiosks. They need to clarify that their staff understands to approach passenger actively. The accumulation of continuous diligent effort would lead to higher self-service usage rate and increase the number of frequent self-service users.

VII. Summary

A. Conclusion

As this study stated in the related work, service has its natures such as "intangibility", "perishability", "simultaneity" and "heterogeneity". It is very difficult for service to be evaluated, because service quality depends upon the person who receives and the situation to which the service is provided. In this study, by utilizing ABM, we reproduced the context of "simultaneity" and "heterogeneity" in the experimental space as follows, those are characteristic of service and are difficult to quantify.

- The external context which consumer perceive at the moment of choosing a service option (the congested situation of each service productive: the conventional check-in position and self-service kiosk)
- The consumers' internal context when the service is provided to (the attribute of passenger attitude when they choosing the service from either the conventional way or new way)

Conducting series of experiments under various conditions with data extracted from data warehouse, it was verified that the model equipping the important factors of decision making approximated to the real world with reproduced passenger's external/internal context.

In short, this work indicates that decision-making mechanism of consumer's service selection could be reproducible with ABM.

1) Self-service adoption model

In this study we have conducted experiments and found that the results of the expanded model of self-service adoption in the airport approximated to the observed values. In consideration of this outcome, there are two indications:

- How passenger decides whether using self-service is explicable without their demographics
- Simple rules with combination of three factors can mostly explain how passengers select a check-in option.

Three factors are "estimate waiting time of queuing in front of the conventional check-in position", "perceivablity of Self-Service Kiosk" and "passengers' hesitation".

Another perspective from the outcome of experiments is agent-based model simulation may be able to reproduce extracted context of the real world in which passengers select a check-in option with simple rules and observed values.

In related literatures, there are many useful indications. They explain the attributes, which influence consumer to use self-service products, advantage of time saving and the internal status of consumers. We introduce those efforts to the proposed model from the works of service marketing. And the active approach of change-agent, which is mentioned as an important explanatory variable for diffusion's speed in Diffusion of innovation, is reflected in the proposed agent-based model as implementation of CSRs, which reduces hesitation of passengers through interaction.

However, though statistical analysis explains major reasoning of consumer who uses or not uses self-service products, but does not mention the mechanism, which could reproduce the observable outcome. This study displays that the proposed agent-based model is approximating to the real world and reproduces the almost close outcome to the observed result in the real world by using the existing data. The proposed "Self-service Adoption model" is validated and expanded through conducting a series of experiments with observed data collected from the airline's DCS by using the agent-based model.

2) Scenario analysis

Through conducting the simulations of carefully prepared scenarios, we suggest the efficient way of passenger handling to increase self-service usage rate with less impact for service quality. As each firms and local management should define the perspective and its priorities to evaluate the experiments results, we describe our perspective in VI (2). The result of experiments indicates that reducing the number of conventional check-in position could increase self-service usage rate and active approach of lobby service agents are effective to urge passenger to choose self-service kiosks.

It also indicates that ratio of "frequent self-service user" needs to be increased up to 20% of check-in passenger as soon as possible. This is the threshold to determine whether the local manager needs to appoint lobby service agents or not.

B. Subject and discussions

This model mapped the limited space and environment of the real world. Even though our experiments display one of the possibilities of how passengers make a decision, our focus is limited and there should be other important influential factors of passenger behavior.

This is another fact that even though we have observed and learned their visible group behavior (i.e. herd behavior); we haven't yet implemented it into the proposed model. It may be possible to find it in the airline's database; however, we need to search those influential factors by analyzing the airline's database in depth.

To enhance the validity of the model, it would be better to apply the estimated parameters to another dataset of same characteristics with the training data. However, since collected data was limited, we don't have the same characteristic dataset as training data. Collecting ample data could be contributory to enhance the validity of the model.

We display that how the agent-based model may work for managers to obtain the idea of alternative ways of handling passenger. It is very important how we design the simulation scenarios because scenarios should come from the business priority.

It is obvious that we need to continue to analyze the data details regarding how and why consumers choose self-service product. There are huge data and attributes in airline's database, in which we have not yet looked.

It is our hope that our study may give some feasible indications in case the airline industry will introduce totally new self-service products, or to other industries seeking the possibility of using self-service technology.

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APPENDED TABLE 1.
THE OBSERVED DATA OF THE DATA COLLECTED DAYS

real data	date406	date408	date409	date410	date411	date412
Number of CC positions	3	2	2	2	2	3
Number of BD positions	3	3	2	2	2	2
Number of Self-Service Units	4	4	4	4	4	4
cck passenger	85	100	68	67	63	67
ssu passenger	46	60	39	54	62	25
total passenger	131	160	107	121	125	92
usage-rate	0.351	0.375	0.364	0.446	0.496	0.272
CSR	2	2	2	3	3	0

APPENDED TABLE 2.
SUMMARY OF PARAMETERS

parameter	value	factor	explanation, remarks
speed-limit	0.25	Speed limit of passenger agents	The speed limit of passenger agents. The negative correlation was observed in the experiments.
p1	5.1	Weighting parameter of the conventional service preference	"*p*1" is one of coefficient value in equation. (1), which calculate the quantified value of "Estimated Queuing Time" of conventional check-in position.
classic-ckin-speed	0.02	Check-in speed of the conventional check-in positions	Check-in speed of the conventional check-in position in the experimental space: about 3 min. for 1 passenger 3 min. per 1 passenger for check-in is industry standard.
ssu-ckin-speed	0.03	Check-in speed of the self-service positions	Check-in speed of the self-service position in the experimental space: about 2 min. for 1 passenger.
bagdrop-ckin-speed	0.035	Check-in speed of the Bag Drop positions	Baggage Check-in speed of the Bag Drop position in the experimental space: about 1.7 min. for 1 passenger.
frequent-ssu-user	0.05	Ratio of "self-service users"	The ratio of " Passenger who most likely use self-service kiosk" among departing passengers; We collect the 13 month boarding history of FFP holders who departed in 7 days. FFP holders who travel more than 4 times within 13 months and chose self-service kiosk in all occasion for check-in
CSR-number	0〜3	Lobby service agents who urge passenger to use self-service products	The number of lobby service agent, which is generated in "Hesitation-model".

Party Competition and Voter Decision-Making

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***Abstract*—This paper combines two important findings from research on how voters and parties interact: Firstly, it acknowledges that voters possess different decision making mechanisms: Instead of weighing the parties' policy promises, they might also vote based on past performance or the personal qualities of party leaders. Secondly, it incorporates empirical findings challenging a prominent device by which party-voter linkages are modeled, i.e. the left-right scheme. Modern party systems have been shown to vary in the number of dimensions parties compete on. We model how voters aggregate issues into party rankings, assuming that voters switch decision making mechanisms contingent on their heuristic value, and develop hypotheses on how issue diversity in party competition influences voter heuristic use.** ***Keywords*: Political Psychology, Party Competition, Voting Behavior, Heuristics.**

I. Introduction

KEEPING up to date with politics is quite a demanding aim: Besides keeping track of current events, every new problem that arises can be studied in practically unrestricted depth. Moreover, the former of these decisions is afflicted with most citizens not assessing the rewards of political information too high. In other words: They do not care that much.

Because of that, there has been a lot of research on whether voters, uninformed as they may be, can make decisions 'as if' they were fully informed [21] [17] [16]. Its fundamental idea is that they use information shortcuts or *heuristics* that summarize information to workable quantities. That means they neglect certain aspects of the real world, but to a degree that 'by and large' probably does the matter justice.

Examples for these heuristics include voting based on the retrospective evaluation of candidate performance [9] or the endorsements of politically significant groups the voter has a positive affect for [3]. However, the most prominently discussed information shortcut probably is ideology, i.e. a broad summarizing device that allows voters to judge how close a party represents their preferences without having to learn about each and every issue that is currently politically salient. It is usually modeled as a continuum on which political discourse can be mapped, a conception mostly known as the left-right dimension. It has indeed become the default model of party competition [8] and has also taken deep root in the everyday language of politicians and citizens alike.

Accordingly, there is a lot of evidence that voters understand the left-right scheme well [10] and make ample use of it [27]. However, there is considerable variation in both of these aspects across countries as well as time. In countries where voters have very heterogeneous perceptions of the parties' left-right position, the correlation between party choice and left-right positions is weaker [26]. This, we would argue, can be related to the degree to which parties adhere to the left-right dimension as the arena of competition: The model's performance relies heavily on the assumption that the political space that voters perceive relates to the space that parties build.

Empirically, this assumption is met imperfectly at best. Party competition in Europe has become increasingly complex over time [1], so that today, adherence to unidimensionality varies widely across party systems [23]. Agent-based models have tremendously advanced the understanding of party competition in spaces of higher dimensionality (e. g. [20]), but work remains to be done concerning situations where dimensionality differs between the political supply and demand side.

Here, we try to model how this variation impacts on the likelihood of voters relying on policy promises as a voting heuristic. Using a 'strongly spatial' model [13] [20, p. 30], this would be straightforward: If parties compete on more dimensions than voters can perceive, this adds 'noise' to the 'ideology signal' and makes it less valuable.

However, acknowledging that dimensions of political conflicts are abstractions from the clustering of statements on different issues [11] and that these clusters need not necessarily be simple reverse images of each other [4], the picture becomes less clear: On the one hand, if parties compete over a too diverse set of issues, voters may be less and less able to extract messages on the issues they actually care about. On the other hand, the core mechanism of ideology, that is to evaluate parties only on issues of interest and to ignore 'clutter', may work very well even if the range of topics is very diverse.

Thus, the question we ponder here is *how the issue diversity of party competition influences the decision making of voters*. We study it by combining parties' capability to 'sort' voters by issues [2] [22] and voters' tendencies to overlook issues that do not fit their decision making heuristic [12]. Voters are assumed to possess different decision heuristics, one of them driven by party programs, between which they switch according to what heuristic has the smallest decision costs [7].

This criterion is defined to be fulfilled if the signal that a heuristic creates as to which party a voter should support is the strongest possible. Voters in the model assemble an individual ranking of the parties for each heuristic. Since voting is a process of *choice* rather than *evaluation* [19], voters decide by that heuristic that produces the greatest distance between the first and second ranked party, since it most clearly separates 'the best' from 'the rest'.

II. Model

The model is executed by running simulations with 1,000 voters each. The simulations consist of an iterative taking-turns of voters choosing a party to support and parties adapting their program to improve their support share. 1,000 iterations of these taking-turns are carried out per simulation.[1] The key variables that vary across simulations are the number of issues *I*, i.e. the maximum number of topics that can be politically debated, and the number of parties *P* that compete in the system (here, *I* ranges from 2 to 16 and *P* from 2 to 8).

A. Voter Behavior

There are three possible attitudes a voter can hold towards an issue: She can either regard it positively, negatively, or not care about it. The number of issues a voter cares about, as well as what preferences she holds concerning it are chosen at random. Moreover, each voter uses a subset of *I* as *diagnostic issues* that she employs to judge whether a party conforms to her preferences. This means she may have preferences on a lot of issues, but does not consider all of them making a party choice, as is consistent with the 'fast and frugal decision making' model of party choice [19]. The *programmatic preference profile* I_v of voter *v* can therefore be expressed as a set of categorical variables indicating how *v* feels about an issue and whether she employs it to assess how she feels about a party:

$$I_v = \{i_1, ..., i_I; i_1^d, ..., i_I^d\} \tag{1}$$

$$i_j = \begin{cases} 1 & \text{if pos. issue} \\ 0 & \text{if does not care} \\ -1 & \text{if neg. issue} \end{cases}, \quad i_j^d = \begin{cases} 1 & \text{if diagnostic} \\ 0 & \text{if not} \end{cases}$$

Feelings about the issues are uniformly distributed across voters and issues. How many diagnostic issues each voter has and which these are is determined by the following procedure: Each voter is randomly assigned a number d_v that serves as the expectation of her number of diagnostic issues to simulate different degrees of 'political sophistication'. Which issues are diagnostic is then determined (contingent on d_v) through random assignment of 'diagnostic status' by use of three different 'correlation profiles' (see Fig. 1). In the first of these profiles, each issue has the same probability of being used as a diagnostic tool. In the second (third) profile, probabilities are shifted such that the first issue, compared to the uniform distribution, is 1.25 (1.5) times likelier to be diagnostic; the respective multiplier for the last issue is 0.75 (0.5). In between, the probability decreases linearly. This enables incorporating the effects of different degrees of correlation across voters with regard to their diagnostic issues in the model.

When making up their mind about which party to support, voters observe what each party has to say on their diagnostic issues. Specifically, they use the saliency of an issue in a party's program, measured by the share that statements on the issue occupy among all of the party's statements, $\frac{s_{pi}}{S_p}$, to judge how much a party advocates the issues they care most about (the process of how parties 'make statements' is elaborated on below). The score a voter assigns to a party is computed as

[1]A 'burn-in' phase of 100 iterations was included in which voters only decide on programmatic basis, without switching. Also, parties ignore issue ownership in this phase (see below) to allow for 'political debate' to develop.

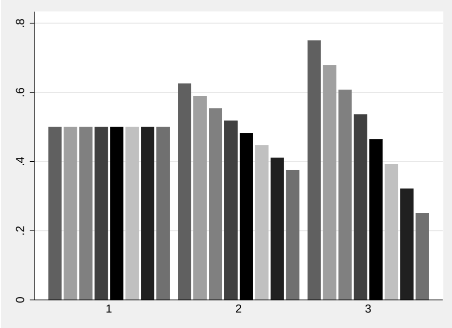

Fig. 1. Examplary probability profiles for assignment of diagnostic issues with $I = 8$ and a voter with $d_v = 4$.

$$V_{pv} = \sum_{j=1}^{I} i_j i_j^d \frac{s_{pj}}{S_p}, \tag{2}$$

which means a party is punished for statements the voter does not like to hear ($i_j = -1$) and rewarded for views the voter agrees with ($i_j = 1$). Voters produce a ranking of parties based on these scores. However, there is a second, exogenously given parameter by which they rank parties referred to as 'Likability' (L_{pv}) here. It is randomly chosen from a uniform distribution and can be interpreted as either of the other voting heuristics established in electoral research, such as the candidate appearance heuristic [18], retrospective voting [9], or as a residual category of 'all others'.

As mentioned earlier, voters use that heuristic producing the ranking with the maximal distance between the first and second best party. This is not to say that heuristic choice is a deliberate decision made by the voter, but it is modeled in that fashion for the sake of explicitness [15]. More precisely, a voter supports a party p^* if

$$V_{p^*v} = \max_p [V_{pv}] \text{ and } V_{p^*v} - \max_{p \neq p^*}[V_{pv}] > L_{p'v} - \max_{p \neq p'}[L_{pv}], \quad \text{where } L_{p'v} = \max_p [L_{pv}], \text{ or if} \tag{3}$$

$$L_{p^*v} = \max_p [L_{pv}] \text{ and } L_{p^*v} - \max_{p \neq p^*}[L_{pv}] \geq V_{p'v} - \max_{p \neq p'}[V_{pv}], \quad \text{where } V_{p'v} = \max_p [V_{pv}]. \tag{4}$$

Voter behavior as a whole can thus be summarized as follows: In each iteration (i) compute the programmatic score V_{pv} of each party according to its updated issue statements and (ii) compare the ranking of the parties on basis of programmatic scores to that on basis of likings L_{pv}. Use that ranking as voting heuristic that produces the clearest 'winner' and (iii) declare support for said winner.

B. Party Behavior

In the model, parties select issues they do or do not emphasize on grounds of the image they have of voter preferences and whether other parties have already taken up these issues. They do not know how voters process political debate into their choice of party support, but concentrate on the issue that is currently on the agenda: One issue $i_{ts} \in I$ and one party $p_{ts} \in P$ are randomly selected at the beginning of each iteration t; i_{ts} could for example be interpreted as a topic gaining acute media coverage that p_{ts} is expected to react to.

p_{ts} now faces a choice between emphasizing the issue in its program or keeping quiet about it. Since parties ultimately need to gather electoral support to gain access to both the spoils of office and the ability to implement policies, we assume that they emphasize issues that they think are seen positively by a majority of voters and keep quiet about those that they think most voters see negatively or are not interested in. To gather information about which is the case, p_{ts} "polls" a subset of voters at the begininng of its turn.[2] While the fact that parties cannot influence what the 'issue of the day' is probably does not do the reality of party competition full justice (see [6]), it seems to be a reasonable approximation of modern political campaigns, where parties try to find appropriate reactions to issues the salience of which they can often not control. It also appears to be most consistent with the 'issue-based' theories of party competition this model rests on.

The party concludes that the issue is 'relevant' if those who regard the issue positively make up 34 percent or more of the polled voters and outnumber those who regard it negatively (this threshold is chosen since it is just above the expected value for the share of voters in favor of the issue). In that case, it makes a statement on the topic (i.e. it increases s_{pj} by 5 or 10, depending on model specification); otherwise it remains quiet (does nothing). Note that this means that a party cannot 'take back' statements should its first idea about an issue's popularity turn out to be wrong.

One additional behavioral rule that parties have is that they take into account 'Issue Ownership', a concept which lies at the core of issue-driven theories of party competition [4] [5]: Each party wants to be associated with specific issues by the electorate to appear as the party with the most expertise in this field. Analogously, parties do not want to emphasize issues that are already 'owned' by others, because that is expected to benefit the issue's 'owner' more than themselves. Therefore, in the model, parties do not make statements on an issue i if for any other party p, $\frac{s_{pi}}{S_p}$ is larger than the 'ownership threshold'. The simulations were run with this threshold at 0.2, 0.5 and 1 (= no issue ownership) to be able to control for any efffects it might have on voter decision-making.

Party behavior, once the issue and party 'of the day' are chosen, can thus be summarized in the following way: (i) Poll a subset of the electorate on their preferences regarding the currently salient issue i_{ts}; (ii) if a sufficiently large share of the polled voters has a positive view of the issue and if the issue is not 'owned' by another party, emphasize this issue (increase s_{pj}).

[2]Of course, this is not to say that an actual poll is conducted, but rather that party leaders, through the party's member base, citizen appeals etc. have some kind of 'hunch' what voters think about an issue. This hunch is obviously likely to be biased towards the preferences of voters that already support the party. Since this bias cannot be quantified, the simulations were carried out both with the parties drawing representative samples of the electorate and them tending only to their own supporters' preferences, which turns the model into a kind of sorting model similar to that of Tiebout [25] (also see [14]). This should provide for appropriate benchmarks, although the actual bias remains unknown.

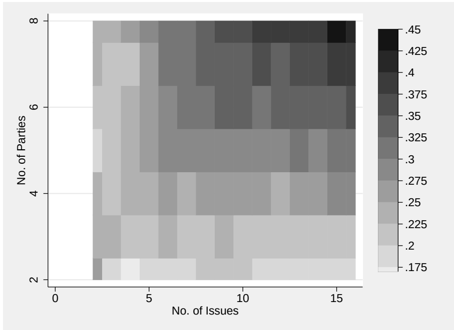

Fig. 2. Predicted share of voters using party programs as a voting heuristic, by number of parties and issues.

III. Results

Fig. 2 gives an overview of the model's dynamics by indicating the average share of voters who are in 'programmatic voting mode' at the end of each simulation across the number of issues I and the number of parties P used. It suggests that voters have a higher probability to use their diagnostic issues as decision heuristic the more parties compete in a system. This is intuitively plausible: More parties should ceteris paribus cater to more specific preference profiles and make it easier for a voter to find 'her' party. Likewise, more issues also increase the share of programmatic voters. This seems to mean rather than confusing voters, a more diverse range of topics induces them to vote based on party programs more often.[3]

Table I provides further insight into the matter: It shows the results of several logistic regression analyses estimating the probability of a simulated voter to be in programmatic voting mode. To compute these, the 'virtual electorates' produced in the simulations are pooled into one data set. This allows using the numbers of both parties and issues, as well as the degree of correlation of diagnostic issues in the electorate, as macro level predictors. Furthermore, the analysis controls for the ownership threshold and the amount by which parties increment s_{pj} when making a statement. Additionally, individual characteristics of the simulated voters are controlled for, i.e. (i) the number of issues used as diagnostic as a share of all issues and (ii) the number of issues a voter sees either positively or negatively (but is not indifferent about; also divided by I).

The results support the previously stated: An increase in the numbers of parties and issues both lead to an increased probability of programmatic voting on the voters' side. The same is true if voters increasingly use the same issues as diagnostic issues, as is reflected by the coefficients of dummy

[3]Graphs for subsamples defined by polling mode, ownership threshold and amount of increment when making an issue statement (available on request) show differences in the level of programmatic voting, but the general pattern remains.

TABLE I
MICRO-LEVEL EXAMINATION OF SIMULATION RESULTS

Variables	**1**	**2**	**3**
	Coeff. (se)	Coeff. (se)	Coeff. (se)
No. of Issues	0.063***	0.045***	-0.060***
	(0.000)	(0.001)	(0.001)
No. of Parties	0.159***	0.159***	-0.017***
	(0.001)	(0.001)	(0.001)
Diagnostic Issues	1.842***	1.589***	1.536***
(Ratio)	(0.004)	(0.009)	(0.009)
Preference Issues	1.812***	1.815***	1.824***
(Ratio)	(0.004)	(0.004)	(0.004)
Diag. Iss. * Issues		0.029***	0.036***
		(0.001)	(0.001)
Parties * Issues			0.020***
			(0.000)
Med. i_j^d Correlation	0.038***	0.036***	0.037***
	(0.003)	(0.003)	(0.003)
High i_j^d Correlation	0.102***	0.100***	0.100***
	(0.003)	(0.003)	(0.003)
Issue Increment = 10	-0.007**	-0.007**	-0.007**
Reference: 5	(0.002)	(0.002)	(0.002)
Ownership Threshold=0.2	0.469***	0.469***	0.472***
Ref.: no ownership	(0.003)	(0.003)	(0.003)
Ownership Threshold=0.5	0.093***	0.094***	0.094***
Ref.: no ownership	(0.003)	(0.003)	(0.003)
‘Tiebout polling’	1.228***	1.229***	1.236***
	(0.003)	(0.003)	(0.003)
Constant	-5.315***	-5.151***	-4.222***
	(0.008)	(0.009)	(0.011)

Logistic Regression, DV: Programmatic Voting Mode (***$p \leq 0.001$; **$p \leq 0.01$)

variables indicating the different correlation profiles depicted in fig. 1. Issue ownership generally increases the probability of programmatic voting, more so as parties find it easier to claim an issue as theirs (i.e., the threshold for $\frac{s_{pi}}{S_p}$ decreases). The coefficients on ‘polling mode’ (see ftn. 2) and ‘issue increment’ suggest an interesting pattern with regard to party responsiveness, implying that programmatic voting should be most prevalent if parties primarily respond to their followers (as opposed to the electorate as a whole) and make not too large adjustments of their program.

On the micro level, the probability of programmatic voting is increased if a voter uses a higher share of the overall issues as diagnostic issues. This is consistent with the well established empirical finding that more ‘sophisticated’ voters are better able to use ideology as a heuristic [24] [16]. A rather interesting finding is that voters who have preferences (i.e. $i_j \neq 0$) on a higher share of issues have a higher probability of programmatic voting although these issues may not even be used in the programmatic assessment of parties.

Model 3 qualifies our findings regarding the numbers of parties and issues in an interesting way: The interaction effects included there suggest that in an environment with relatively few parties, greater issue diversity *can* make the parties’ programs less available as a choice heuristic. When accounting for this interaction, that also extends to voters who consider fewer issues when making their minds up about the parties.

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Reconstructing the Question of School Choice: Towards a Geographical Agent-Based Model for Chile

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Abstract— The aim of this paper is to reformulate the question of school choice in a voucher system, by moving towards a perspective, assessing competition between schools and the choice of students using Geographic Information Systems (GIS) and Agent-Based Modeling (ABM). How spatial structure affects competition among schools? How do socio-geographic structuration and social interaction affect this process? We show a preview of the proposed model and main social mechanisms of school choice: Quality, Distance, Cost, Expectations, Homophily and Mimesis for students and their families, and Selection, Supply and Local Competition for schools.

I. Introduction

THIS paper aims reformulate the question of school choice within the Chilean educational system, moving towards assessing the levels of competition among schools and the freedom of choice of students and families using Geographic Information Systems (GIS) and Agent Based Modeling (ABM). The school choice voucher system that operates in Chile is one of the most studied research topics in Chilean education. It was created to maximize competition between schools in favor of increasing the quality and coverage of education in Chile. Evidence about the success of the system to fulfill its objectives is inconclusive, and studies including geographical factors are scarce. Most of the researches are based on variations of regression models trying to link school choice to educational quality. There have been no attempts to approach this issue though ABM, nor from complex geographic methodologies nor from the perspective of analytical sociology. Using the available databases for the city of Santiago, it is possible to geo-reference families' position in relation to the; position of the schools to assess the distance between them and by using GIS, it is possible to identify other socio-spatial conditions that affect school choice processes. ABM can be developed to simulate the behavior of families and schools, and the distance effects on variables of educational interest. It is relevant that future researches address the study of the effects of the spatial structure on the level of competition among schools, and how this structure affects the quality of education. The ABM may be calibrated with empirical geographic, socioeconomic and educational data, to simulate the manner in which families and educational institutions behave in relation to the conditions of their spatial environment. This could allow the generation of simulations of future behavior of the educational system if current conditions are maintained and could help social scientists and policy-makers to project counterfactual policy scenarios by the way of simulation, in order to compare different alternatives for the current system. Then, by reconstructing the question of school choice in Chile, new questions emerge, as the following: How does the spatial structuring affects competition between schools? Do agents make choices in constrained or full freedoms and rationality? Are agents pushed or pulled by the educational offer and socio-geographic structure? To what extent this spatial structuring as a context of operation of a voucher system is efficient and improves quality, in comparison with alternative systems? What would be the effects of changes in public policy regarding school choice? To what extent the existence of a school choice system and a voucher financing system favors improvement or decline quality of education in Chile? Future research with ABM and GIS offer an innovative alternative to assess theoretical, methodological and practical questions on school choice in Chile and in other choice based systems around the world. We show a preview of the proposed model and main social mechanisms of school choice: Quality, Distance, Cost, Expectations, Homophily and Mimesis for students and their families, and Selection, Supply and Local Competition for schools.

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II. TOWARDS A GEOGRAPHICAL AGENT-BASED MODEL OF SCHOOL CHOICE IN CHILE

The choice process in the field of education is complex and multidimensional. It has attracted the interest of sociologists, psychologists and economists, who have approached the subject from different points of view [1]. In addition, there are several school attendance policy models operating in different countries and contexts, and one of them is the model of free choice −Enforced regulatory zoning model (France, Germany); unforced regulatory zoning model (Finland, Norway, Scotland); restricted choice model (Spain, Italy or Sweden) and choice model (Belgium, the Netherlands and, to a lesser extent, England and Wales), according [2] − The current Chilean system –since the massive implementation of the demand subsidy mechanism through school vouchers in primary and secondary education– constitutes a unique scenario in the global context to assess the school choice process. It follows strong abstract assumptions and criteria: by means of maximizing of the freedom of choice of the families, the system would supposedly lead to increased competition within schools to capture as many students as they can [3]. Competition among schools will finally derive in increasing quality, as lower performance schools would tend to disappear. From this point of view, competition among schools would occur by increasing the quality of the education provided [4]), which can be distinguished by student's families.

This educational funding model based on demand subsidies (vouchers) offers a privileged observation context of the school choice process, motivating national and international research based on the Chilean case [5] Due to the social relevance of the matter, most researches combine the academic discussion of choice processes with public policy recommendations [6] Some authors, in favor of a voucher system, argue that it increases efficiency, competiveness and quality of education, while providing greater educational opportunities to disadvantaged students [7], [8], [9]. Critics of the voucher system claim that the school choice based in vouchers increases inequality, segregation and educational stratification. Others argue that the optimal competition conditions that the model intends cannot be met because of market flaws [10] The sociological problem beneath these questions is related to freedom of choice, and how it can be complete, limited or even possible, in diverse social contexts [11] It is also related to Diego Gambetta's question: "*Were they pushed or did they jump?*" [12] structural constrains and incentives may be exerting influence on school choices.

On one hand, neoliberal economic theory –focused in the freedom of choice of the individual– assumes the generation of optimal market competition conditions by means of aggregated individual rational decisions intended to maximize benefits. On the other hand, classic sociological theories highlight the importance of structural factors that motivate, alter, distort, orient or inhibit behavior on individuals, while the individuals can modify their own position within the structure or even have influence over the structure [13], [14], [15], [16]. The analytical sociology perspective of this paper assumes that although the individual has some freedom to choose, this choices always take place in empirically situated contexts, where several structural factors and the interaction with others may limit choice in its pure and exclusively rational form. The process of choice will be addressed from the perspective of what has been termed "real freedom" [17] which supposes that individuals make decisions based on limited relevant or identifiable options within his or her context.

Empirical data on reasons for school choice put into perspective the theoretical arguments in which voucher systems are based. Table 1 shows that the reason most mentioned establishment choice criterion by parents is not the academic quality results (only 31%), measured by the standardized tests, SIMCE for primary and secondary education and PSU for college entry, but the proximity to the family home (52%).

In addition, the mention of the shortest distance as the reason of choice is more common (65%) in the first two income quintiles, corresponding to the poorest 40% of the population. By contrast, the academic quality is mentioned as a reason for choosing more frequently in the richest families in the country (41% and 49% in quintiles IV and V).

TABLE I – PERCENTAGE OF PARENTS WHO MENTIONED THE FOLLOWING REASONS FOR SCHOOL CHOICE AMONG THE TOP THREE CHOICES. SOURCE: SIMCE SURVEY 2009.

Reasons for school choice	**Total**	**I**	**II**	**III**	**IV**	**V**
Because it is close the family home	**52%**	65%	65%	62%	59%	50%
Because it offers high quality of education (SIMCE and PSU)	**31%**	25%	31%	37%	41%	49%
Because of their values and orientation	**29%**	23%	28%	32%	38%	47%
Because of its infrastructure	**23%**	18%	22%	26%	31%	36%
Because brothers attend this school	**2%**	29%	29%	26%	23%	21%
Because it was the cheapest one	**21%**	34%	32%	27%	21%	12%
Because friends attend this school	**10%**	12%	12%	12%	11%	10%
Because it was bilingual	**5%**	2%	3%	3%	4%	10%
Because it was the only one on the district	**4%**	7%	6%	4%	4%	3%
Because it offered the vocational course that looked for	**3%**	4%	4%	3%	3%	2%
Because my son/daughter was not accepted in other school	**2%**	2%	2%	2%	2%	1%
Other Reason	**26%**	25%	29%	31%	33%	33%

There is evidence that the process of choice, therefore, is configured socioeconomically; [18], [19], [20]. In this regard, the study conducted in [21] stands out, as it recognizes three types of parents regarding their ability to operate in the "education market": parents that are "competent", with high cultural capital and information to choose school depending on the quality; parents that are "semi-competent" to choose using the reputation of the school as reference to opt; and finally, "disconnected" parents, who choose according to the closeness. In Chile, according to the SIMCE 2009 survey results, "disconnected" parents seem to predominate, especially in the poorest (Table 1).

Methodologically, the effects of the voucher system have been addressed from two perspectives: the perspective of verbalization or declaration (by means of qualitative or quantitative research) of reasons for choice which is generally limited to the description, and another perspective of ex post facto analysis of school choices. From the latter perspective, economic studies using statistical methods and econometric models have been conducted to assess effects of the system in quality [22], [23], [24]. To the date, no conclusive results have been brought up regarding the impact of the school choice process on quality. Such investigations tend to emphasize the effects of the voucher system in academic results, regardless of the spatio-temporal structure that relates to the position, distance and other conditions affecting elections of families in socio-geographic contexts. Contrarily, national [25] and international [26] evidence have been gathered supporting the hypothesis that school choice policies tend to affect negatively the equality of education. The OECD alerts about the risks: "School choice has increased across OECD countries. Yet, it can result in segregating students by ability, income and ethnic background and in greater inequities across education systems. School choice schemes should include mechanisms that mitigate the negative effects on equity" [27].

Only few authors have proceeded through geo-referencing methodology, GIS and distance analysis to observe school choice processes and to assess the role of quality in this choice, both internationally [28], [29] and nationally [30], [31], [32]. However, these researches do not consider the interaction among educational stakeholders –between students/families and schools and among schools– in different conditions, according to specific geographical contexts and distribution of educational agents. Therefore, they cannot conclusively determine the validity of the assumption of choice and competition in the system, as social and spatial interaction has not been considered.

The great amount of individuals and groups involved, the complex interaction networks and different levels of aggregation in the educational sphere have led some authors to describe the field of education as a complex system [33], [34], to the extent that it is recursive, self-referential, self-regulates its operation and from which emergent properties arise from the interaction of agents and their different relation between them [35]. In this kind of systems, it is not possible to predict with absolute precision the evolution and changes they will experience, as complex networks of interaction aggregate to shape its conditions [36], [37], [38], [39]. Therefore, the authors who are observing the systems from the complexity perspective note that there are specific tools to address them, which have been called the "complexity algorithms" [40]. In particular, the ABM seem best suited to observe social systems as complex local interactions networks [41], [42], [43]. ABM has been recently used to assess educational choice in France and Italy [44]. This work offers an ABM of educational choice, in which agents make decisions regarding going up another year of education. Another paper [45] is highly relevant, as offers a revisiting of Schelling's model applied to school dynamics. The main mechanisms presented in that paper is the preference for shorter distance and the preference for similar ethnicity; however, although highly relevant, this works do not offer data calibration for their models.

Finally, the voucher system has been challenged from different theoretical, methodological and policy perspectives, evaluating their effectiveness, usefulness and validity of basal assumptions through diverse methods. Therefore, the theoretical question of how social conditions and the spatial setting affect the choice process emerges. It is also relevant from a policy-maker perspective to ask what effect this school choice policy (vouchers) has on the overall quality of the educational system. On the other hand, it is methodologically relevant to address the question of how to approach the social phenomenon of school choice in this context, as it seems necessary to move forward in applying innovative methodologies to allow a more comprehensive view of the process of choosing schools.

III. National Context: Vouchers and School Choice in Chile

In Chile, since the educational reform of 1981, the school education funding scheme operates through a demand-based subsidy mechanism, commonly referred to as voucher or coupon, which means that the State pays monthly to the school private owners or public responsible institutions or individuals, conditional to effective attendance of students averaged over the last three months prior to payment. This mechanism is intended to provide greater choice for families, promote competition for the attraction and retention of pupils amongst schools, resulting in improved levels of educational quality. The amount of the school subsidy was established by law, which have been slightly modified applying some minor changes during the last three decades, as the subsidy amount has increased and it now differs by education level and modality of education, and there are bonuses for the subsidy if the school is in a rural area, if it is in a geographically isolated area, amongst other bonuses (DFL N ° 2, Ministry of Education, 1996, called "Subsidies Act").

The reform of the early '80s was based on the theoretical proposal of Milton Friedman [46] which held the convenience of installing a predominantly private system of educational provision based on market mechanisms, reducing the role of the State [47]. Although school choice in Chile has always been the student allocation policy, it is very important to note that the law that created the voucher system was passed during the military dictatorship and it was not subject of democratic discussion. After 1990, with the return of democracy, the demand-based scheme has been deepened, corrected and consolidated. The main changes of the system were that the government partially funds general education and requires a minimal curriculum, leaving the administration of schools in the hands of competing companies. The State delivers a payment to the schools that are selected by the families, assuming that it maximizes their capabilities of choice. The voucher was assumed as a system which would create a virtuous competition amongst schools.

Since the implementation of the voucher model, the Chilean education has significantly increased enrollment and coverage [48] and recently, performance has slightly improved in some international measurement results [49], although there is no evidence that the voucher system has been the one and only cause of this growth. However, gaps remain in the performance indicators of schools from different income levels [50], an issue that has given place to many studies which have tried to explain this phenomenon. Most of them have been looking at the effects of the demand-based subsidy model [51].

Supporters of the voucher system argue that maximized the choice of families, educational institutions will compete to attract students and increase enrollment. Gradually, this design would eliminate the schools that fail to attract students, while increasing the range of options, so that the system would enjoy the benefits of market competition. Supporters of this model tend to emphasize the benefits of competition in a context of free choice, which would lead to improved quality, while opponents point to the inequity of the system and the lack of evidence for the quality improvement. The voucher system has been subject of extensive discussion in academic, political and ideological spheres, being highly relevant to Chile. Recently, the 2011 student movement pointed-out the flaws and inequalities of Chilean education, in which the demand subsidy was highly criticized. From this perspective, it is very important to account for the effectiveness and usefulness of the voucher as funding model, which would allow scientists to establish technical criteria for the policy development of the educational system, better satisfying social demands for quality and equity in education.

IV. Empirical context: research on vouchers and school choice in Chile

Some authors have argued that the voucher system in a model of educational choice would lead to an improvement in the quality of education [52], [53] because the only way that a school have to attract students and increase and retain enrollment is quality of education.

The introduction of the voucher system has also raised a number of criticisms, as we have seen. [54] and [55] suggest that the demand subsidy mechanism necessarily generates inequality. Other authors argue that there are market failures that prevent the optimal results expected of competition [56]. Although some researchers claim that the voucher system improves the quality of education by maximizing the freedom of families [57] other authors discuss these results, arguing that there are profound socioeconomic and information differences, which lead to increasing inequality and segregation [58], [59], [60].

In the national and international literature, so far, there is no consensus about the effectiveness of the system of subsidizing demand and school choice mechanisms, mainly because there is no conclusive research on the actual conditions of freedom of choice ("real choice"). For example, [61], [62] argue that introducing the income level and parental education as control variables, no significant differences between the quality of public and subsidized can be observed. Previous research have not yet found a clear answer regarding the usefulness or not of vouchers on improving quality, as suggested by [63], [64] and [65] among others. These studies apply statistical controls to the process of self-selection of families when they choose school. However, these studies do not include the distance amongst the factors that influence choice, even though it appears to be an extremely relevant variable as it was shown in Table 1.

Regarding the inclusion of distance in the selection process, in the international literature the work of Hastings, [66] stands out: They find that the distance and school performance on standardized tests are increasingly important for parents and families with higher income level and students with stronger cognitive abilities. [67] conclude that the differences in information levels are highly relevant in the process of choosing school.

In Chile there have been few studies in which students' homes are geo-referenced or that include geographical variables regarding students and their schools. [68] and also [69] provide some examples. They attempt to approach the matter of the distance between the households and the schools that students attend, calculating travel distances for each student. A more recent study [70], geo-referenced the students who took the PSU (College Entry Test) in 2009, in order to evaluate the school selection process that took place. The authors postulate that households make different decision processes, including a first choice among schools (distinguishing excellent performance schools from others), and then choose between schools closer to home. In addition, the authors found that families are willing to set aside 7 PSU points, to travel one less kilometer.

However, the agents in the system do not make educational choices in a homogeneous or neutral environment. Considering the geographical and demographical distribution of the educational suppliers and demanders, different conditions of choice can be found, involving diverse competition schemes between schools. Some authors have termed this situation as "quasi-markets" in education [71]. These conditions can generate a scenario of what we can call a "geo-competitive isolation" of certain schools, due to the differentiated social, economic, cultural conditions of their environment. These geo-isolated schools do not have the same incentives to improve that other schools, because they are under different competitiveness conditions. This situation may contradict the principles of perfect competition in which the voucher and school choice systems are based. It is for this reason that the methodology of geo-referencing to approach school choice [72] must become more complex to allow the approach of transportation phenomena or differentiated urban spaces that generate changes in agents' decisions. This implies to go beyond the measurement of travel distances, and address connectivity, security, levels of trust, social cohesion, availability of options to choose, and several other variables that can be affected by geographic location.

Similarly, the mere application of statistical correlations to geographic phenomena does not solve the problem of local interaction nor allows social scientists to simulate alternative scenarios to test hypotheses. That is innovative methodologies are required to account for the complexity of the school choice process in this voucher scheme of educational choice. The complex social systems perspective offers several tools for its analysis [73], as cellular automata [74], [75] and agent-based modeling and social simulation [76], [77], [78]. These modeling techniques are theoretically related with the analytical sociology perspective [79], [80], [81], etc.).

We have developed this subject for the last 4 years in the Institute of Philosophy and Complexity Sciences (IFICC), getting involved on methodologies of agent-based modeling [82]. Currently, it is relevant to explore the possibility of using agent-based models and GIS to assess school choice [83], [84], [85]. The models can be calibrated with real data available, which indicate academic performance, socioeconomic conditions, demographic data, location of facilities, etc., provided by the Chilean Ministry of Education. Therefore, from the perspective of geo-referenced modeling of local interaction of agents which understands education as a complex system, it is relevant to try to respond about the influence of social and geographical heterogeneity in school choice processes, particularly in the current educational voucher system in Chile. Agent-based modeling techniques calibrated with geo-referenced data can aid in generating predictions and project simulated counterfactual scenarios [86], [87].

V. THEORETICAL CONTEXT: INDIVIDUAL CHOICE WITHIN SOCIAL STRUCTURES

The concept of education as a competitive market is the basis of the theory of Milton Friedman [88], who proposed a model of educational provision based on freedom of choice for families, in which the state subsidizes the attendance of children of the schools of their choice through a voucher. As schools compete for students in this market, the individual incentive of schools is on improving the quality, which enables an overall system optimization. In a related line of thought, but with a more theoretically complex approach, authors like Coleman [89] Hedström [90] and Elster [91] analyze the relationship between freedom of choice and individual rational choice. The seminal work of Boudon [92]

[93], [94] shed lights in the link between social structure and school choice, opening the door for limited rationality or different rational approach in diverse socioeconomic contexts, with his concept of “primary” and “secondary” effects of culture and class, respectively. Boudon’s work is also very interesting as he proposed changes to the educational system in order to reduce segregation, which is crucial in the approach of the Chilean voucher system of school public funding.

From the more structural sociological theory (not structuralism as [95] warned), individual rational choice is put into perspective within an analysis of the structure-agent relationship, meaning that the organization of social space and time is understood as dynamic relationship of interdependence between agent and structure. In this line of thought, the social structure determines into a certain extent the action of the agents so they would not act in a fully "rational" manner, while the projects and actions of the agents may also lead to structural changes [96], [97], [98]. The choice of educational establishment, in this sense, can be understood as a dynamic process in which combine structural and individual actions to shape social reality. In this regard, this research assumes the theoretical question the extent in which agent and structure determines each other. In the matter of school choice, it intends to reveal if they “were pushed” into selecting certain school or if they “jumped” by themselves to enroll in it, or if it is a little bit of both mechanisms [99].

One of the most interesting approaches to the problem of this research is the Theory of Real Freedom. In general, we refer to the concept of educational opportunities to all those possibilities that are available for opting in education, which together with not being prohibited are feasible to afford in terms of resources. In this sense, the notion of increasing educational opportunities relates to the concept of real freedom provided by the Belgian philosopher Philippe Van Parijs [100]. Under this concept, real freedom conjuncts in one instances the negative dimension of the concept of freedom (“no one can stop me from exerting my will”) with the positive idea of having the resources and capabilities to do it. In this sense, the concept of "real freedom" of Van Parijs is more demanding than that of negative freedom, as it interrogates for the effective availability of resources (of various kinds) to execute the will of the individual [101]).

Due to the above, in the context of this research, the question addresses the real possibilities beyond the merely virtual ones, from which people may choose. In this case, it is relevant to assess the possibilities of action of parents, in regard of the selection of the educational institution where their children will attend. This means asking for the educational opportunities, involving the combination of no prohibition with effective resource allocation to do so. This notion of opportunity applied to education, is clearly connected with the notion of opportunity presented in the DBO model (Desires, Beliefs & Opportunities) proposed by [102]). Under this model, although opportunities may exist independently of the actor, they must be known, so that they can affect the actor’s behavior through their beliefs. This phenomenon adds an additional element, subtle but important for the present analysis: it calls into question that if those educational opportunities are not prohibited and are affordable in terms of resources, the actors should be fully aware of their real feasibility.

In referring to the DBO model, it must also be considered that the action of an actor affects the opportunities of other actors, too. This shows the importance of the interaction between agents in a complex system of relationships, which determines the conditions of real freedom of the agents of the system: A desire or belief of an agent can affect its perception of opportunity, and an observing agent may shift his desires or beliefs because of this action, allowing new opportunities to emerge for that agent. Agent-based modeling seems to be one of the few formal tools for coping with this issue [103]. Under these conditions, a reformulation of the sociological research question in rather manner is required, as conditions of real freedom for educational choice must now be addressed in socio-spatially located contexts.

VI. Proposed School Choice Mechanisms for a Voucher-Based Educational System

The results of background research and statistical analysis of socio-economical, educational conditions and geographical information, a restructuration of the question regarding school choice –in order to construct a model– requires the identification of some fundamental elements: a) Environmental conditions; b) Agent characteristics; c) Rules of behavior. But previous to define those model-related issues, a sociological analysis should identify the mechanisms behind the model’s operational conditions.

Regarding the environmental conditions, we have constructed a quantitative taxonomy of districts in the city of Santiago, using several socioeconomic, local, cultural, developmental and educational variables. We resumed the information of the 33 districts of the Chilean Capital City into 7 different groups of districts in which conditions for school choice vary. Methodologically, the taxonomy of districts comes from a factor analysis of principal components, with varimax rotation (on appendix).

From over 200 social and educational indicators from several governmental datasets, from which 20 relevant index were constructed. Six factor explain 63% of total variance, and helped us to construct groups of districts. Details in the factor and cluster analysis may be found in [104].

The factors were denominated according to the kind of phenomena that variables were related to: (1) “Distrital local development" (including security, public school conditions, local entrepreneurship, health services quality and municipal finances). (2) "Economic and cultural capital" (ownership of means of transportation, socioeconomic level, quality of dwellings, educational level). (3) "Secondary socialization an integration" (including access to information, school life). (4) "Power" (including labor scale position and daily need to travel). (5) "Health and growth of housing" (including growth of housing and municipal health) and (6) "Local uprooting" (including housing mobility, civic culture and ethnicity).

Then, we applied a cluster analysis, which grouped districts according to the factors. Interpreting the dendrogram (on appendix), seven types of districts emerged, with differentiated conditions for school choice. Great environmental differences –that may be affecting school choice conditions– emerge with the analysis, showing great geographic diversity in terms of opportunities for families. More and better choice conditions concentrate in the wealthy eastern zone of Santiago. Great and new residential districts with high growth in the last years (in red) configure a reality of its own. Concentric distribution of school choice conditions, from the central Santiago district to the more peripheral districts. An interesting relation occurs regarding the concentration of better social conditions with availability of the subway and the encirclement highway (with involves all orange districts).

We resumed the information of the 33 districts of the Chilean Capital City into 7 different groups of districts in which conditions for school choice vary:

Agents, therefore, will have diverse contexts for choosing school depending on their location in the city, which offer a differentiated structure of opportunities for choice.

To build the proposed model it is necessary to identify the main social mechanisms of school choice. Statistical and theoretical research led the team to reduce the complexity of school choice to six different mechanisms for students and their families: Preference for quality, Preference for shorter distance, Preference for lower costs, Differences in expectations for different agents, Homophily in terms of socioeconomic similarity and Mimesis of neighbors behavior. Preliminary evidence on Chile suggest that distance, quality and price are the most relevant determinants of school choice [105].

We also preliminary present three main mechanisms to explain school behavior: Selection, Supply and Local Competition.

• Preference for higher quality is a relevant concept both theoretically and empirically, as parents tend to choose schools that show better performance. Choice system's advocates defend the importance of quality as a signal for the choosing families, as an ideal school system will lead most families to choose better schools and the rest would simply disappear (although this have been contested by evidence). Still quality is frequently used as a choice mechanism, but the relative importance that different kinds of actors give to quality to make decisions vary greatly among socioeconomic

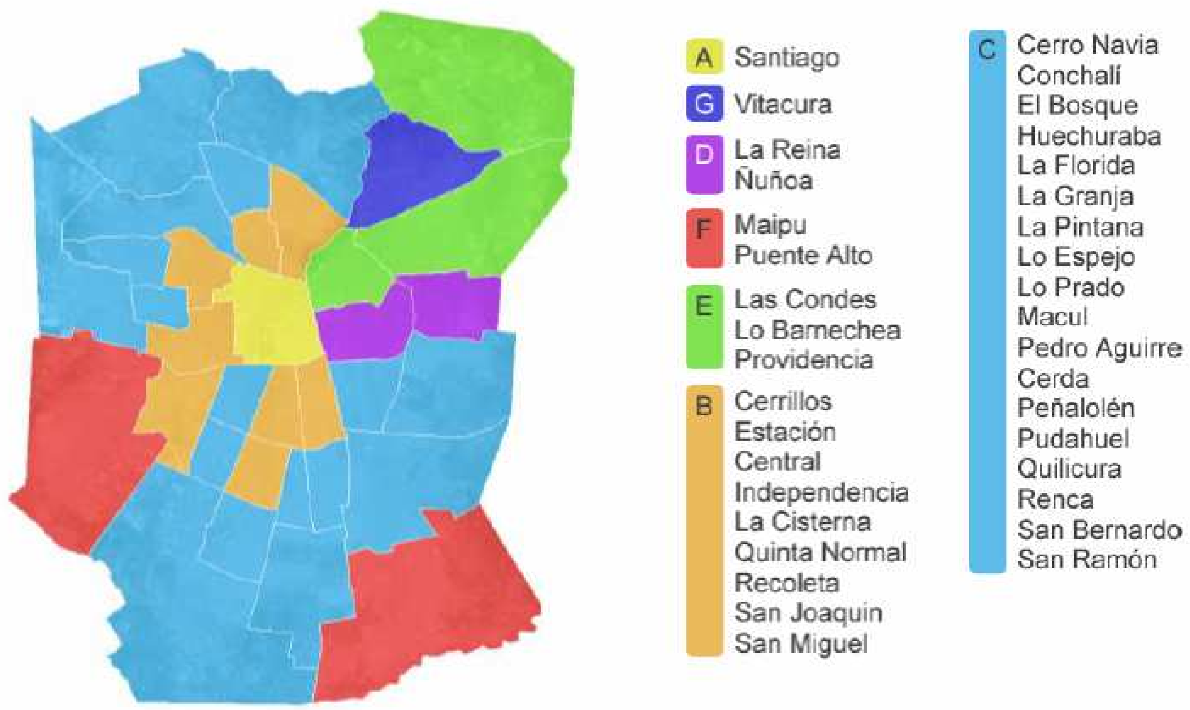


Figure 1– Typology of districts of Santiago, Chile, varying school choice conditions. Source: authors' own elaboration.

and educational backgrounds. The social mechanism expressed in its more general way is the following: “Parents prefer higher quality schools”. Although the “level of quality of a school” is still a social construction, there is multiple evidence that parents tend to prefer schools that they view as higher quality schools for their children [106].

• Preference for shorter distance is the most general geographic condition affecting school choice. Although usually neglected, distance has been included solely as Euclidian distance, thus not considering other issues as connectivity, geographical obstacles and availability of transportation, which varies in different socioeconomic, cultural and educational contexts. In this preliminary research, the social mechanism of distance may be expressed as: “Parents prefer schools which are close to their homes”, and the strength of that preference is diverse according to the context and agents’ conditions. Preference for shorter distance appears frequently in the literature, both for Chile [107] and internationally [108], so it is reasonable to use this mechanism in our model.

• Preference for lower price is the third mechanism. The financial aspect in a voucher system with the possibility of complementing the schooling cost beyond of what is covered by the voucher implies a form of segregation by payment capacities. Poorer parents will not be able to access to some schools, in which tuitions cost are higher. There is abundant evidence that in poorer backgrounds the preference for low cost is overwhelmingly high and even at some levels, paid schools are simply out of the choice set [109]. On the other hand, for richer parents, a more expensive school may signal quality or separation from other social groups, so tuition levels may act attracting high income families. This cost effect varies among different socioeconomic levels. Therefore, the social mechanisms can be simplified to the following: “Parents tend to choose schools with lower tuition costs”, but the intense of the preference varies as some parents may afford higher tuition fees and may interpret them as quality indicators. This calls for a deeper discussion that will not be address here, but we acknowledge it, for it to be included in further versions of the model, once a first version is concluded.

• Expectations play a major role in school choice, as higher expected results may lead to higher investments from parents, while the need for an immediate income may lead poorer families to prefer a vocational, work-oriented and shorter educational track. This implies that the rule should be “Parents with lower expectations of educational continuity may select vocational tracks, while parents with higher educational perspectives tend to choose scientific and humanistic tracks”, which intensities’ varies across social groups. Expectations are included in [110] and [111].

• Homophily is a long identifiable social mechanism for several kinds of choice. In this proposal, homophily is regarded as the tendency to choose schools in which student with similar characteristics attend. Therefore, the mechanism in this case is “Parents choose schools in which students that are similar to them attend”, which relative importance is different depending on other variables. Homophily is a traditionally used variable to explain social behavior [112], and there is evidence of homophilic behavior in educational contexts [113], [114]. Much of the literature in this regard approaches the issue of race and ethnicity, which is not relevant to Chile. Therefore, the socioeconomic background may operate in the same way that racial variable does, as reported in US schools.

• The final concept is mimesis, theoretically and empirically proved mechanism for decision making and behavior in social conditions. Imitating other people behavior is probably the most basic behavior scheme in social contexts, and no difference is expected in educational choice situations. The rule can be formalized as “Parents choose schools that other parents of their local neighborhood do”. Imitative behavior is also a widely used mechanism to explain social phenomena. Reference [115] reports that imitative behavior may foster a growing tendency to inequality, which may be applied to educational choice. Reference [116] includes the variable of social interaction between members of different groups, which may allow some kind of inter-group mimesis.

School behavior, although much more limited (as school play a mostly passive role trying to attract students), still is important to model school choice. Therefore, we had identified three main mechanisms that we can summarize on:

• If possible, Schools will select student with better initial conditions, as education costs an efforts will be smaller if children and teenagers already have higher social and cultural capital. Selection has two versions: a) Academic version: “Schools tend to select higher performing students” and b) Economic version: “Schools tend to select higher income students”. These mechanism present variations across diverse social groups and varies by levels of demand for educational services.

• Preference for limited relative educational supply: Where School is located will define much of it ability to attract and capture student enrollment. They choose according to several variables: “Schools tend to prefer locations in search of increased profit, increased enrollment, and lower investment”, varying by school type.

• Schools will reduce levels of effort in improving education in contexts of lower local competition: This relates directly to geocompetitive isolation, market share and market power. This mechanism implies an increase on the levels of freedom for school with less competition around.

Although several other mechanisms may be identified, this research shows the basic geographical contextual structural factors and the main social mechanisms for choice, as well as the reasons for them to vary across groups. This approach will serve as theoretical and empirical background for the construction and programming of a school choice model for simulating the evolution and effects of diverse choice conditions, first in Chile, but then in other contexts in which voucher policies and school choice mechanisms are relevant configurators of the educational system.

VII. Towards a "zero" model of school choice for Santiago, Chile

Although this is a preliminary work, some light can be shed on how a model could be constructed, with the available variables and data.

As stated before, the model feeds on real data regarding the position of each school in Santiago. In the first set of images, we present the distribution of schools in Santiago, according to their dependence: (1) District (municipal) public schools; (2) Private subsidized school and (3) private schools. It is evident how public schools are evenly distributed in the city, as are the private subsidized schools. To these kinds of schools mostly poor and lower middle class attends. In the third image, private schools tend to be on the eastern part of the city.

The blue curves represent levels of density of schools, and the closer they are, the more density they indicate. To these schools student go daily, travelling nearly 1 km to their school, as showed in the following distribution of travel distances to school:

Based on these georeferenced data, the preliminary model include two kind of agents: families and schools. The operation rules with which agents act depend on three mechanisms: the evaluation of distance, the evaluation of quality and the evaluation of price (for all of which data and other evidence suggest that are relevant variables for school choice process). As this is a preliminary attempt, other mechanisms that may be relevant were excluded for the moment, in hope of including them in more sophisticated versions of the model.

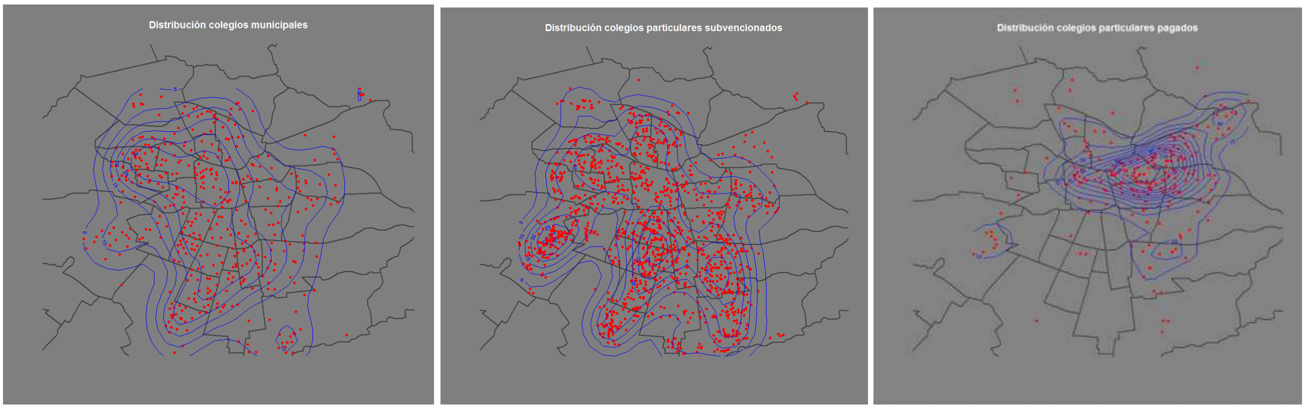
Each variable is calculated from each family regarding all schools of the city. After the decision-making process, the output of the agent-family is –as a behavior– the selection of a given school among all included in the choice set. In the simplest model, the choice set is comprised of all schools in the city.

For agent-schools, behavior rules depend of two kind of variables: the number of families that chose the school and the student's academic performance. The output of the agent-school performance as a behavior is a change of price and school quality (standardized test performance). The positions of families and schools are real positions reported in the geographical coordinated of the databases, included in the GIS. Each iteration of the model represent one academic year.

VIII. Pseudo-coding of the zero model

Agent-Family Rules of Behavior

a. A random family is selected randomly among the georeferenced ones (Ai). If the family has already chose a school for their children, another family is selected randomly.



(1) District (municipal) public schools; *(2) Private subsidized school* *(3) private schools*

Figure 2– Schools distribution by type

b. A school is selected among the georeferenced ones (Cj). If a school has completed their available vacancies, another school is randomly selected. School vacancies are calculated as the real enrolment plus 5%, as basal flexibility.
c. The distance between Ai y Cj (dij) is calculated and the quality value (qj) and price (cj) of the school are assigned using the database information. These values are normalized.
d. An utility function for each school is calculated for each family U(Ai,Cj) from the values calculated in (c). The utility function is equivalent to the sum of the partial utility function of each variable (which are considered independent by hypothesis) U(Ai,Cj)= U(dij)+U(qj)+U(cj). The utility function is logistic.
e. A probability of choice P(Ai,Cj) for Ai to choose Cj in a logit model []Benenson and Torrens 2004) in the form of P(Ai,Cj)= exp[βU(Ai,Cj)].
f. A random number between 0 and 1 is determined. If the value is the less or equal to $P(A_i,C_j)$ the family A_i chooses the C_j school and the model goes back to (a). If the value exceeds $P(A_i,C_j)$ the family A_i does not choose C_j school and the model goes back to (b).
g. This part of the model ends when all families have selected a school for their children.

Agent-School Rules of Behavior

h. Once the previous process is finished (all families chose schools). The changes of states of schools are calculated.
i. The price of school c_j is updated in the following year according to the following rule: if vacancies are not filled, the price of school updates as c_j-Δ_j, if vacancies are indeed filled, the price is updated as c_j+Δ_j, where Δ_j follows a normal distribution N(x,ε).
j. Quality q_j (in SIMCE standardized test results) is updated each year as the average SIMCE average of the students of the school.
k. The simulation ends when all schools have updated their states.
l. The process from (a) is repeated for a Y% of randomly selected students. As at least 25% of students a year change schools (Y% > 25%).

This pseudo-coding will be programmed in the R environment, using the GIS data of schools and families. Future versions of the model will include the taxonomy of districts as choice determinants and the other mechanisms that have been identified as relevant for social choice processes.

IX. The New Question of School Choice in Chile

Finally, the school choice process in the current educational voucher system in Chile, put against the contextual, empirical, conceptual and methodological background, must go beyond the question of the utility of the voucher system, but it must also encompass the question for the conditions of real freedom of educational choice for families,

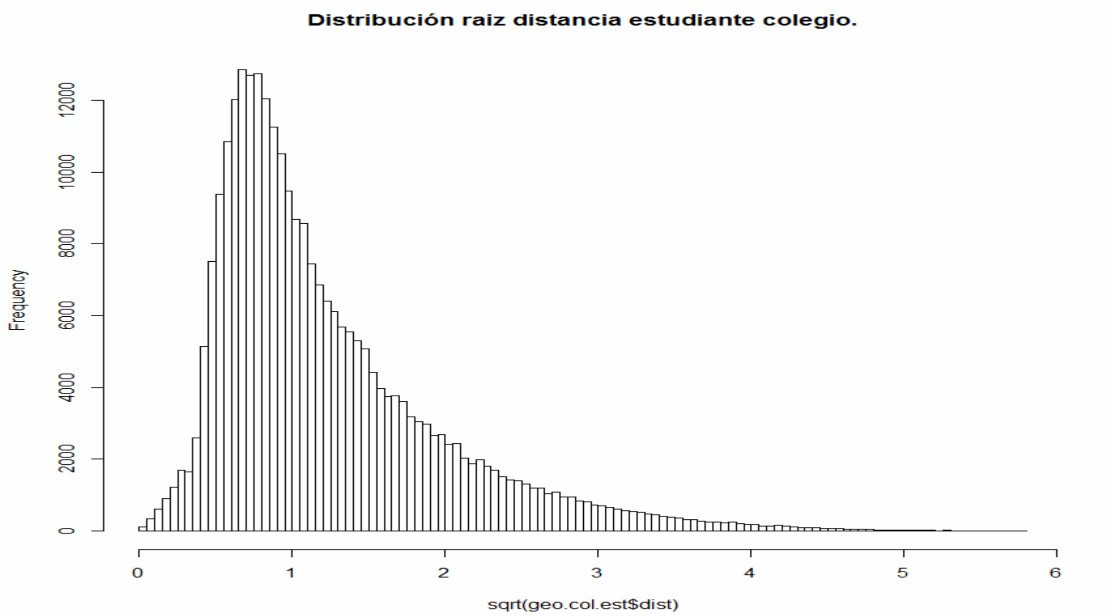


Figure 3–Distribution Square Distance Student from Schools.

understanding education as a complex system. It is necessary to rethink the approach to this research problem, introducing innovative methodologies that combine statistical elements, agent-based modeling and geographical information systems (GIS research should guarantee full confidentiality the personal data of individuals and families, according to the ethical principles of scientific research [117]). Therefore, to reformulate the research question, the following questions should be addressed: how socio-spatial structure affects the interaction between educational agents and, particularly, how it affects the competition between educational institutions? How they affect the real freedom of choice in socially interactive contexts? Due to the above, to what extent the spatial structure reduces the efficiency of the voucher system, in comparison to alternative systems? What would be the effects of changes in public policy, considering geographical condition and interaction networks? Therefore, future research should approach educational choice by means of agent-based modeling and simulation of the effect of the space-time structure on the choice of educational institutions by the families, in the context of a free choice system and State funding through vouchers.

X. APPENDIX

i. Factor analysis of principal components: eigenvalues and total variance explained to derive six factors

Total Variance Explained

Initial Eigenvalues			Extraction Sums of Squared Loadings	
Total	% of Variance	Cumulative %	Total	% of Variance
3,863	19,314	19,314	3,863	19,314
2,808	14,041	33,356	2,808	14,041
2,042	10,208	43,563	2,042	10,208
1,687	8,435	51,998	1,687	8,435
1,146	5,731	57,729	1,146	5,731
1,052	5,262	62,991	1,052	5,262
,937	4,686	67,677		
,921	4,604	72,281		
,870	4,348	76,630		
,683	3,413	80,042		
,649	3,243	83,285		
,594	2,969	86,254		
,491	2,456	88,710		
,477	2,383	91,092		
,448	2,242	93,334		
,383	1,914	95,249		
,295	1,477	96,725		
,254	1,269	97,995		
,227	1,133	99,128		
,174	,872	100,000		

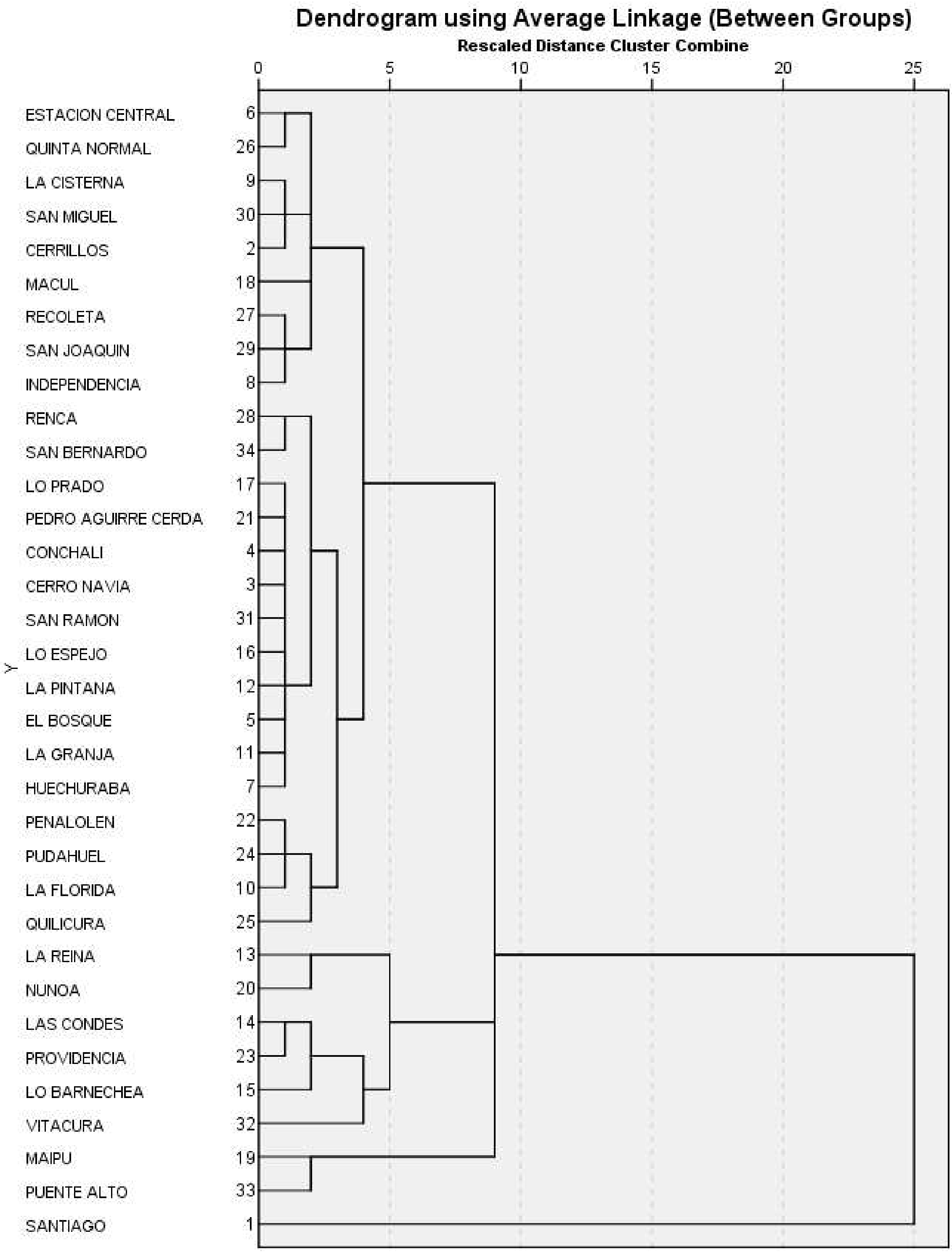
ii. Factor analysis of principal components: Rotated component matrix

Rotated Component Matrix[a]

	Component					
	Desarrollo comunal	Capital económico y cultural	Socialización secundaria	Poder	Servicios de salud y crecimiento habitacional	Desarraigo
Seguridad	-,752	-,020	,011	-,066	,257	,055
Condiciones Educacionales Municipales	,718	-,020	,488	,184	,017	-,090
Desarrollo empresarial	,633	,189	-,176	,251	,163	,097
Espacio	,541	,273	,238	,370	,302	,123
Calidad de Salud	-,510	,395	,088	,160	,393	,279
Finanzas Municipales	,483	-,104	,393	-,170	,206	-,078
Propiedad de transporte	,084	,800	,032	,252	,042	,115
NSE	,049	,766	,018	-,159	,018	-,054
Calidad de Vivienda y Hogar	-,179	,704	-,003	-,328	-,093	-,097
Nivel educativo	,283	,627	,063	,447	,133	,046
Acceso a informacion	,068	,108	,872	,052	,026	,014
Clima escolar	-,153	-,120	,791	-,021	-,196	-,059
Calidad de empleo	,193	,146	,674	,078	,120	,122
Posicion Ocupacional	,036	,070	,023	,749	-,061	,029
Inmovilidad diaria	,127	-,185	,061	,743	,243	-,151
Crecimiento de Vivienda	,089	-,013	,069	,085	,854	-,123
Salud municipal	,452	-,124	,421	,019	-,619	-,049
Movilidad habitacional	,014	,082	,028	,079	-,099	,771
Cultura civica	,131	,081	-,015	,342	-,095	-,412
Etnia	,010	-,369	-,017	-,109	-,050	,382

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 11 iterations.

iii Cluster analysis dendrogram



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Teaching Simulation on Collaborative Learning, Ability Groups and Mixed-ability Groups

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***Abstract*—In this research, a teaching simulation model is built where the understanding status, knowledge structure, and collaborative effect of each learner are integrated by using a doubly structural network model. The purpose of the model is to analyse the actual conditions of understanding of learners regarding instructions given in classrooms. The influence of teaching strategies on learning effects is analysed in the model. Moreover, the influence of the seating arrangement of learners on collaborative learning effects and ability groups are discussed. As a result of the simulation, the following points were found: (1) the learning effects depend on the difference in teaching strategies, (2) a teaching strategy where learning skills, material structure, and collaborative learning are integrated is the most effective, (3) the seating arrangement affects collaborative learning, and (4) ability groups have adverse effects on learners in collaborative learning.**

I. Introduction

In education, it is important to understand the status of the understanding of each learner and design instruction content according to their understanding status. Additionally, there exist relationships between knowledge and the content to be instructed, and it is important to consider the structural dependency relationship when teaching is done. The effectiveness of the collaborative effect among learners has also been clarified.

In the research field of network models, recently, a new model building method, referred to as a complex doubly structured network model, has been proposed[4]. By using this complex doubly structured network model in this research, we tried to integrate the understanding status, knowledge structure, and collaborative effect of each learner in order to simulate the actual conditions of the learners' understanding for instructions given in a classroom. Moreover, we set and examined the issues described below by applying the simulation method. (1) What kind of influence could teaching strategies have on learning effects? (2) What kind of influence could the seating arrangement of learners have on collaborative learning effects? (2) What kind of influence could ability groups and mixed-ability groups have on collaborative learning effects?

II. In-Class Learning Process Simulation

In this research, we tried to build a simulation with a class consisting of 30 learners, where it was assumed that five instructions, from X1 to X5, are used when teaching them. This simulation was to estimate what material should be taught, in what order and how many times, until all learners in the classroom could give the correct answer. To build the teaching simulation, we used correct answer history data for model estimations, correct answer data in the class, and seating data. Correct answer history data for model estimation has two values, correct/incorrect answers, of all 300 learners for five questions that correspond to the instructions taught from X1 to X5. The history data was gathered from an online learning system where primary school children study arithmetic.

A. Definition of the Internal Network

The internal network is composed with multi-layers combined the understanding probability model of knowledge according to the academic capability of each learner and the learning material structure model. When certain knowledge is taught, based on the understanding probability model, the understanding probability according to the academic capability of each learner is calculated. As for knowledge items, the understanding probability propagates along with the material structure model. In this way, the internal network is defined.

1) Understanding Probability Model: When it comes to the understanding probability model of all knowledge that corresponds to the academic capability of each learner, the item parameter is estimated by conducting the marginal maximum likelihood estimate based on the quasi-Newton's method and the EM algorithm which is an iterative method for finding maximum likelihood in statistical models. The ability parameter is estimated by using the experience Bayesian method. By using these estimated values, the understanding probability model is built. Specifically, this estimation is done by using the correct answer history data for model estimation and the ltm-package for Item Response Theory analyses on software R [18]. The result of this estimation is quantified as the form of Ability. The estimated Ability parameter (item characteristic curve) is set according to the knowledge, and the understanding status for all knowledge of each learner at the point in time before teaching, in order to estimate the understanding probability of knowledge of each learner.

2) The Course Material Structure Model: The material structure model was built by utilizing the structure estimation on the Bayesian network. As for model estimation, the correct answer history data for model estimation was used. The result was estimated with the greedy method on the package deal of software R . This was estimated as formula 1.

$$P(X1, X2, X3, X4, X5) \\ = P(X1)P(X3|X1)P(X4|X1, X3) \\ P(X2|X1, X3, X4)P(X5|X2, X3, X4) \quad (1)$$

The conditional probability was calculated with the bnlearn package of software R by using the model of formula 1.

B. Definition of the Teaching Simulation Model

When it comes to the classroom network, in order to build a model, we assumed an all-together (brick-and-mortar) classroom lecture consisting of one teacher and 30 learners, where collaborative learning would be done between each of learners sitting left to right. Learners were allocated according to seating data. If it was found according to correct answer history data that either those learners on the left or those on the right understood the targeted knowledge taught, he/she should conduct collaborative learning when the teacher teaches that knowledge so that the other learners could also understand the knowledge taught.

Based on the complex doubly structured network model consisting of an internal network and a social network, this agent-based simulation estimates the progress of understanding status of the learner when teaching is done.

III. Experimental Results and Discussion

A. Experiment 1: Evaluation of Teaching Strategies

In the experiment, we tried to discuss the issue of what kind of influence teaching strategies could have on learning effects. In this experiment, we move our discussion forward by applying the following four teaching strategies for the class pattern 1 in which students are seated randomly, and then by comparing the average time of teaching sessions and the attainment degrees.

- TS 1 Teaching along with the complex doubly structured network method
- TS 2 Teaching by selecting items to teach in a random manner
- TS 3 Teaching an item where many learners gave wrong answers
- TS 4 Teaching by moving to next item when all learners understood an item by order of the highest correct answer rate according to each model question

TABLE I
The average teaching time.

Teaching Strategy(TS)	Teaching time
TS 1	22.5
TS 2	42.9
TS 3	32.3
TS 4	23.4

As the result of conducting 10 simulation sessions, the average teaching time is shown in Table I. This result confirmed that learning effects depend on teaching strategies. When observed from the viewpoint of the average teaching time, in both teaching strategy 1 and 4, the teaching time was less than 24 times. We can consider that these strategies had higher learning effects. From the viewpoint of the attainment degree, teaching strategy 1 has a tendency where the initial growth was higher than the other strategies. For example, when the attainment degrees after the fifth teaching session are compared with the degree of each strategy, teaching strategy 1 was 0.70, 2 was 0.59, 3 was 0.42, and 4 was 0.49. Therefore, this shows that the teaching strategy 1 had the highest attainment degree.

B. Experiment 2: Evaluation of Collaborative Learning

In this second experiment, preparing three different environments for the lecture model, the left-and-right collaborative learning model, and the group collaborative learning model, we compared the results. The left-and-right collaborative learning model is a model where the seating arrangement is the same as the lecture model and collaborative learning occurs between left and right seats as shown in Fig. 1. On the other hand, the group collaborative learning model is a model where the seating arrangement is grouped in a class room and collaborative learning occurs in the groups as shown in Fig. 2.

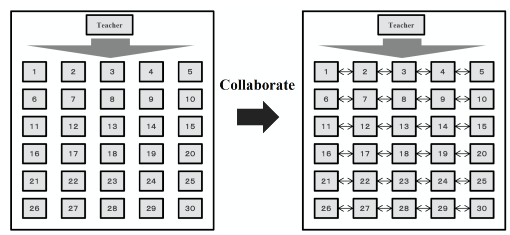

Fig. 1. Placement of the left-and-right collaborative learning model

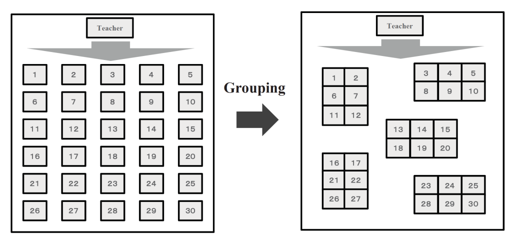

Fig. 2. Placement of the left-and-right collaborative learning model

We conducted 10 simulation sessions. Table II shows the average number of teaching of the simulations. In any of environments for the lecture model, the average number of teaching decreases in order of the lecture model, the left-and-right collaborative learning model, and the group collaborative learning model. Therefor, it is obvious that the collaborative learning models has a positive effect on leaners more than the lecture model, and the wider the range of collaborative learning is, the more the effect on learners is. On the other hand, the attainment degree did not reach 1 in any of teaching strategies of 1, 2, 3, or 4. In the group collaborative learning model, the teaching strategy 4 has virtually the same effect as the strategy 1 in terms of the average number of teaching times. This result means that the teaching strategy 4, which is the teaching method in order of the highest correct answer rate, is the second best strategy for a newly-appointed teacher, because she or he has difficulty teaching while understanding their knowledge structure, ability and collaborative relations.

TABLE II
THE AVERAGE TEACHING TIME.

Teaching Strategy(TS)	1)	2)	3)
TS 1	22.5	8.20	6.0
TS 2	42.9	17.7	13.6
TS 3	32.3	11.8	8.3
TS 4	23.4	9.30	6.0

C. Experiment 3: Evaluation of the seating arrangement on learning effects

The third experiment considered what kind of influence the seating arrangement of learners could have on collaborative learning effects. In this experiment, preparing four different environments for the social network, concentrated arrangement and dispersed arrangement on the left-and-right collaborative learning model and the group collaborative learning model, we conducted 10 simulation sessions by using teaching strategy 1. Afterward, we compared the results. The concentrated arrangement is a model where learners with high academic capability are gathered in one place. The dispersed arrangement is a model where learners with high academic capability next to those learners with low academic capability. About the left-and-right collaborative learning model, we created particular situations with the concentrated and dispersed arrangements by changing the seating arrangement of learners as shown in Fig. 3 and Fig. 4. We compared both situations for discussion. In this experiment, we estimated the academic capability of each learner by using IRT based on the correct answer history of the learner. According to the estimated value, we determined those learners with high academic capability. Determining those learners that have above a certain estimated value to be excellent learners, we structured the concentrated arrangement and the dispersed arrangement by changing the seating arrangement of those excellent learners. As for the average teaching times, the concentrated arrangement was 9.5 and 8.4 times, while the dispersed arrangement was 7.7 and 5.6 times as shown in Table III. While the average teaching times increased in the concentrated arrangement, it decreased in the dispersed arrangement. Through this result, we were able to confirm that learning effects vary by making changes in the seating arrangement for learners and the dispersed arrangement could enhance teaching effects.

TABLE III
AVERAGE NUMBER OF TEACHING IN EXPERIMENT 3

Collaborative type	Centralized	Dispersed
1) Left-and-right	9.5	7.7
2) Group	8.4	5.6

1) the left-and-right collaborative learning model
2) the group collaborative learning model.

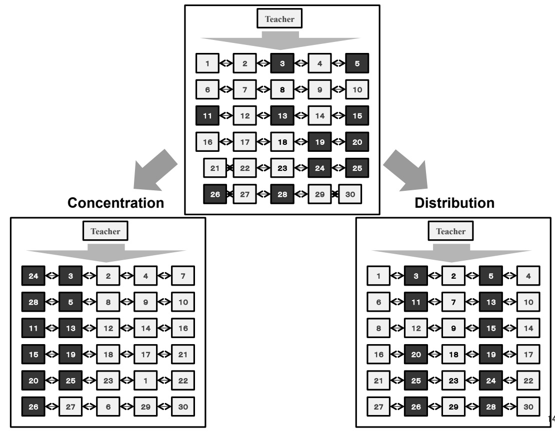

Fig. 3. Placement of the left-and-right collaborative learning model

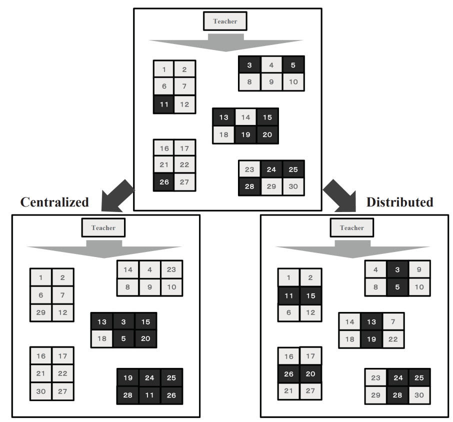

Fig. 4. Placement of the group collaborative learning model

D. Experiment 4: Evaluation of the effects of grouping according to ability

The fourth experiment considered the issue of ability groups in a school. Ability groups mean that children are divided up into groups according to their ability levels to be taught. In this experiment, preparing two different environments for ability groups and mixed-ability groups, we conducted 10 simulation sessions by using teaching strategy 1. The environment of ability groups has three classes divided by their ability level of the answer data on online learning. Although the environment of mixed-ability groups has also three classes, all the learners are mixed by ability randomly. The total number of teaching times in three classes of the lecture model, the left-and-right collaborative learning model and the group collaborative learning model are shown in Table IV. And the results of the average number of teaching times in ability groups are shown in Table V.

When observed from the viewpoint of the teaching time, the number of teaching times for the ability groups is less than the mixed ability groups in the lecture model. On the other hand, the number of teaching times for the ability groups

TABLE IV
TOTAL NUMBER OF TEACHING FOR MIXED-ABILITY AND ABILITY GROUPS

	Mixed-ability groups	Ability groups
1) Lecture	67.5	60.7
2) Left-and-right	23.1	25.5
3) Group	16.8	19.9

1) the lecture model
2) the left-and-right collaborative learning model
3) the group collaborative learning model.

TABLE V
AVERAGE NUMBER OF TEACHING IN THREE ABILITY GROUPS

	All	High*	Medium**	Low***
1) Lecture	60.5	17	20	23.7
2) Left-and-right	25.5	7.8	8.4	9.3
3) Group	19.9	6	6.9	7

*high ability group, **medium ability group, ***low ability group

is more than the mixed ability groups in both the left-and-right collaborative learning model and the group collaborative learning model. The results indicates that ability groups have adverse effects on learners in collaborative learning.

E. Discussion

We utilised the simulation for in-class learning processes considering academic capability, learning material structure, and collaborative relationship. In the first experiment, using four teaching strategies, we quantified the teaching procedure selected by each teaching strategy and the learning effect status, visualised them in chronological order, and compared the influence of each teaching strategy on learning effects. By so doing, we were able to evaluate the educational effects of each teaching strategy.

In the second experiment, we modelled three different environments for the lecture model, the left-and-right collaborative learning model, and the group collaborative learning model. Comparing the results, it is obvious that the collaborative learning models have a positive effect on leaners more than the lecture model, and the wider the range of collaborative learning is, the more the effect on learners is.

In the third experiment, we arranged learners using a concentration arrangement and a dispersed arrangement, quantified the learning effect status, and compared both arrangements. By so doing, we were able to evaluate the influence of seating arrangements on learning effects. Through these evaluations, we confirmed that teaching would work more effectively where there is a dispersed seating arrangement, not a concentrated seating arrangement in collaborative learning.

The fourth experiment considered the issue of ability groups in a school. The environment of ability groups has three classes divided by their ability level of test results on online learning. The environment of mixed-ability groups has also three classes, and all the classes has 30 learners mixed by ability randomly. The results of the experiment indicates that ability groups have adverse effects on learners in the collaborative learning models, while ability groups are more effective than the mixed ability groups in the lecture model.

According to these experiments, ability groups in a school possibly have negative effects to learning because they reduce diversity in a class. Homogeneity between learners on collaborative learning has the risk to take away diversity from learners and make collaborative effect fall into decline.

IV. CONCLUSION

Traditional approaches to analyse the learning effect have focused on the internal knowledge structure or collaborative effect between learners respectively. On the the hand, this study aims to integrate these approaches to analyse the knowledge structure, each learner's state and their collaborative effect simultaneously on the single agent based model.

The purpose of this research was to clarify the actual conditions of understanding of teaching done in a classroom. As a means to do so, we proposed a simulation for in-class learning processes with consideration given to academic capability, learning material structure, and collaborative relationships. We built an agent-based teaching simulation model on an internal network by estimating the understanding probability network by the use of IRT and estimating the learning material structure model with the use of the Bayesian network. We were able to quantify the teaching effects in the classroom and conduct simulations to determine effects.

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A Markov Chain approach to ABM calibration

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***Abstract*—Agent based model are nowadays widely used, however the lack of general methods and rules for their calibration still prevent to exploit completely their potentiality. Rarely such a kind of models can be studied analytically, more often they are studied by using simulation. Reference [1] show that many computer simulation models, like ABM, can be represented as Markov Chains. Exploting such an idea we illustrate an example of how to calibrate an ABM when it can be revisited as a Markov chain.**

I. Introduction

Agent Based Models (ABMs) is an increasing popular approach in social sciences and economics, see [2] and [3]. Generally speaking, in an ABM a set of behavioural rules are defined at the individual level and some aggregate results are derived. Often this approach requires the use of large sets of parameters, needed to describe agent's attitudes. In order to validate the model and then use it for various purposes (prediction, policy analysis etc) finding the parameters value, which better fit the real world, is crucial. Parameters can be explicitly macro variables, as some in [4], or they can be directly estimated by data, as in [5]. Sometimes the peculiarity of the model allows a specific calibration, as in [6], where the maximum likelihood method can be applied since a closed form solution of the distribution of returns can be derived. However it is not always possible to have a closed form for some distributions or a direct simulation of some observables. Often we tackle with individual parameters, that cannot be derived directly from the real world, from which we observe only aggregated variables; in general model complexity does not allow an analytical tractability. That's why the majority of cases must be treated via simulation-based estimation techniques.

A first attempt of calibration can be found in [7], which propose a method of simulated moments with a focus on optimisation heuristic. However, when working with simulated moments, problems related to consistency and identifiability can be relevant, see [8].

In [7] the parameters estimators are obtained as minimum of the simulated minimum distance between moments via a combination of a simplex algorithm [9])and a threshold accepting algorithm [10]. In [11] this optimisation technique has been compared with Genetic Algorithms [12] and the latter appear to perform better; see also [13].

We refer to [14] for a more general discussion about calibrating ABM in economics.

Notwithstanding such interesting attempts, the field of parameters estimation in ABM is not yet enough explored and it needs to find general rules.

According to [1] "..many computer models in the social simulation literature can be usefully represented as time-homogeneous Markov chains." Following this idea we study the problem of setting parameters when the model can be seen as a Markov chain. To this aim we propose a classical minimum distance estimation using a genetic algorithm as minimum searching procedure. The Markov chain approach helps in finding consistent estimators to consider in the objective function. In particular an ergodic and aperiodic Markov chain admits maximum likelihood estimators (MLE) both for the transition probability matrix entries and the equilibrium distribution vector. To test this approach we fit the Kirman model [15], for which it is suitable to use the MLE for the transition probability. Then we compare the result with a direct fit performed using the analytical form of the transition probability.

In order to avoid problems due to the model specification we generated pseudo real data by the model itself with a known set of parameters, then we fitted the model on these data. Future researches are dedicated to improve such a methodology testing other models, enlarging the number of parameters and considering other estimators as the sample occupancy distribution.

We present the main concepts on parameter estimation and Markov chains needed to explain this approach in Section II; in Section III we briefly describe a standard Genetic Algorithm, in Section IV we present an example introducing the model and its Markov chain-version; in Section V we present and discuss the results; Section VI concludes.

II. Parameters Estimation and Markov Chain

Usually, when treating with simulation models, the estimation procedure is based on the comparison of the statistical properties of data with the statistical properties of the model. Indeed, rarely the model properties can be studied analytically directly by the model, hence they are inferred by analysing simulated data. By another hand revisiting the model as a markov chain allows to study some model properties.

In the following we discuss briefly some important issues related to the estimation, as consistency and parameters identification, and we introduce some basic concepts about Markov Chains.

A. Parameters Estimation: consistency and identifiability

We explore the idea to use a Generalized Method of Moments (GMM) or a Classical Minimum Distance (CMD) (see [16]), suitable for simulation models, in which the objective function is built using known estimators for Markov chain. In this paragraph we address briefly problems related to consistency, identifiability and convergence.

Definition 1: A consistent estimator $\hat{\theta}$ is one that converges in probability to the true value θ_0, i.e. $\hat{\theta} \to^p \theta_0$.

Definition 2: An estimator $\hat{\theta}$ is an extremum estimator if there is an objective function $\hat{Q}_n(\theta)$, with $\theta \in \Theta$, such that $\hat{\theta}$ maximizes such a function.

The extremum estimator depends on n and must be denoted by $\hat{\theta}_n$. The following theorem gives the conditions for consistency.

Theorem 3: If there exists a function $Q_0(\theta)$ such that

i) $Q_0(\theta)$ is uniquely maximised at θ_0;
ii) Θ is compact;
iii) $Q_0(\theta)$is continuous;
iv) $\hat{Q}_n(\theta)$ converges uniformly in probability to $Q_0(\theta)$;

an extremum estimator $\hat{\theta}$ is consistent, i.e. $\hat{\theta} \to^p \theta_0$.

Condition i) and ii) are substantive and are called the identification condition and the compactness condition, respectively. Conditions iii) and iv) are regolarity conditions.

Let us consider an objective function of the form

$$\hat{Q}_n(\theta) = -\hat{g}_n(\theta)'\hat{W}_n\hat{g}_n(\theta), \tag{1}$$

where $\hat{W}_n$ is a positive semi-definite matrix and $\hat{g}_n(\theta)$ is a vector of data and parameters.

When $\hat{g}_n(\theta)$ takes the form

$$\hat{g}_n(\theta) = \frac{1}{n}\sum_{i=1}^{n} g(z_i, \theta),$$

where $g(z_i, \theta)$ are sample moments, we have the generalized method of moments (GMM), while when

$$\hat{g}_n(\theta) = \hat{h}_n - h(\theta),$$

where $\hat{h}_n$ is a set of estimators, $h(\theta)$ is a vector of functions that map between the model and the estimator, we speak of classical minimum distance (CMD).

By the law of large numbers $\hat{g}_n(\theta) \to^p g_0(\theta)$, where $g_0(\theta) = E[g(z, \theta)]$, so that if $\hat{W}_n \to^p W$, where W is a positive semi definite matrix, by continuity of multiplication $\hat{Q}_n(\theta) \to^p Q_0(\theta) = -g_0(\theta)'Wg_0(\theta)$. Similarly for the CMD, if $\hat{h}_n \to^p h_0$ and $\hat{W}_n \to^p W$ then $\hat{Q}_n(\theta) = -[\hat{h}_n - h(\theta)]'\hat{W}_n[\hat{h}_n - h(\theta)] \to^p -[h_0 - h(\theta)]'W[h_0 - h(\theta)]Q_0(\theta)$.

The identification condition i) consists in requiring that the distribution of data at the true parameter is different than that at any other possible parameter value. For the GMM we have the following lemma.

Lemma 4: If W is positive semi definite and, for $g_0(\theta) = E[g(z, \theta)]$, $g_0(\theta_0) = 0$ and $Wg_0(\theta) \neq 0$ for $\theta \neq \theta_0$ then $Q_0(\theta) = -g_0(\theta)'Wg_0(\theta)$ has a unique maximum at θ_0.

The analysis of the CMD is similar. The condition for $Q_0(\theta)$ to have a unique maximum at θ_0 is that $h(\theta_0) = h_0$ and $h(\theta) - h(\theta_0)$ is not in the null space of W if $\theta \neq \theta_0$. If W is non singular this condition reduces to say $h(\theta) \neq h(\theta_0)$.

If the moment functions $g(z, \theta)$ or the estimator map $h(\theta)$ are linear in θ the previous identification conditions become the rank condition (to have at least as many functions or moments as parameters) otherwise the analysis of global identification is difficult.

Compactness of the parameter space Θ, that is condition ii) of theorem 3 is also relevant, but it depends on the parameters nature. Uniform convergence and continuity, i.e. condition iii) and iv) of theorem 3 are easily verified when we use moments or maximum likelihood estimators (MLE).

B. Markov Chain

A Markov chain is a stochastic process with the Markov property. Formally it is a sequence of random variables $X_1, X_2, ..$ such that

$$P(X_{t+1} = x|X_1 = x_1, ..., X_t = x_t) = P(X_{t+1} = x|X_t = x_t).$$

The random variable X_t represents the state of the system at time t. If the probability of X_t to be x does not depend on t, the Markov chain is time homogeneous. Let $\mathcal{S}$ be the space of possible values of X_t; $\mathcal{S}$ is called the state space, which can be finite or infinite. We consider here only finite state space. Thus, let $\mathcal{S}$ have m possible states, we define the transition matrix as the $m \times m$ matrix, whose element p_{ij} is the transition probability from state i to state j, i.e.

$$P = \{p_{ij}\} = \{P(X_{t+1} = j|X_t = i)\} \qquad i, j = 1, ..., m.$$

A stationary distribution π is a row vector whose entries are non negative, sum to 1 and

$$\pi P = \pi.$$

An irreducible Markov Chain has a stationary distribution if and only if all its states are positive recurrent. Let denote by $p_i^{(t)}$ the probability to be in state i at time t, formally

$$p_i^{(t)} = Pr(X_t = i) \qquad i = 1, .., m.$$

If the positive recurrent chain is both irreducible and aperiodic it has a limiting distribution, formally

$$\pi_i = \lim_{t\to\infty} p_i^{(t)},$$

for $i = 1, .., m$, which is called also the equilibrium distribution and equals the stationary one. On the long run the probability to be in state i at time t equals the equilibrium distribution.

Let

$$N_i = \sum_{t=1}^{n} \mathbf{1}_{x=i}(x_t),$$

where $\mathbf{1}_{x=i}$ is the indicator function, be the number of time the system stays in the state i. Let

$$N_{ij} = \sum_{t=1}^{n-1} \mathbf{1}_{x=i}(x_t)\mathbf{1}_{x=j}(x_{t-1}),$$

be the sample number of transitions between i and j.

We consider two estimators which can both be derived as MLE:

- The sample occupancy distribution
$$\hat{P}_i = \frac{N_i}{\sum_i^m N_i} \qquad i = 1, .., m, \tag{2}$$
as estimator for the equilibrium distribution.
- The estimator for the transition probability
$$\hat{p}_{ij} = \frac{N_{ij}}{\sum_j N_{ij}}. \tag{3}$$

These estimators are candidates to be $\hat{h}_n$.

III. Genetic Algorithm

Genetic algorithm are search procedure based on natural selection and genetics, see [17].

A GA starts with a population of strings (a string is a coding of parameters) and thereafter generates successive populations of strings. Among the advantages of GA compared to traditional methods, we encounter that GA works simultaneously on a large number of points (a population of strings) while traditional methods on a point at time. In this way, they explore widely the search spaces and the probability of finding a false peak is reduced. Moreover GAs works with a coding of the parameters set, no with parameters themselves and use payoff information (objective function), while traditional methods use other auxiliary information, as for example derivatives in gradient techniques. Finally GAs use probabilistic transition rules.

Briefly, the algorithm starts generating a random population of N chromosomes (which are the suitable solution). Then, the algorithm evaluate the objective function, also called the fitness function, for each chromosomes set and select the individuals (each individual owns a chromosome set), which show the best ability to survive. Those individuals are elected as parents of a new population which will be generated by two following steps: crossover and mutation. Moreover propagation can be also considered. The crossover consists in the generation of new chromosome sets starting from parents' chromosome, then each new chromosome set undergoes to a mutation with a certain probability. Propagation consists in replicating a certain number of old individuals into the new population. Usually these individuals are those with best fitness function. The newborn offspring replaces the old population and the procedure is repeated till a best solution is reached.

The combination of crossover, mutation and propagation gives the evolutionary motion and ensure the convergence to a feasible optimum.

IV. An example of a model seen as Markov chain

The model, we consider here, was proposed in 1993 by Kirman. Taking inspiration by ants behaviour in exploiting two equal sources of food, the model simply considers the interaction between individuals; as result it emerges a herding behaviour which is typically observed also in human behaviour.

There are two sources of food, denoted by two colours (black and white), there are N ants, each feeding at one of the two sources. The state of the system X_t is defined by the number of ants feeding at the black source and can vary between 0 and N. At each time t, two ants meet at random and the first adopts the second's colour with probability $(1-\delta)$. There is also a probability ϵ that the first ant will change autonomously the colour. The dynamical evolution is described by a Markov chain where X_t can assume values k, with $k = 0, 1, ..N$. The transition probabilities $P(k, k+1)$ from k to $k+1$ and $P(k, k-1)$ from k to $k-1$ are the following

$$\begin{array}{l} p_1 = P(k, k+1) = \left(1 - \frac{k}{N}\right)\left(\epsilon + (1-\delta)\frac{k}{N-1}\right) \\ p_2 = P(k, k-1) = \left(\frac{k}{N}\right)\left(\epsilon + (1-\delta)\frac{N-k}{N-1}\right) \end{array},$$

where $p_1 + p_2 \leq 1$ and the probability to stay unchanged is $1 - p_1 - p_2$.

This Markov chain is regular, ergodic and admits a stationary distribution $\pi(k)$, for $k = 0, .., N$, which can be obtained solving

$$\pi(k) = \sum_{j=0}^{N} \pi(j) P(j, k). \tag{4}$$

Hence, we have

$$\pi(k) = \frac{\frac{P(0,1)}{P(1,0)}\frac{P(1,2)}{P(2,1)}\cdots\frac{P(k-1,k)}{P(k,k-1)}}{1 + \sum_{j=1}^{N}\frac{P(0,1)}{P(1,0)}\frac{P(1,2)}{P(2,1)}\cdots\frac{P(j-1,j)}{P(j,j-1)}}. \tag{5}$$

The calibration of this model consists in estimating ϵ, δ and N, hence we have $\theta = (\epsilon, \delta, N)$. In a first istance we prefer to avoid the estimation of N, because either it is an integer or it can assume infinite values and the parameter space Θ could not be compact. Instead considering only $\theta = (\epsilon, \delta)$, the parametere space Θ is the square $([0, 1]^2)$, which is closed and bounded in $\mathbb{R}^2$, hence compact.

To ensure identifiability it is preferable to choose the MLE for the transition probability, see (3), because the corresponding map $h(\theta)$ is linear in θ so that we have global identifiability. Note that the transition probability is not linear in N, another reason to avoid preliminary a calibration with respect to N.

V. Preliminary Experimental Results

Using the model we produced the pseudo real data to be fitted. The true parameters are set to $\epsilon_0 = 0.02$ and $\delta_0 = 0.5$, the number of agents is 100 and is not fitted at this stage.

Data consists of 10000 simulations of the random variable X_t described above; observed values go from 20 to 91. Generating data from the model itself allows to avoid problems related to model specification. The sample transition matrix has been estimated using a subsampling bootstrap methodology, extracting 1000 times a subsample of length of 300. In this way we could also estimate the variance of each single probability and derive the matrix $\hat{W}_n$, which is the inverse of the diagonal matrix constituted by the variances. We used only 6 transition probabilities, specifically the $P(k,k)$ for $k = 40, ..., 46$. In this way the rank condition is verified and the computational time is reduced.

The genetic algorithm has been run with 40 individuals, with a mutation probability of 90%, a crossover probability of 90%, a propagation of 2 individuals at each generation and "tournament" as selection rule.

A minimum has been reached in $\hat{\epsilon} = 0.0218$ and $\hat{\delta} = 0.5047$.

The algorithm has fitted quite precisely δ and satisfactorily ϵ. We compare this result to a direct fit possible in this case having an explicit formula for the transition probability. Considering the probability to go from k to $k+1$, p_1 in (IV), we can re-write it as a second-degree function:

$$f(k) = -\frac{(1-\delta)}{N(N-1)}k^2 + k\left(1 - \delta - \frac{\epsilon}{N}\right) + \epsilon.$$

Fitting this function using a non linear least square standard algorithm we get $\hat{\epsilon} = 7.48 \cdot 10^{-5}$, $\hat{\delta} = 0.4387$ and $\hat{N} = 98$. In this case we are able to fit also the number of agents, but results are decisively worste.

VI. Conclusion

In order to contribute to the field of ABM calibration we proposed to exploit the idea to revisit an ABM as a Markov chain, see [1]. To this aim we consider the Kirman model which can be easily described as an ergodic and aperiodic Markov chain and we calibrated it using a Classical Minimum Distance minimised by using a Genetic Algorithm. Since the model allows us to derive analytically the transition probabilities, we also fit directly such a function extracting then the parameters. The first method is more general and performs better than the second. Indeed results are preliminary but satisfactory. We believe that this study can contribute to enlarge our knowledge on the field of ABM calibration and for this reason deserves more investigation. Future researches will test this approach with other models, enlarging the number of parameters and considering cases in which the map $h(\theta)$ cannot be derived analytically but it must be obtained via simulation.

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Quality, advertisement and social influences in cultural market: The case of motion picture.

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***Abstract*—In the motion picture industry the winner takes it all. Every year a few blockbuster movies such as Avatar, Pirates of the Caribbean, and Toy Story gather most of the Box Office sales while many other movies obtain very low sales. Why do movie goers cluster so much on the same movies? In this paper we propose an agent-based model in which the movie goer's decision-making depends on external influence such as advertisement, internal influence such as imitation, shared consumption influence such as the desire of visiting a movie with someone else and movies' quality. We study how the movie goer's decision-making determines Box Office sales. We find that the average importance consumers attach to movies' quality is low, much lower than the importance consumers attach to external, internal and shared consumption influences. Moreover, we find that the dispersion of Box Office sales is mainly determined by the internal and external forces of the market. Finally we find that additional investments in ad expenditure budgets are particularly beneficial for high budget movies of high quality whereas low budget movies and movies of poor quality do not substantially benefit from additional advertising.**

1. INTRODUCTION

The winner takes it all is a principle which applies to many economies. According to this basic and general principle, a few successful hits get the largest part of the market shares whereas the rest obtain very low shares (Frank and Cook, 1995). The winner takes it all principle applies to entertainment industries as well (Vogel, 1998). For example, in the motion picture industry, a few blockbuster movies like *Avatar*, *Pirates of the Caribbean*, *Toy Story*, *The Avengers* are the real leaders of the market. They gather most of the revenues of the cinema market and the many other movies obtain very low shares (Elberse and Oberholzer-Gee, 2006). For example, in 2003, when the mean of the revenues was $37,000,000, *Spider Man* (1st in rank) earned more than $400,000,000 and *The Piano Teacher* (250th in rank) earned $1,012,000, or in 2009, when Avatar obtains the highest box office of all times, about $750 million, the 250th in the rank, *The Merry Gentleman* obtains only $348,000. Figure 1 shows the distribution of movies' revenues in the USA market averaged from 1981 until 2011. They are ranked according to their revenue, from the first position until the 250th position. The variance of the distribution is very high and the mean is not very informative as it heavily depends on the upper tail[1].

The Gini index is a measure of statistical dispersion representing how much a given distribution deviates from a perfectly equal distribution. It is usually used to measure the dispersion of the income distribution of a nation's residents and also to indicate dispersions of income (http://en.wikipedia.org/wiki/Gini_coefficient) or market shares (Salganik, Dodds and Watts, 2006). We use the Gini index to measure the dispersion of movies' Box Office sales at the cinema theaters. A Gini index of zero indicates perfect equality of revenues, that is a hypothetical market where all movies gain the same, and a Gini index of one indicates a hypothetical maximal inequality with a single movie getting the revenue of the entire cinema theatrical market. From 1999 until 2011 Box Office revenues have always shown very high dispersion, with a Gini index of about 0.5. Questions arise on whether and how social influences could be responsible for the success of certain movies. Could it be that other people visiting a movie trigger a person's interest to visit that movie too? And does the fact that most people consider visiting a movie as a social event, and hence go with companions, has an impact on the sales of a movie? How strong these effects are compared to other effects such as quality and advertising?

FIGURE 1 ABOUT HERE

In our ABM of the movie market we formalize artificial consumers that decide on visiting a particular movie according to external influence such as advertisement, internal influence such as imitation, shared consumption influence such as the desire of visiting a movie with someone else and movies' quality. In this way it is possible to disentangle the different drivers of agent's decision making to visit a movie, and hence get a clear picture of how these factors determine the success or the failure of the movies released in the market.

Understanding the drivers of movies' success is crucial for studio producers' managers, and within this context it is very relevant to understand how social processes may ignite a social avalanche that creates a success (e.g., Elberse, 2013). Experiments with our ABM show that the dispersion of Box Office sales is mainly determined by the internal and external forces of the market and not by the real qualities of the movies. In addition we find that additional investments in ad expenditure budgets are particularly beneficial for movies with high advertising budgets whereas movies with low ad budgets do not substantially benefit from additional advertising.

2. THE AGENT BASED MODEL

2.1. The demand

We simulate the motion picture market for one year with *N* consumers and *M* movies. Each simulation time step represents a week and at each step a fraction $NEW\_ENTRIES_t$ of movies enter the market. Each movie *j* enters the market at time T_j and remain in the market for *MOVIE_LENGTH* time steps. Thus, at each time step *t* agents choose among a given number of available movies, which we indicate with $AVAILABLES_t$.

We use a logit formulation to define the probability that agent *i* visits movie *j* at time step *t* (1) and model agent *i*'s attraction to movie *j* at time step *t* as in (2). For agent *i*, the attraction A_{ijt} of movie *j* at time step *t*, depends on four components: *internal influence*, *external influence*, *shared consumption influence* and *quality*, respectively weighted by β_1, β_2, β_3, and β_4. Internal influence determines how much agent *i* copies other agents' choices, external influence identifies how much agent *i* is affected by the pre-release marketing campaign, shared consumption influence indicates how much agents' choices depend on the availability of companions to visit the movie with, and the quality component indicates how much agent *i* choice depends on movie *j*'s quality.

$$P(agent\ i\ visits\ movie\ j\ at\ time\ step\ t \mid i\ has\ not\ visited\ \ j\ yet) = \frac{\exp(A_{ijt})}{\sum_{m=1}^{AVAILABLES_t} \exp(A_{imt})} \quad (1)$$

$$A_{ijt} = \underbrace{\beta_1 \cdot x_{jt}}_{\substack{\text{external}\\ \text{influence}}} + \underbrace{\beta_2 \cdot y_{jt}}_{\substack{\text{internal}\\ \text{influence}}} + \underbrace{\beta_3 \cdot z_{ijt}}_{\substack{\text{shared}\\ \text{consumption}}} + \underbrace{\beta_4 \cdot q_{jt}}_{\substack{\text{quality}\\ \text{level}}} \quad (2)$$

[1] Source: www.boxofficemojo.com

The weights β_1, β_2, β_3, and β_4 indicate how much importance agent *i* attaches to each component and β_1, β_2, β_3, and β_4 set the average weights of the consumers. In our ABM, movies are like new innovations that launch, diffuse and exit the market. Our model borrows from other simulation models of diffusions and formalizes internal and external influences in a very similar fashion. However, respect with these models, our formalization allows us to simulate several competing diffusions and analyze the distribution of Box Office sales. In order to simulate a market with a realistic competition, we empirically validate our ABM using vast information from the real cinema market. In section 3, following the rigorous guidelines by Rand and Rust (2011), we set the number of movies released per year, how many movies enter the market at each time step ($NEW\_ENTRIES_t$), how many weeks they remain available in the theaters (*MOVIE_LENGTH*) and how many agents attend at each week ($ATTENDANCE_t$) based on the US theatrical market.

Finally, as our main goal is to study the macro outcomes of the market at the aggregate level, we opt for an ABM with a very simple formalization of the individual interactions among agents. For example, we did not explicitly formalize agents' connections and adopt a fully connected network in which each agent is connected to any other agent.

2.2. The supply

The attraction associated to internal influence x_{jt} is based on a herding effect with agents imitating other agents that have visited the movie at the previous time step. We assume that such a herding phenomenon increases when more agents have visited movie *j* at the previous time step:

$$x_{jt} = \frac{VISITS_{jt-1}}{N} \qquad (7)$$

As for the external influence force y_{jt}, we derive it from movie *j*'s advertising budget. As in the real cinema market where studios spend almost the entire advertising budget before the movie release, in our ABM we model movies' launch with a pre-release advertising campaigns. When movie *j* launches at T_j it is characterized by an external influence $y_{jT_j} = \exp\left(-\omega \frac{\overline{AD\_BUDGET}}{AD\_BUDGET_j}\right)$. This formalization assumes that, everything else being equal, the advertising effect depends on the ad expenditures that movie *j* invests in the pre-release marketing campaign (AD_BUDGET_j) and on the average ad expenditures that movies invest in the market ($\overline{AD\_BUDGET}$). We opt for an S-shaped functional form that reflects the empirical relation between the advertising budget and the external influence (Lilien and Rangaswamy 2003). Here ω=[0, Inf] determines the overall effectiveness of the pre-release advertising campaigns in the motion picture market. We adopt a S shaped functional form for the advertising effect, which is in line with findings that show diminishing returns between advertisement investments and their effects on consumer's awareness and behavior and with inconclusive marketing campaigns that may result from insufficient amount of money spent in advertising (Lilien and Rangaswamy, 2003; Tellis, 2006). After launching, in the following weeks, y_{jt} evolves as specified in (8). Here, the external influence component decays depending on δ=[0, 1] which formalizes the retention rate of advertising messages over time. At higher levels of δ, consumers retain the advertising messages for a longer period (Lilien and Rangaswamy 2003; Hanssens et al 2001).

$$y_{jT_j} = \delta^{t-T_j} \cdot \exp\left(-\omega \frac{\overline{AD\_BUDGET}}{AD\_BUDGET_j}\right) \tag{8}$$

The consumption of experience goods such as movies strongly depends on whether they are consumed together with other consumers. Many studies have shown how the decision making of the movie goers is strongly driven by the desire to have a joint experience with someone else. To formalize shared consumption influence we adopt a simple formalization based on the social influence of potential joint consumers who have not yet purchased. Assuming that agent *i* wants to go to the cinema at time step *t* with g_i companions, we model shared consumption influence z_{ijt} as the probability that none of her or his g_i companions have seen movie *j* already (9). Here $\sum_{k=T_j}^{t-1} VISITS_{jk}$ indicates how many agents have already visited movie *j* at time *t* and thus the overall effect refer on the fraction of agents that have not seen the movie yet and can potentially still go. The utility derived from shared consumption decreases when there are fewer other agents available, because it is more difficult to find companions with whom to visit the movie (Weinberg, 2003). Moreover, the probability that all companions have not seen yet the movie decreases also with g_i because the more companions agent *i* wants to include in the shared consumption, the more likely it is that some companion has already seen movie *j* and will steer the group's visit toward other movies. This simple formalization of shared consumption influence strongly depends on an important assumption: consumers do not visit a movie at the cinema more than once. If they have visited a movie at the theaters they are not interested to see the same movie with other companions.

$$z_{ijt} = \prod_{k=1}^{g_i} \left(1 - \frac{\sum_{l=T_j}^{t-1} VISITS_{jl}}{N\_AGENTS} \right) \quad (9)$$

Finally in our ABM when movie j launches and spreads into the market it is also characterized by a quality level q_{jT_j} that corresponds with the overall judgment of the movie among consumers, Q_j (10).

$$q_{jt} = Q_j \quad (10)$$

3. EMPIRICAL VALIDATION OF THE ABM

Rand and Rust (2011) propose rigorous guidelines to validate ABMs. They particularly stress the importance of empirical validation, which is the process of determining how well the implemented model corresponds to reality using real data. They define empirical input and empirical output validations as two forms of validation that confirm that the real data being added to the model are accurate and that the output of the ABM corresponds with real data. These two forms of validations differ from micro-face and macro-face validation that instead ensure that the micro-mechanisms of the agents and the macro-patterns of the model correspond “on face” to the real world and do not need empirical confirmation. In this section, we empirically validate our ABM with data of the real US market, including ad expenditures, production budgets, peer review scores, etc. In Table 1 we list the parameters of our ABM, including their description, their values, and how we validate them.

TABLE 1 ABOUT HERE

In order to validate our ABM, we use overall statistics on the US cinema market. In addition, we build up a rich dataset on movies released in the US market from 1999 until 2011, including the 150 movies with the highest Box Office sales year by year, which corresponds to more than 95% of the total yearly revenues of the industry. Besides Box Office sales, our database includes the weekly ad expenditures and the peer reviews scores of each movie. In the next subsections we illustrate how we use this information on the real US cinema market to empirically validate our ABM.

3.1. Empirical validation of the number of movies per year, new releases per week, movies’ life cycle length and weekly attendance

We begin setting M = 521 and MAX_LENGTH = 15 as in the US cinema market, from 2000 until 2010, an average of 521 movies were released each year and obtain 98% of their Box Office sales within the first 15 weeks of their life cycles. Then, investigating the releasing date of these movies and the total Box Office sales of the market, we could also empirically validate $NEW\_ENTRIES_t$, and A_t that are the number of newly released movies per week and the fraction of N that visit the cinema at each time step t.

3.2. Empirical validation for external influence

Regarding the external influence component, we could empirically set AD_BUDGET_j and estimate ω and δ values. Using real weekly advertising expenditures of movies launched in the US market from 2000 to 2010, we randomly extract AD_BUDGET_j from a Normal distribution, with the mean and variance of the real advertising expenditures of the week movie j is released and estimate. Then, using the total advertising budgets of the movies of our database and their Box Office sales we estimate ω and δ values for each movie. Our estimation procedure converged for 1857 out of 1950 movies, providing the following results: average(ω)=2.56; std(ω)=1.11; max(ω)=8.2; min(ω)=0.04; average(δ)=0.62; std(δ)=0.16; max(δ)=0.99; min(δ)=0.24. Thus, in our ABM we set ω=2.5 and δ=0.6. In the technical appendix we provide further details about ad expenditures data, Box Office sales data and the results of our estimations.

3.3. Empirical validation for shared consumption

Using statistics on group sizes for visiting movies (FFA 2013) we can validate g_i, that is the number of companions with whom agent i visits a movie. On average, from 2007 until 2012, 9.3% of the tickets sold were single visits, 43.7% involved couples, 20.2% included groups of three, 13.3% were groups of four, and 13.5% involved groups with five or more consumers. The distribution of group visits remained stable, with no significant changes across the five-year span. In our simulation, at each time step we re-assign g_i values to each agent. In the Technical Appendix we provide information year by year on groups' attendance.

3.4. Empirical validation for quality

We could empirically validate Q_j values using three movies' variables: production budget, peer and expert judgments. We created a quality measures according to the following formula:

$$Q_j = \frac{Ln\left(P\_BUDGET_j\right) + PEER\_JUDGMENT_j + EXPERT\_JUDGMENT_j}{3} \tag{11}$$

Our database of movies launched in the US market from 2000 to 2010 also contains production budgets, peer and expert judgments. In our simulation, for each AD_BUDGET_j randomly drown we select the corresponding values for P_BUDGET_j, $PEER\_JUDGEMENT_j$ and $EXPERT\_JUDGEMENT_j$ and determine Q_j.

4. RESULTS

4.1. Simulation experiment 1. The effects of quality, external and internal influences on the dispersion of movies' Box Office sales

In this simulation experiment we simulate different scenarios to analyze how the importance consumers attach to internal, external, shared consumption influences and quality impacts the motion picture market. In particular, we focus on three main aspects of the motion picture market:

- *Distribution of Box Office sales.* In each scenario we compute the GINI coefficient which indicates whether Box Office sales differ across movies.

  $$GINI = \sum_{i=1}^{N}\sum_{j=1}^{N}\frac{\left|VISITS_i - VISITS_j\right|}{2N^2 \cdot \overline{VISITS}} \qquad (12)$$

  This index varies between 0 and 1.

- *The difference between the rankings of quality and Box Office sales.* In each scenario we compute an overall index which indicates whether the good movies are also and the most visited movies. For each movie *j*, Q_RANK_j and BO_RANK_j indicate its positions in the quality and Box Office rankings, respectively. Then we can compute an overall index of the market based on the sum of the absolute differences of the rankings:

  $$RANK\_DIFF = \sum_{j=1}^{N}\frac{\left|Q\_RANK_j - BO\_RANK_j\right|}{N^2/2} \qquad (13)$$

  This index varies between 0 and 1.

- *Movie life cycles.* In each simulation scenario, we also compute an index representing the life cycle of the movies. For each movie *j*, it is possible to keep track of the Box Office sales along the life cycle of the movie. Thus, we calculate the percentage of the Box Office sales in opening week respect to the cumulative Box Office sales and the average percentage over the movies in the market.

We design an experimental design with 625 simulation scenarios using a wide range of values: β_1 = [0.1, 0.3, 0.5, 0.7, 0.9], β_2 = [0.1, 0.3, 0.5, 0.7, 0.9], β_3 = [0.1, 0.3, 0.5, 0.7, 0.9] and β_4 = [0.1, 0.3, 0.5, 0.7, 0.9]. Table 2 presents the results of the experiment. It reports the coefficients of three regression models, estimating the effects of internal, external, shared consumption influences and quality (independent variables) on the three market indicators described above.

TABLE 2 ABOUT HERE

The most important driver of Box Office sales' dispersion is internal influence. If consumers attach more importance to internal influence, the GINI index increases, indicating a larger gap between successful and unsuccessful movies. This effect is trivial because when consumers attach more importance to internal influence they copy each other more and their visits tend to converge more to the same movies. The effects of external influence, shared consumption influence and quality display more interesting results. While their directions are straightforward; it is interesting to compare their magnitude. The impact of external influence is surprisingly bigger than the effects of shared consumption and quality. Moreover, the effect of quality is really low, indicating that the big gap between successful and unsuccessful movies does not crucially depend from the fact that consumers visit good movies and avoid bad movies.

Our analysis also suggests that the gap between good movies and successful movies depend mainly on how much importance consumers give to internal influence and quality and that the percentage of the opening week strongly depends on the external influence.

Our experiment allows us to identify the most realistic simulation scenarios. In the real market *GINI*=0.504; *RANK_DIFF*=0.405 and *OPENING*=35%. The three simulation scenarios with the closest values to the real values are presented in Table 3. These results clearly indicate that in the real market consumers attach high importance to shared consumption and low importance to quality.

TABLE 3 ABOUT HERE

5.2. Simulation experiment 2. Increasing advertising budget

Our ABM allows us to investigate budget allocation strategies. In particular we can study whether an additional investment in advertising expenditures and a heavier marketing campaign is efficient. Such an instrument is one of the most efficient managerial tools that studio producers can use to positively affect the success of their movie. In this simulation experiment we study what happens when a studio increases the pre-release ad expenditures for the movie is about to launch.

We cluster the simulated movies based on four variables: expert review, peer review, advertising budget and production budget and clearly identified three clusters. In Figure 3 we plot the movies based on their advertising budgets and on the quality measure used in our ABM and we color them based on the cluster they belong to, so that we can sharply identify the three clusters. It is clear that the three selected clusters depend much more on the advertising budget than the quality measure. Red, blue and green dots indicate movies with high, medium and low ad budgets. Finally, we use the centroids of these five clusters to simulate what would have happen if studio producers had increased the advertising budgets of these five movies by 30%. We simulate this change in ad expenditures in five different simulation runs, all with the most realistic scenario' values, i.e. $\beta_1 = 0.5$, $\beta_2 = 0.5$, $\beta_3 = 0.7$ and $\beta_4 = 0.1$.

TABLE 4 ABOUT HERE

FIGURE 3 ABOUT HERE

Figure 4 shows the results of this simulation experiment. The benchmark indicates the movie's visits without any additional budget. Interestingly, we find that movies with low and medium ad budgets do not obtain significant improvement, whereas movies with high advertising budgets do much better and significantly improve their success with additional advertisement.

FIGURE 4 ABOUT HERE

5. CONCLUSIONS, IMPLICATIONS AND LIMITATIONS

The motion picture industry is often considered a risky industry because studios have to invest high budgets to produce and market artworks whose quality is highly uncertain. Movies' quality depends very much on artistic talent, creativity and intangible assets so that it is very difficult to predict whether a script may result in a good or bad product and whether the public will eventually like and buy it.

Our results suggest that this is not true. The importance consumers attach to quality is not the main driver of Box Office dispersion. The importance people attach to quality determines whether good movies are successful and bad movies are unsuccessful and indeed we observe that good movies have much more chances to be successful than bad movies, but the gap between good and successful movies exists and it is mainly due to the fact that people are strongly affected by external influences such as advertisement and social influences such as imitation and shared consumption. We found that on average the importance consumers attach to advertisement is more important than the importance they attach to quality. This suggests that this industry is not a very risky industry because quality is unpredictable. This industry is very risky because people do not give importance to quality and only a few movies succeed to ignite imitation (Salganik, Dodds and Watts, 2006).

The results of our second experiment provide support for the so called "blockbuster strategy" (Elberse, 2013), which suggests to concentrate studio's investments towards a few big projects. Although theoretical and empirical works have shown that the marginal effects of advertising campaigns decrease when they become big (Tellis, 2006) and that high advertising investments in cultural markets such as the motion picture market, are inefficient (Elberse and Anand, 2007; Joshi and Hanssens, 2009) the blockbuster strategy suggests to insist with heavy investments for high-budget projects.

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TABLE 1. The parameters of the ABM

Parameter	Description	Values
N	Number of agents	5,000
M	Number of movies released per year	521
$NEW\_ENTRIES_t$	Number of new entries per week	Min = 3 (week 1); Max = 14 (week 38)
$ATTENDANCE_t$	Weekly attendance, or fraction of N that visit the cinema at time step t	Min = .3 (week 37) Max = 1 (week 52)
$MOVIE\_LENGTH$	Number of weeks of a movie life cycle	15
AD_BUDGET_t	Advertising budget of movie j	Min = $0, Max = $60.8 million, <AD_BUDGET>= $11.7 million
Ω	Strength of advertising messages	2.56
δ	Retention rate of advertising messages	0.62
g_i	Number of movie visit companions of agent i	9.3% alone, 43.7% in couples, 20.2% in groups of three, 13.3% in groups of four, and 13.5% in groups of five or more
β_1	Overage importance people attach to internal influence	[0.1, 0.3, 0.5, 0.7, 0.9]
β_2	Overage importance people attach to external influence	[0.1, 0.3, 0.5, 0.7, 0.9]
β_3	Overage importance people attach to shared consumption influence	[0.1, 0.3, 0.5, 0.7, 0.9]
β_4	Overage importance people attach to quality	[0.1, 0.3, 0.5, 0.7, 0.9]

TABLE 2. Simulation experiment 1.

Parameter	Description	GINI	RANK DIFF	PERC_OPENING
β_1	Overall importance consumers attach to internal influence	.778**	.038**	-.445**
β_2	Overall importance consumers attach to external influence	.518**	.527**	.789**
β_3	Overall importance consumers attach to shared consumption influence	-.174**	.033*	.230**
β_4	Overall importance consumers attach to quality	.079**	-.775**	-.108**
R^2		.91	.88	.89

Notes: *p<0.05; **p<0.01.

TABLE 3. The most realistic simulation scenarios.

	β_1	β_2	β_3	β_4	GINI	RANK DIFF	PERC_OPENING
Real market values					.504	.405	35%
The best simulation scenario	0.5	0.5	0.7	0.1	.503	.463	31%
The second best simulation scenario	0.5	0.5	0.9	0.3	.487	.342	32%
The third best simulation scenario	0.5	0.5	0.9	0.1	.483	.473	32%

FIGURE 1. Revenues in the motion picture market in US from 1981 until 2011.

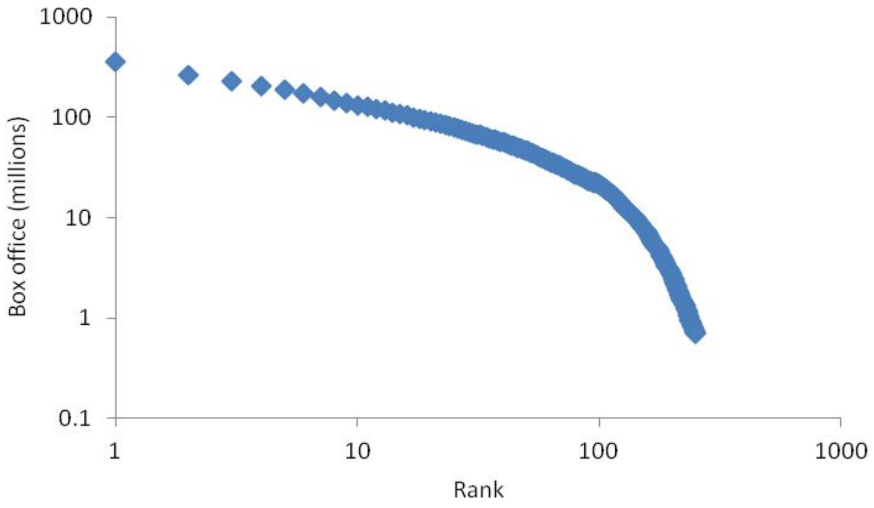


FIGURE 2. Movies' clusters.

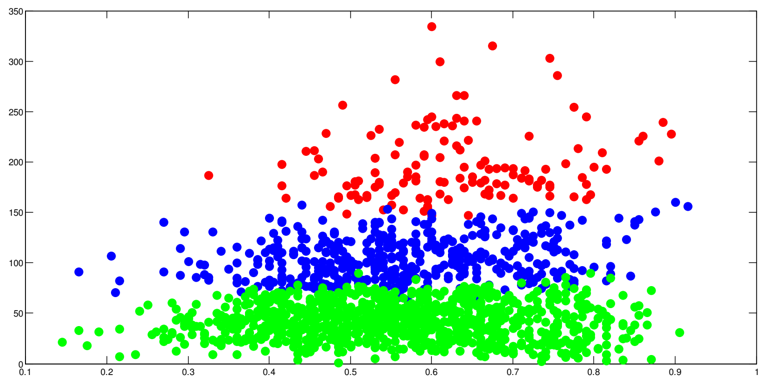
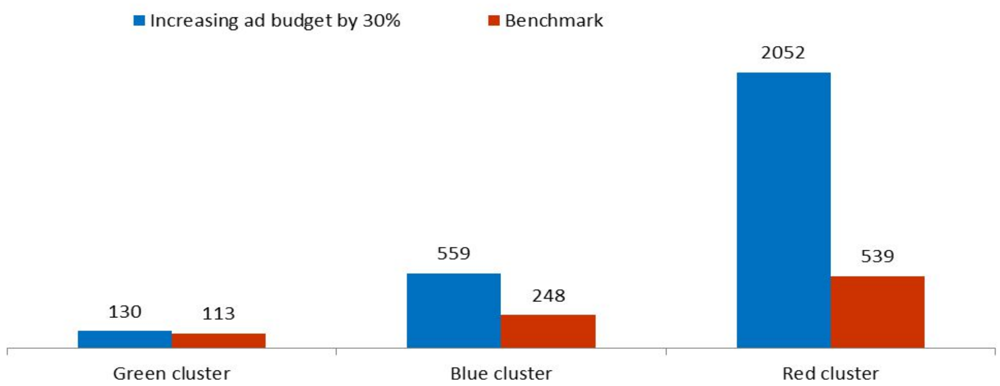


FIGURE 4. Investing in ad expenditures.



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Sensitivity analysis for agent-based models: a low complexity test-case

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***Abstract*—Methodologies for sensitivity analysis are considered to be of great importance for analyzing agent-based models (ABMs), even more because calibration and validation of ABMs often prove problematic. Different methodologies for sensitivity analysis may help to understand ABM dynamics and (thus) aid in the calibration and validation of ABMs. However, model complexity of ABMs is a significant hinderance for a detailed research on which (combination of) sensitivity analysis methods may provide the best option. We present here an agent-based model of low complexity to be used as test case for different methodologies of sensitivity analysis.**

I. Introduction

Calibration and validation are considered to be key challenges for agent-based modelling [1]. Sensitivity analysis is a statistical tool to analyze the effects of variations and uncertainty in input on the resulting output [2]. Sensitivity analysis can be helpful for model calibration and validation. For instance, it may reveal what level of data is required for certain inputs, and thus what type of experimental design is minimally required for model validation. A protocol for the numerical experimental design of sensitivity analysis for ABMs has recently been proposed [3].

One weak point of currently available methodologies for sensitivity analysis is that they are not particularly well-suited for models with strong nonlinearities and tipping points [4]. Yet, systems simulated by ABMs may display exactly these characteristics typical of Complex Adaptive Systems (CAS). For instance, an ABM simulating a fishery system in the Philippines shows a near linear increase in revenue under a decrease in the tightness of fishing quota, followed by a tipping point at which the ecological system - and hence the revenues - completely collapses [5]. This result was found using one-at-a-time sensitivity analysis.

It is conceivable that a combination of different methods for sensitivity analysis offers better insight on the sensitivity of models representing CAS. We therefore explore here a strategy of combining methodologies for sensitivity analysis to analyze an ABM. In practice, however, many ABMs have a rather high complexity, which means it may prove cumbersome to perform sensitivity analysis - up to the point of being practically infeasible. We therefore propose a low complexity test case ABM to ascertain the best strategy for doing sensitivity analysis. This approach allows us to start out simple, while letting us add further CAS properties to the model once the present version has been sufficiently analyzed.

TABLE I: Process overview of the model

sites: grow and diffuse resource
agents: observe
agents: harvest?
agents: move?
agents: pay maintenance
agents: die?
agents: breed?

TABLE II: Table containing the main variables and parameters

i	Agent index
n_{tot}	Total number of agents
$N_x \times N_y$	Field size
t	Time index
x, y	Spatial orientation indices
$E_i[t]$	Internal energy content of agent
$n_{x,y}[t]$	Number of agents at a site
$R_{x,y}[t]$	Resource density at a site
$\alpha_{h,i}$	Harvest coefficient of an agent
$\alpha_{m,i}$	Move coefficient of an agent
D	Diffusion coefficient
E_a	Energy expenditure on maintenance per time unit
E_{birth}	Minimal energy for procreation
E_h	Energy expenditure on harvest
E_m	Energy expenditure on move
H_{max}	Maximum harvest by agent at a site per time unit
k	Carrying capacity per site
n_0	Initial number of agents
r	Growth rate of resource
R_{unc}	Uncertainty in agent's observation of resource
γ	Mortality coefficient
η	Efficiency of converting resource to internal energy
κ	Procreation coefficient
ξ	Variation in offspring characteristics

II. Test case description

The test case ABM considers agents that harvest a resource in a spatially explicit environment. The ABM contains two types of entities: lattice sites and agents. The lattice sites form an $N_x \times N_y$ lattice that represents the spatial environment. Each site contains an abstracted resource density $R_{x,y,t}$.

Because agents have a basic energy expenditure, they need to harvest resource from sites to maintain their internal energy balance. Every time-step, agents decide to either harvest at their current location, move to a neighbouringing site (which costs energy), or stay (preserving energy with the risk of finding the resource taken by another agent). This decision depends on both the external environment and the internal state of the agent.

The ABM is implemented in NetLogo [6]. The main process overview for a single time-step is shown in Table I. All parameters and variables are given in Table II. A summarized description of the submodels in the process overview follows below.

1) Grow and diffuse resource: The resource grows logistically on each site and diffuses between sites following following Fick's second law [7],

$$\frac{dR(x,y,t)}{dt} = rR(x,y,t)\left(1 - \frac{R(x,y,t)}{k}\right) + D\nabla^2 R(x,y,t). \quad (1)$$

We use the exact solution for the logistic growth, avoiding numerical destabilization. The diffusion equation is solved using a forward Euler algorithm, which is stable for $D < \frac{1}{4}$.

2) Observe: Agents check their current site and the 4 Von Neumann neighbours for resource $R_{x,y}$, the number of agents nx, y, and the internal energy E_i of each agent. Agents do not have perfect information on the amount of resource or internal energy; there is a random difference between the observed amount and the true amount. The difference is distributed normally around zero with standard deviation R_{unc}.

3) Harvest?: Agents decide whether they will harvest this time-step. The agent is more likely to harvest if E_i is low (ie., the agent is 'hungy'), if $R_{x,y}$ is high, if $n_{x,y}$ is low (ie., there is no need to share) and if the resource on neighbouring sites is low. Agents also have an individual harvest coefficient α_h. Agents with a low value of α_h harvest more often. If an agent decides to harvest, an amount of resource up to a maximum harvest H_{max} is converted to internal energy with an efficiency η, .

4) Move?: If an agent does not decide to harvest, it may spend energy to move. Moving is likely in the direction of the highest expected harvest. That is, a move is made in the direction with the highest $R_{x,y}$ and the lowest number of agents. In addition, agents have an individual move coefficient α_m. Agents with a low value of α_m are more likely to move.

5) Pay maintenance: Agents pay a constant amount of energy for maintenance E_a each time-step.

6) Die?: Each agent has a probability to die each time-step. This probability is higher if the internal energy of the agent is low.

7) Breed?: Agents with a sufficient internal energy level have a probability of procreating by dividing their internal energy over two newly created 'daughter' agents. These inherit the characteristics of the 'parent' agent with minor deviations.

III. Results

A. Local sensitivity analysis

Local sensitivity analysis is a low-cost methodology that can expose tipping points and other strong nonlinearities. Local analysis starts from a nominal parameter set. From this set, each parameter, including the initial number of agents n_0, was varied individually over a large range. As output variables, we chose n_{tot}, and the average values of α_h and α_m, taken over all agents. Many runs showed periodic solutions (see Fig. 1). For simplicity, we averaged over the second half of each run and did not consider the periodicity. Each run lasted 10^3 time-steps. A number of runs of 10^5 time-steps showed this to be sufficient to capture the long-term model behaviour. Each run was repeated 10 times to account for stochastic variations.

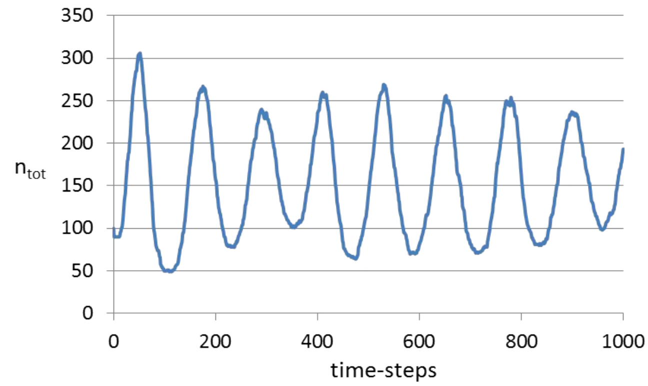

Fig. 1: Time-series of the total number of agents in the nominal parameter set.

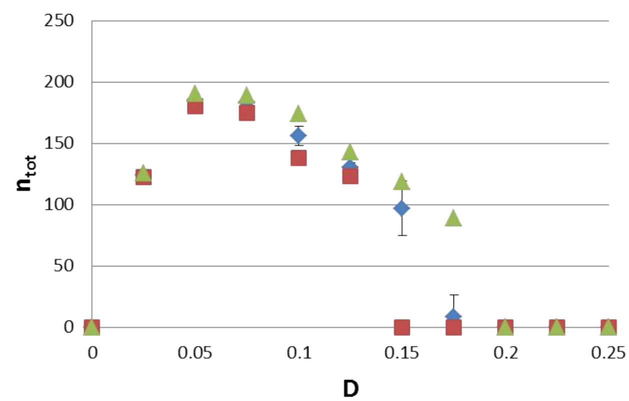

Fig. 2: The number of agents n_{tot} for different values of D. The reported values are the averages over the second half of each run, and over 10 replication runs. The mimimum and maximum among replicates are shown in red squares and green triangles respectively. The error bars show the 95% confidence interval.

The results for the diffusivity D are shown in Fig. 2. If there is no diffusion ($D = 0$), the number of agents goes to zero. This is to be expected, since sites cannot gain resource after having been emtied completely. The agents thus empty the sites one by one, until the system collapses. As the diffusivity is increased, the number of agents increases, up to an optimal value of D where the number of agents is maximal. As D increases further, n_0 decreases and eventually goes to zero (depicted in Fig. 2 as red squares). Visual inspection of simulations reveals that this results from an increase in the amplitude of the oscillations in the number of agents. For $D = 0.15$ and $D = 0.175$ some of the runs went to zero as the mimimum of the oscillations reached $n_{tot} = 0$. For higher values of D, this happened in all of the runs.

Figs. 3 and 4 show the effect of the diffusivity on α_h and α_m. A low value of α_h or α_m means that agents harvest or

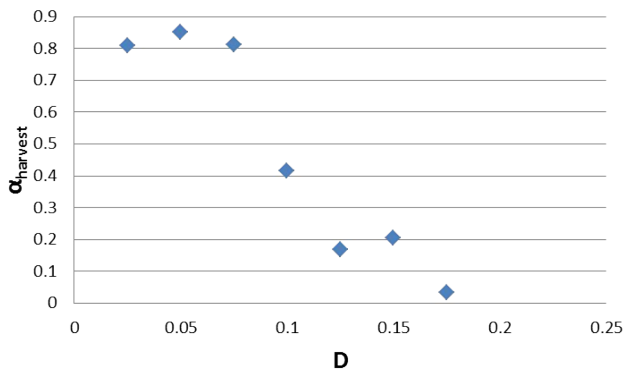

Fig. 3: OAT sensitivity analysis of D on α_h. The reported values are the averages over the second half of each run, and over 10 replication runs.

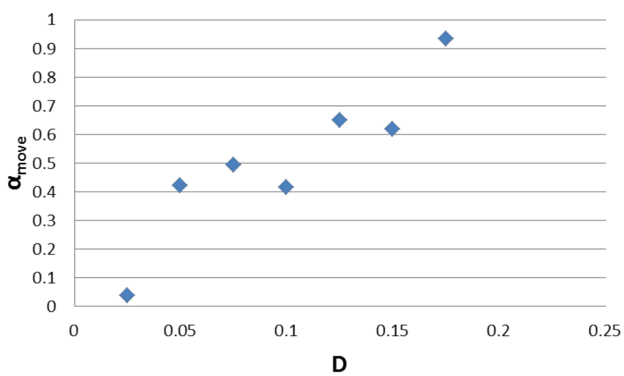

Fig. 4: OAT sensitivity analysis of D on α_m. The reported values are the averages over the second half of each run, and over 10 replication runs.

move more often respectively. For low values of D agents move more often, trying to find sites that are rich in resource. For high values of D the resource spreads out more evenly, so that agents tend to harvest at their present location more often. Further one-at-a-time analyses for all other parameters revealed that η, k, E_h, E_a, E_{max} and θ_{die} all have tipping points where n_0 goes to zero, i.e. this is a robust property of the ABM.

B. Global sensitivity analysis

After revealing nonlinearities and tipping points by using a local method, a global variance-based analysis was used to sample from the full parameter space and to obtain information about interactions between parameters. For a variance-based method one assumes probability distributions to account for uncertainty in the input parameters. The method then decomposes the variance of the output in terms that are attributed to these input uncertainties. We chose uniform input distributions over a large range, to explore the model behaviour over a large part of the parameter space. The analysis was based on an independent draw of 1000 parameter sets from these input distributions. Inspection of the histograms showed that the input sample sufficiently covered the uncertainty range of each parameter. Furthermore, there were no significant correlations between the input parameters in the sample. As was done in the local analysis, all outputs were averaged over the second half of the simulation. For each sample point, 10 replicates were generated to account for stochastic effects. Table III shows the mean of the variance among replicates, expressed as a percentage of the variance over all model runs. Stochastic effects did not cause a large amount of variation in n_{tot}, but α_h and α_m showed larger variations between replicates.

Following the method employed earlier by [9], we fitted a regression model on the averaged output of the 10 replicates. The resulting polynomial was then used to attribute output variance to parameter uncertainties. A linear regression of all the parameters and initial conditions explained 49.6 % of the output variance in total. The first order sensitivity of a parameter is the percentage of the output variance that is accounted for by that parameter, excluding interactions with other parameters. These are printed for all parameters in table IV. The total order sensitivity of a parameter is the percentage of the output variance accounted for by that parameter and its interaction with other parameters. For our test case, the differences between the first and total order sensitivities were found to be very small. This indicates that interactions between parameters did not account for a significant part of the variance.

To also take into account nonlinearities, we computed the sensitivities based on a regression model with third order splines for all parameters. The difference between the linear terms and terms with splines is small, indicating that nonlinearities up to that order also do not account for a large percentage of the variance. The best fit was obtained by taking into account all possible interactions up to second order and third order nonlinearities for all parameters. This fit explained 64.0 % of variance.

Fig. 2 suggests that nonlinearities account for some of the unexplained variance. The number of agents collapses rapidly as the diffusivity increases, which is not easily captured using a regression based method. The one-at-a-time sensitivity analysis shows similar tipping points for other parameters. In the results for the global sensitivity analysis, the number of agents went to zero in about half of the runs, again suggesting the presence of tipping points. As a test, regression based sensitvity analysis was also applied to the remainder of the runs, omitting all the runs that went to zero. This increased the amount of explained variance to 76.0 %. However, omitting these runs introduces correlations between the input parameters, which makes it impossible to fully separate the contributions of those parameters to the output.

TABLE III: Mean variance among replications, as percentage of variance among all runs

Output variable	% of variance
n_{tot}	0.4
α_h	6.0
α_m	13.5

TABLE IV: First order sensitivities, ranked from most to least influential on the model output n_{tot}. The total % of explained variance in n_{tot} is 49.6%

Parameter	Uncertainty range	% of variance n_{tot}
η	0 - 1	18.4
r	0 - 0.5	11.5
k	1 - 5	8.0
M	0 - 0.4	3.8
γ	0 - 5	3.0
$E_{harvest}$	0 - 0.5	2.2
E_{move}	0 - 2	1.4
E_{birth}	1.0 - 10	1.3
D	0 - 0.25	1.2
E_{max}	0.2 - 2	0.2
N_0	0 - 1000	0.0
R_0	0 - 1	0.0
R_{unc}	0 - 1	0.0
ξ	0 - 0.5	0.0

IV. Discussion

We have been able to explain 64.0 % of the output variance by regression methods, including third order nonlinearities and interaction effects. This leaves a significant part of the variance unexplained. Table III shows that stochastic effects do not explain this variance. Nonlinearities may be another source of unexplained variance. Nonlinearities up to third order were considered, but this does not account for a result like in Fig. 2, where the output variable abruptly goes to zero as the diffusivity is increased. Similar tipping points were found for other parameters.

An important aim of sensitivity analysis is to better understand model behaviour. Our test case shows that one-at-a-time sensitivity analysis helps to achieve this aim by uncovering tipping points and strong nonlinearities. We therefore recommend to use one-at-a-time sensitivity analysis in addition to global sensitivity analysis. While global sensitivity analysis does not allow for the straightforward identification of tipping points, it does provide summary measures for the sensitivities of (interactions between) parameters over a large region of the parameter space. For complex relations between inputs and outputs, such as in our test-case, regression-based sensitivity analysis does not yield accurate estimations for these sensitivities. "Model-free" methods of sensitivity analysis, like the Sobol method [2] [8], may aid in this case. In contrast with regression-based methods, model-free methods do not a priori assume any specific form for the relation between the input parameters and output variables.

A. Future work

The analysis so far has used outputs that were averaged over time. However, the sensitivities can vary strongly in time. To understand the dynamics of an ABM, it is relevant to compute the sensitivities as a function of time [10]. In our test case model, the existence of oscillations in the output variables (see Fig.1) makes the computation of time-dependent sensitivities particularly relevant.

Furthermore, the outputs were also averaged over space. Since the model features local interactions it is relevant to consider spatial correlations. Due to the difficulties in dealing with spatial correlations, this is not a common approach [11], but may be worthwhile for a simple test model.

We plan to perform a model-free method of global sensitivity analysis. This should yield accurate estimations for the global sensitivities, even in the presence of tipping points such as the one in Fig. 2. We also plan to examine such tipping points in more detail. For example, we will zoom in around the tipping point in the region of $D = [0.15, 0.2]$ using a smaller step-size in D and more replicates to unravel the exact dynamics around that point.

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The quality of social simulation: an example from research policy

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Abstract— **This contribution deals with the assessment of the quality of a simulation. After discussing this issue on a general level, we apply and test the assessment mechanisms using an example from policy modelling.**

The construction of a scientific social simulation implies the following process: "We wish to acquire something from a target entity *T*. We cannot get what we want from *T* directly. So we proceed indirectly. Instead of *T* we construct another entity *M*, the "model", which is sufficiently similar to *T* that we are confident that M will deliver (or reveal) the acquired something which we want to get from *T*. [...] At a moment in time the model has structure. With the passage of time the structure changes and that is behaviour. [...] Clearly we wish to know the behaviour of the model. How? We may set the model running (possibly in special sets of circumstances of our choice) and watch what it does. It is this that we refer to as "simulation" of the target" (quoted with slight modifications from [1]).

We also habitually refer to "simulations" in everyday life, mostly in the sense that a simulation is "an illusory appearance that manages a reality effect", cf. [2], or as Baudrillard put it, "to simulate is to feign to have what one hasn´t" while "substituting signs for the real" [3]. In a previous publication [4], we used the example of the Caffè Nero in Guildford, 50 km southwest of London, as a simulation of a Venetian café – which will serve as the 'real' to illustrate this view. The purpose of the café is to "serve the best coffee north of Milan". It tries to give the impression that you are in a real Italian café – although, most of the time, the weather outside can make the illusion difficult to maintain. The construction of everyday simulations like Caffè Nero has some resemblance to the construction of scientific social simulations (see Table 1). In both cases, we build models from a target by reducing the characteristics of the latter sufficiently for the purpose at hand; in each case, we want something from the model we cannot achieve easily from the target. In the case of Caffè Nero, we cannot simply go to Venice, drink our coffee, be happy and return. It is too expensive and time-consuming. We have to use the simulation. In the case of a science simulation, we cannot get data from the real system to learn about its behaviour. We have to use the simulation.

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TABLE I.
COMPARING SIMULATIONS

	Caffè Nero Simulation	**Science Simulation**
Target	Venetian Café	"Real System"
Goal	Getting "the feeling" (customers) and profit (owners) from it	Getting understanding and/or predictions from it
Model	By reducing the many features of a Venetian Café to a few parameters	By reducing the many features of the target to a few parameters
Question	Is it a good simulation, i.e. do we get from it what we want?	Is it a good simulation i.e. do we get from it what we want?

I. Methods to Evaluate Simulations

The question, whether one or the other is a good simulation, can therefore be re-formulated as: do we get from the simulation what we constructed it for? Heeding these similarities, we shall now try to apply evaluation methods typically used for everyday simulations to scientific simulation and vice versa. Before doing so, we shall briefly discuss the "ordinary" method of evaluating simulations called the "standard view" and its adversary, a constructivist approach asserting, "anything goes".

A. The standard view

The standard view refers to the well-known questions and methods of *verification*, namely whether the code does what it is supposed to do and whether there are any bugs, and *validation*, namely whether the outputs (for given inputs/parameters) resemble observations of the target, although (because the processes being modelled are stochastic and because of unmeasured factors) identical outputs are not to be expected, as discussed in detail in [5]. This standard view relies on a realist perspective because it refers to the observability of reality in order to compare the 'real' with artificial data produced by the simulation.

Applying the standard view to the Caffè Nero example, we can find quantitative and sometimes qualitative measures for evaluating the simulation. Using quantitative measures of similarity between it and a "real" Venetian café, we can ask, for example,

- whether the coffee tastes the same (by measuring, for example, a quality score at blind tasting),
- whether the Caffè is a cool place (e.g. measuring the relative temperatures inside and outside),
- whether the noise level is the same (using a dB meter for measuring purposes), whether the lighting level is the same (using a light meter) and whether there are the same number of tables and chairs per square metre for the customers (counting them) and so on. In applying qualitative measures of similarity

we can again ask

- whether the coffee tastes the same (while documenting what comes to mind when customers drink the coffee),
- whether the Caffè is a 'cool' place (this time meaning whether it is a fashionable place to hang out),
- whether it is a vivid, buzzing place, full of life (observing the liveliness of groups of customers),
- whether there is the same pattern of social relationships (difficult to operationalise: perhaps by observing whether the waiters spend their time talking to the customers or to the other staff), and
- whether there is a ritual for serving coffee and whether it is felt to be the same as in a Venetian café.

The assumption lying behind these measures is that there is a 'real' café and a 'simulation' café and that in both of these, we can make observations. Similarly, we generally assume that the theories and models that lie at the base of science simulations are well grounded and can be validated by observation of empirical facts. However, the philosophy of science forces us to be more modest.

1) The problem of under-determination

Some philosophers of science argue that theories are under-determined by observational data or experience, that is, the same empirical data may be in accord with many alternative theories. An adherent of the standard view would respond that one important role of simulations (and of any form of model building) is to derive from theories as many testable implications as possible, so that eventually validity can be assessed in a cumulative process[1]. Simulation is indeed a powerful tool for testing theories in that way if we are followers of the standard view.

However, the problem that theories are under-determined by empirical data cannot be solved by cumulative data gathering: it is more general and therefore more serious. The under-determination problem is not about a missing quantity of data but about the relation between data and theory. As [6] presents it: if it is possible to construct two or more incompatible theories by relying on the same set of experimental data, the choice between these theories cannot depend on "empirical facts". Quine showed that there is no procedure to establish a relation of uniqueness between theory and data in a logically exclusive way. This leaves us with an annoying freedom: "sometimes, the same datum is interpreted by such different assumptions and theoretical orientations using different terminologies that one wonders whether the theorists are really thinking of the same datum" ([7], own translation).

The proposal mentioned above to solve the under-determination problem by simulation does not touch the underlying reference problem at all. It just extends the theory, adding to it its "implications", hoping them to be more easily testable than the theory´s core theorems. The general reference between theoretical statement – be it implication or core theorem - and observed data has not changed by applying this extension: the point here is that we cannot establish a relation of uniqueness between the observed data and the theoretical statement. This applies to any segment of theorising at the centre or at the periphery of the theory on any level – a matter that cannot be improved by a cumulative strategy.

2) The theory-ladenness of observations

Observations are supposed to validate theories, but in fact theories guide our observations, decide on our set of observables and prepare our interpretation of the data. Take, for example, the different concepts of the two authors concerning Venetian cafés: For one, a Venetian café is a quiet place to read newspapers and relax with a good cup of coffee, for the other a Venetian café is a lively place to meet and talk to people with a good cup of coffee. The first attribute of these different conceptions of a Venetian café is supported by one and the same observable, namely the noise level, although one author expects a low level, the other a high one. The second attribute is completely different: the first conception is supported by a high number of newspaper readers, the second by a high number of people talking. Accordingly, a "good" simulation would mean a different thing for each of the authors. A good simulation for one would be a poor simulation for the other and vice versa. Here, you can easily see the influence of theory on the observables. This example could just lead to an extensive discussion about the "nature" of a Venetian café between the two authors, but the theory-ladenness of observations again leads to more serious difficulties. Our access to data is compromised by involving theory, with the consequence that observations are not the "bed rock elements" [8], our theories can safely rely on. At the very base of theory is again theory. The attempt to validate our theories by "pure"

[1] We owe the suggestion that simulation could be a tool to make theories more determined by data to one of the referees of [4]).

theory-neutral observational concepts is mistaken from the beginning.

Balzer et al. summarise the long debate about the standard view on this issue as follows: "First, all criteria of observability proposed up to now are vulnerable to serious objections. Second, these criteria would not contribute to our task because in all advanced theories there will be no observational concepts at all – at least if we take `observational´ in the more philosophical sense of not involving any theory. Third, it can be shown that none of the concepts of an advanced theory can be defined in terms of observational concepts" [8]. Not only can you not verify a theory by empirical observation, but you cannot even be certain about falsifying a theory. A theory is not validated by "observations" but by other theories (observational theories). Because of this reference to other theories, in fact a nested structure, the theory-ladenness of each observation has negative consequences for the completeness and self-sufficiency of scientific theories, cf. [9]. These problems apply equally to simulations, which are just theories in process.

We can give examples of these difficulties in the area of social simulation. To compare Axelrod´s *The evolution of cooperation* [10] and all the subsequent work on iterated prisoners´ dilemmas with the 'real world', we would need to observe 'real' IPDs, but this cannot be done in a theory-neutral way. The same problems arise with the growing body of work on opinion dynamics (e.g. [11], [12], [13]). The latter starts with some simple assumptions about how agents' opinions affect the opinions of other agents and shows under which circumstances the result is a consensus, polarisation or fragmentation. However, how could these results be validated against observations without involving again a considerable amount of theory?

Important features of the target might not be observable at all. We cannot, for example, observe learning. We can just use some indicators to measure the consequences of learning and assume that learning has taken place. In science simulations, the lack of observability of significant features is one of the prime motivations for carrying out a simulation in the first place.

There are also more technical problems. Validity tests should be "exercised over a full range of inputs and the outputs are observed for correctness" [14]. However, the possibility of such testing is rejected: "real life systems have too many inputs, resulting in a combinatorial explosion of test cases". Therefore, simulations have "too many inputs/outputs to be able to test strictly" (ibid.).

While this point does not refute the standard view in principle but only emphasises difficulties in execution, the former arguments reveal problems arising from the logic of validity assessment. We can try to marginalise, neglect or even deny these problems, but this will disclose our position as mere "believers" of the standard view.

B. The constructivist view

Validating a simulation against empirical data is not about comparing "the real world" and the simulation output; it is comparing *what you observe as the real world* with what you observe as the output. Both are constructions of an observer and his/her views concerning relevant agents and their attributes. Constructing reality and constructing simulation are just two ways of an observer seeing the world. The issue of object formation is not normally considered by computer scientists relying on the standard view: data is "organized by a human programmer who appropriately fits them into the chosen representational structure. Usually, researchers use their prior knowledge of the nature of the problem to hand-code a representation of the data into a near-optimal form. Only after all this hand-coding is completed is the representation allowed to be manipulated by the machine. The problem of representation-formation […] is ignored" [15].

However, what happens if we question the possibility of validating a simulation by comparing it with empirical data from the "real world"? We need to refer to the modellers/observers in order to get at their different constructions. The constructivists reject the possibility of evaluation because there is no common "reality" we might refer to. This observer-oriented opponent of the realist view is a nightmare to most scientists: "Where anything goes, freedom of thought begins. And this freedom of thought consists of all people blabbering around and everybody is right as long as he does not refer to truth. Because truth is divisible like the coat of Saint Martin; everybody gets a piece of it and everybody has a nice feeling" [16].

Clearly, we can put some central thoughts from this view much more carefully: "In dealing with experience, in trying to explain and control it, we accept as legitimate and appropriate to experiment with different conceptual settings, to combine the flow of experience to different 'objects'" [17].

However, this still leads to highly questionable consequences: there seems to be no way to distinguish between different constructions/simulations in terms of "truth", "objectivity", "validity" etc. Science is going coffeehouse: everything is just construction, rhetoric and arbitrary talk. Can we so easily dismiss the possibility of evaluation?

C. The user community view

We take refuge at the place we started from: what happens if we go back to the Venetian café simulation and ask for an evaluation of its performance? It is probably the case that most customers in the Guildford Caffè Nero have never been in an Italian café. Nevertheless, they manage to "evaluate" its performance – against their concept of an Italian café that is not inspired by any "real" data. However, there is something "real" in this evaluation, namely the customers, their constructions and a "something" out there, which everybody refers to, relying on some sort of shared meaning and having a "real" discussion about it. The philosopher Searle shows in his work on the *Construction of Social Reality* [18] how conventions are "real": they are not deficient for the support of a relativistic approach because they are constructed.

Consensus about the "reality observed by us" is generated by an interaction process that must itself be considered real. At the base of the constructivist view is a strong reference to reality, that is, conventions and expectations that are socially created and enforced. When evaluating the Caffè Nero simulation, we can refer to the expert community (customers, owners) who use the simulation to get from it what they would expect to get from the target. A good simulation for them would satisfy the customers who want to have the "Venetian feeling" and would satisfy the owners who want to get the "Venetian profit".

For science equally, the foundation of every validity discussion is the ordinary everyday interaction that creates an area of shared meanings and expectations. This area takes the place left open by the under-determination of theories and the theoreticity problem of the standard view.[2] Our view comes close to that of empirical epistemology which points out that the criteria for quality assessment "do not come from some *a priori* standard but rest on the description of the way research is actually conducted" [19].

If the target for a social science simulation is itself a construction, then the simulation is a *second order* construction. In order to evaluate the simulation we can rely on the ordinary (but sophisticated) institutions of (social) science and its practice. The actual evaluation of science comes from answers to questions such as: Do others accept the results as being coherent with existing knowledge? Do other scientists use it to support their work? Do other scientists use it to inspire their own investigations?

An example of such validity discourse in the area of social simulation is the history of the tipping model first proposed by Schelling and now rather well known in the social simulation community. The Schelling model purports to demonstrate the reasons for the persistence of urban residential segregation in the United States and elsewhere. It consists of a grid of square cells, on which are placed agents, each either black or white. The agents have a 'tolerance' for the number of agents of the other colour in the surrounding eight cells that they are content to have around them. If there are 'too many' agents of the other colour, the unhappy agents move to other cells until they find a context in which there are a tolerable number of other-coloured agents. Starting with a random distribution, even with high levels of tolerance the agents will still congregate into clusters of agents of the same colour. The point Schelling and others have taken from this model is that residential segregation will form and persist even when agents are rather tolerant.

The obvious place to undertake a realist validation of this model is a United States city. One could collect data about residential mobility and, perhaps, on 'tolerance'. However, the exercise is harder than it looks. Even US city blocks are not all regular and square, so the real city does not look anything like the usual model grid. Residents move into the city from outside, migrate to other cities, are born and die, so the tidy picture of mobility in the model is far from the messy reality. Asking residents how many people of the other colour they would be tolerant of is also an exercise fraught with difficulty: the question is hypothetical and abstract, and answers are likely to be biased by social desirability considerations. Notwithstanding these practical methodological difficulties, some attempts have been made to verify the model. The results have not provided much support. For instance, Benenson [21] analysed residential distribution for nine Israeli cities using census data and demonstrated that whatever the variable tested - family income, number of children, education level – there was a great deal of ethnic and economic heterogeneity within neighbourhoods, contrary to the model's predictions.

This apparent lack of empirical support has not, however, dimmed the fame of the model. The difficulty of obtaining reliable data provides a ready answer to doubts about whether the model is 'really' a good representation of urban segregation dynamics. Another response has been to elaborate the model at the theoretical level. For instance, Bruch [22] demonstrates that clustering only emerges in Schelling's model for discontinuous functional forms for residents' opinions, while data from surveys suggests that people's actual decision functions for race are continuous. She shows that using income instead of race as the sorting factor also does not lead to clustering, but if it is assumed that both race and income are significant, segregation appears. Thus the model continues to be influential, although it has little or no empirical support, because it remains a fruitful source for theorising and for developing new models. In short, it satisfies the criterion that it is 'valid' because it generates further scientific work.

Summarising the first part of this article, we have argued that a simulation is good when we get from it what we originally would have liked to get from the target. It is good if it works. As Glasersfeld [23] puts it: "Anything goes if it works". The evaluation of the simulation is guided by the expectations, anticipations and experience of the community that uses it – for practical purposes (Caffè Nero), or for intellectual understanding and for building new knowledge (science simulation).

[2] Thomas Nickles claims new work opportunities for sociology at this point: "the job of philosophy is simply to lay out the necessary logico-methodological connections against which the under-determination of scientific claims may be seen; in other words, to reveal the necessity of sociological analysis. Philosophy reveals the depths of the under-determination problem, which has always been the central problem of methodology, but is powerless to do anything about it. Under-determination now becomes the province of sociologists, who see the limits of under-determination as the bounds of sociology. Sociology will furnish the contingent connections, the relations, which a priori philosophy cannot" [20].

II. An example of assessing quality

In this part, we will apply and test the assessment mechanisms outlined using as an example our work with the Simulating Knowledge dynamics in Innovation Networks (SKIN) model in its application to research policy modelling.

There are now a number of policy modelling studies using SKIN [24]. We will here refer to just one recent example, on the impact assessment and ex-ante evaluation of European funding policies in the Information and Communication Technologies (ICT) research domain [25].

A. A policy modelling application of SKIN

The basic SKIN model has been described and discussed in detail elsewhere (e.g. [26], [27], [28]). On its most general level, SKIN is an agent-based model where agents are knowledge-intensive organisations, which try to generate new knowledge by research, be it basic or applied, or creating new products and processes by innovation processes. Agents are located in a changing and complex social environment, which evaluates their performance; e.g. the market if the agents target innovation or the scientific community if the agents target publications through their research activities. Agents have various options to act: each agent has an individual knowledge base called its "kene", cf. [29], which it takes as the source and basis for its research and innovation activities. The agent kene is not static: the agent can learn, either alone by doing incremental or radical research, or from others, by exchanging and improving knowledge in partnerships and networks. The latter feature is important, because research and innovation happens in networks, both in science and in knowledge-intensive industries. This is why SKIN agents have a variety of strategies and mechanisms for collaborative arrangements, i.e. for choosing partners, forming partnerships, starting knowledge collaborations, creating collaborative outputs, and distributing rewards. Summarising, usually a SKIN application has agents interacting on the knowledge level and on the social level while both levels are interconnected. It is all about knowledge and networks.

This general architecture is quite flexible, which is why the SKIN model has been called a "platform", cf. [30], and has been used for a variety of applications ranging from the small such as simulating the Vienna biotech cluster [31] to intermediate such as simulating the Norwegian defence industry [32], to large-scale applications such as the EU-funded ICT research landscape in Europe [25]. We will use the latter study as an example after explaining why the SKIN model is appropriate for realistic policy modelling in particular.

The birth of the SKIN model was inspired by the idea of bringing a theory on innovation networks, stemming mainly from innovation economics and economic sociology, onto the computer – a computer theory, which can be instantiated, calibrated, tested and validated by empirical data. In 1998, the first EU project developing the model "Simulating Self-Organizing Innovation Networks" (SEIN) consisted of a three-step procedure: theory formation, empirical research collecting data both on the quantitative and on the case study level, and agent-based modelling implementing the theory and using the data to inform the model [33].

This is why the SKIN model applications use empirical data and claim to be "realistic simulations" insofar as the aim is to derive conclusions by "inductive theorising". The quality of the SKIN simulation derives from an interaction between the theory underlying the simulation and the empirical data used for calibration and validation. In what way does the SKIN model handle empirical data? We will now turn to our policy modelling example to explain the data-to-model workflow, which is introduced in greater detail in [34]

B. Policy modelling for ex-ante evaluation of EU funding programmes

The INFSO-SKIN application, developed for the Directorate General Information Society and Media of the European Commission (DG INFSO), was intended to help to understand and manage the relationship between research funding and the goals of EU policy. The agents of the INFSO-SKIN application are research institutions such as universities, large diversified firms or small and medium-sized enterprises (SMEs). The model simulated real-world activity in which the Calls of the Commission specify the composition of consortia, the minimum number of partners, and the length of the project; the deadline for submission; a range of capabilities, a sufficient number of which must appear in an eligible proposal; and the number of projects that will be funded. The rules of interaction and decision implemented in the model corresponded to Framework Programme (FP) rules; to increase the usefulness for policy designers, the names of the rules corresponded closely to Framework Programme terminology. For the Calls 1-6 that had occurred in FP7, the model used empirical information on the number of participants and the number of funded projects, together with data on project size (as measured by participant numbers), duration and average funding. Analysis of this information produced data on the functioning of, and relationships within, actual collaborative networks within the context of the Framework Programme. Using this data in the model provided a good match with the empirical data from EU-funded ICT networks in FP7: the model accurately reflected what actually happened and could be used as a test bed for potential policy choices, cf. [25].

Altering elements of the model that equate to policy interventions such as the amount of funding, the size of consortia, or encouraging specific sections of the research community, enabled the use of INFSO-SKIN as a tool for modelling and evaluating the results of specific interactions between policies, funding strategies and agents. Because changing parameters within the model is analogous to applying different policy options in the real world, the model could be used to examine the likely real-world effects of different policy options before they were implemented.

As will be seen in Figure 1, the first contact with "the real world" had already occurred in the definition phase of the project. What do the stakeholders want to know in terms of policies for a certain research or innovation network? Identifying relevant issues, discussing interesting aspects about them, forming questions and suggesting hypotheses for potential answers was a first important step. It aimed to conclude with a finite set of questions and concrete designs of experiment with which to address them with the model. This was an interactive and participative process between the study team, which knew about the possibilities and limitations of the model, and the stakeholders, who could be assumed to know what are the relevant issues in their day-to-day practice of policymaking.

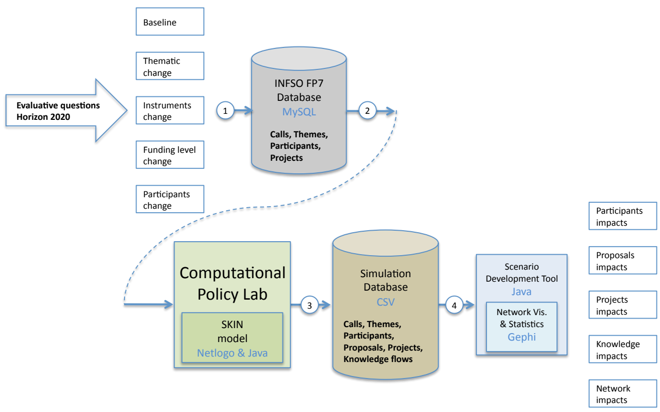

Fig. 1 Horizon 2020 study workflow [34]

After discussing the evaluative questions for the ex-ante evaluation part of this study with the stakeholders from DG INFSO, the following questions were singled out for experiments:

1. What if there are no changes, and funding policies of DG INFSO continued in Horizon 2020 as they were in FP7?
2. What if there are changes to the currently eight thematic areas funded in the ICT domain prioritising certain areas in Horizon 2020?
3. What if there are changes to the instruments of funding and fund larger/smaller consortia in Horizon 2020 than in FP7?
4. What if there are interventions concerning the scope or outreach of funding providing much more / much less resource to more / fewer actors?
5. What if there are interventions concerning the participation of certain actors in the network (e.g. SMEs)?

The next step was to collect relevant data to address these questions and hypotheses. This step is not different from the one every empirical researcher is confronted with. To identify relevant variables for operationalising hypotheses, to be as simple as possible but as detailed as necessary for description and explanation, is in line with the requirements of all empirical social research. For SKIN, the most important type of data is about knowledge dynamics (e.g. knowledge flows, amount of knowledge, diversity of knowledge) and its indicators (e.g. publications, patents, innovative ideas etc.), and about dynamics concerning actors, networks, their measures, and their performance (e.g. descriptive statistics on actors, network analysis measures, aggregate performance data).

These data were used to calibrate the initial knowledge bases of the agents, the social configurations of agents ("starting networks"), and the configuration of an environment at a given point in time. DG INFSO provided the data needed to calibrate the knowledge bases of the agents (in this case the research organisations in the European research area), the descriptive statistics on agents and networks and their interactions (in this case data on funded organisations and projects in ICT under FP7).

The time series data were used to validate the simulations by comparing the empirical data with the simulation outputs. Once we were satisfied with the model performance in that respect, experiments were conducted and the artificially-produced data analysed and interpreted. The stakeholders were again invited to provide their feedback and suggestions about how to fine-tune and adapt the study to their changing user requirements as the study proceeded.

The last step was again stakeholder-centered as it involved visualisation and communication of data and results. We had to prove the credibility of the work and the commitment of the stakeholders to the policy modelling activity.

We worked from an already existing application of the SKIN model adapted to the European research area [35], implemented the scenarios according to the evaluative questions and produced artificial data as output of the simulations. The results are reported in the Final Report, which presented to the European Cabinet, and were communicated to the stakeholders at DG INFSO.

C. *The INFSO-SKIN example as seen by the Standard view*

The standard view refers to *verification*, namely whether the code does what it is supposed to do, and *validation*, namely whether the outputs (for given inputs/parameters) sufficiently resemble observations of the target.

In terms of verification, the Horizon 2020 application has passed the test as far as this can go. Without claiming that realistic policy modelling always has to employ the standard view perspective, our study of course relies on a realist perspective because it refers to the observability of reality in order to compare the 'real' with artificial data produced by the simulation.

For addressing the evaluative questions of the stakeholders, we needed to create a simulation resembling their own world as observed as "empirical reality". The simulation needed to create the effect of similar complexity, similar structures and processes, and similar objects and options for interventions. To be under this *similarity threshold* would have led to the rejection of the model as a "toy model" that is not realistic and is under-determined by empirical data. In the eyes of these stakeholders, the more features of the model can be fed with and validated against empirical data points the better. Of course, there will be always an empirical "under-determination" of the model due to the necessary selection and abstraction process of model construction, empirical un-observables, missing data for observables, random features of the model and so on. However, to find the "right" trade-off between empirical under-determination and model credibility was a crucial issue in the discussions between the study team and the stakeholders.

D. The INFSO-SKIN example as seen by the Constructivist view

The strength of a modelling methodology lies in the opportunity to ask what-if questions (ex-ante evaluation), an option that is normally not easily available in the policy-making world. INFSO-SKIN uses scenario modelling as a worksite for 'reality constructions', in line with Gellner's statement quoted above about the constructivist approach: "In dealing with experience, in trying to explain and control it, we accept as legitimate and appropriate to experiment with different conceptual settings, to combine the flow of experience to different 'objects'" [17]. Scenario modelling was employed in the study both for the impact assessment of existing funding policies, where we measured the impact of policy measures by experimenting with different scenarios where these policies are absent, changed or meet different conditions, and for ex-ante evaluation, where we developed a range of potential futures for the European Research Area in ICT by asking what-if questions.

These are *in silico* experiments, which construct potential futures. Is this then a relativist approach where "anything goes", because everything is just a construction? For the general aspects of this question we refer to Part I of this article. There we talk about the "reality requirements" of the constructivist approach, which mediates its claims.

E. The INFSO-SKIN example as seen by the User Community View

The user community view is the most promising, and in our eyes, the most work-intensive mechanism to assess the quality of this policy modelling exercise.

1) Identifying user questions

In our example, SKIN is applied to a tender study with a clear client demand behind it, where the questions the simulation needs to answer was more or less pre-defined from the onset of the project. Enough time should, however, be dedicated to identifying and discussing the exact set of questions the stakeholders of the work want to see addressed. We found that the best way to do this is applying an iterative process of communication between study team and clients, where stakeholders learn about the scope and applicability of the methods, and where researchers get acquainted with the problems policy makers have to solve and with the kind of decisions, for which sound background information is needed. This iterative process will result in an agreed set of questions for the simulation, which will very often decisively differ from the set proposed at the start of the study. For our example, a so-called "Steering Committee" was assigned to us by the European Commission consisting of policy makers and evaluation experts of DG INFSO.

Evaluative questions can address both, the knowledge and the network level. For example, the agreed set of evaluative questions for the INFSO-SKIN application only contained one question for the knowledge level (the first one) and various questions for the agents/networks level (see list of evaluative questions above).

There are various difficulties and limitations to overcome in identifying user questions. In the case of the DG INFSO study, though the questions under study were outlined in the Tender Specifications in great detail, this was a complicated negotiation process where the stakeholder group

- Had to find out about the exact nature and direction of their questions while they talked to the study team
- Had questioned the original set of the Tender Specifications in the meantime and negotiated among each other for an alternative set
- Did not share the same opinion about what questions should be in the final sample, and how potential questions should be ranked in importance
- Did not share the same hypotheses about questions in the final sample

The specification of evaluative questions might be the first time stakeholders talk to each other and discuss their viewpoints.

What is the process for identifying user questions for policy modelling? In the INFSO-SKIN application, the following mechanism was used by the study team and proved to be valuable:

- Scan written project specification by client (in this case the Tender Specifications of DG INFSO) and identify the original set of questions
- Do literature review and context analysis for each question (policy background, scope, meaning etc.) to inform study team
- Meet stakeholders to get their views on written project specifications and their view on context of questions; inform the stakeholders about what your model is about, what it can and cannot do; discuss until stakeholder group and study team is "on the same page"
- Evaluate meeting and revise original set of questions if necessary (probably an iterative process between study team and different stakeholders individually where study team acts as coordinator and mediator of the process)
- Meet stakeholders to discuss final set of questions, get written consent on this, and get their hypotheses concerning potential answers and potential ways to address the questions

- Evaluate meeting and develop experiments that are able to operationalise the hypotheses and address the questions
- Meet stakeholders and get their feedback and consent that experiments meet questions/hypotheses
- Evaluate meeting and refine experiment set-up concerning final set of questions

This negotiation and discussion process is highly user-driven, interactive, and iterative. It requires communicative skills, patience, willingness to compromise on both sides, and motivation to make both ends meet – the formal world of modellers and the narrative world of policymaking in practice. The process is highly time-consuming. In our example, we needed about six months of a 12-month contract research study to get to satisfactory results on this first step, before the simulation had even started.

F. Getting their best: users need to provide data

The study team will know best what type of empirical data would be supportive to inform the policy modelling activity. In SKIN, data availability is an important issue, because the findings have to be evidence-based and realistic. This is in the best interest of the stakeholders, who need to trust the findings, which will be the more the case when the simulated data resembles the empirical data known to the user. However, the study team might discover that data as desired is not available, either not existing or not willingly released by the stakeholders or whoever holds it.

In our example, the stakeholders were data collectors on a big scale themselves. The evaluation unit of DG INFSO employs a data collection group that provides information about funded projects and organisations at a detailed level. Furthermore, the DG often provides data to study teams of the tender projects they contract for their evaluation projects. This is why our example we had a luxurious and clean database concerning all issues the study team was interested in.

However, it was still an issue to confirm the existence, quality and availability of the data and check for formats and database requirements. Even if the data are there in principal, enough time should be reserved for such issues. The quality of the simulation in the eyes of the user will very much depend on the quality of the informing data and the quality of the model calibration.

What would have been the more common process if the study team had not struck lucky as in our example? In other SKIN applications, the following mechanism was used by the study team and proved to be valuable (the ones with asterisks also apply to our INFSO-SKIN example):

- Identify the rough type of data required for the study from the project specifications
- Estimate financial resources for data access in the project proposal to stakeholders (this can sometimes happen in interaction with the funding body)
- After the second meeting with stakeholders, identify the relevant data concerning variables to answer the study questions and address/test hypotheses*
- Communicate exact data requirements to stakeholders, who are usually experts on their own empirical data environment*
- Review existing data bases including the ones stakeholders might hold or can get access to*
- Meet stakeholders to discuss data issues; make them understand and agree on the scope and limitations of data access*
- If needed and required by stakeholders, collect data
- Meet stakeholders to discuss the final database
- Evaluate the meeting and develop data-to-model procedures*

G.Interacting with users to check the validity of simulation results

The stakeholders put heavy demands on the study team concerning understanding and trusting the simulation findings. The first and most important is that the clients want to understand the model. To trust results means to trust the process that produced them. Here, the advantage of the adapted SKIN model is that it relies on a narrative that tells the story of the users' every-day world of decision-making. In the SKIN model, a good example for "reality" requirements is the necessity to model the knowledge and behaviour of agents. Blackboxing the knowledge of agents or creating merely reactive simple agents would not have been an option, because stakeholders do not think the world works that way.

As mentioned, the SKIN model is based on empirical quantitative and qualitative research in innovation economics, sociology, science and technology studies, and business studies. Agents and behaviours are informed by what we know about them; the model is calibrated by data from this research. We found that there is a big advantage in having a model where stakeholders can recognise the relevant features they see at work in their social contexts. In setting up and adapting the model to study needs, stakeholders can actively intervene and ask for additional agent characteristics or behavioural rules; they can refine the model and inform blackbox areas where they have information on the underlying processes.

However, here again, we encountered the diversity of stakeholder preferences. Different members of the DG INFSO Steering Committee opted for different changes and modifications of the model. Some were manageable within the given time constraints and financial resources; some would have outlived the duration of the project if realised. The final course of action for adapting the model to study needs was the result of discussions between stakeholders about model credibility and increasing complexity and of discussions between stakeholders and the study team concerning feasibility and reducing complexity.

Once the stakeholders were familiar with the features of the model and had contributed to its adaptation to study requirements, there was an initial willingness to trust model findings. This was strengthened by letting the model reproduce FP7 data as the baseline scenario that all policy experiments would be benchmarked against. If the networks created by real life and those created by the agent-based model qualitatively correspond closely, the simulation experiments can be characterized as 'history-friendly', which reproduce the empirical data and cover the decisive mechanisms and resulting dynamics of the real networks (see the *standard view*).

In presenting the results of the INFSO-SKIN study, however, it became clear that there were, again, certain caveats coming from the user community. The policy analysts did not want to look at a multitude of tables and scan through endless numbers of simulation results for interesting parameters; nor did they expect to watch the running model producing its results, for example during a presentation, because one run would last 48 hours. Presenting results in an appealing and convincing way required visualisations and interactive methods where users could intuitively understand what they see, had access to more detailed information if they wanted, e.g. in a hyperlink structure, and could decide for themselves in which format, in which order and in what detail they wanted to go through findings. This part of the process still needs further work: new visualisation and interactive technologies can help to make simulation results more accessible to stakeholders.

This leads to the last issue to be discussed in this section. What happens after the credibility of simulation results is established? In the INFSO-SKIN study, the objective was policy advice for Horizon 2020. The stakeholders wanted the study team to communicate the results as "recommendations" rather than as "findings": They required a so-called "Utility Summary" with statements about what they should do in their policy domain according to study results. Here the study team proved to be hesitant – not due to a lack of confidence in their model but due to (i) an understanding of its predictive limitations and (ii) an apprehension about normative statements, which were seen as a matter of political opinion and not as part of the scientific advisor role. The negotiations of wording in the Utility Summary again afforded an intense dialogue between stakeholders and study team. Nevertheless, the question whether the results had an influence on or were somehow useful in the actual political process of finalising Horizon 2020 policies was not part of the stakeholder feedback after the study ended. The feedback consisted of the formal approval of having fulfilled the contract of the policy advice project.

III. Conclusions

To trust the quality of a simulation means to trust the process that produced its results. This process is not only the one incorporated in the simulation model itself. It is the whole interaction between stakeholders, study team, model, and findings.

The first section of this contribution pointed out the problems of the Standard View and the Constructivist View in evaluating social simulations. We argued that a simulation is good when we get from it what we originally would have liked to get from the target; in this, the evaluation of the simulation would be guided by the expectations, anticipations and experience of the community that uses it. This would make the user community view the most promising mechanism to assess the quality of a policy modelling exercise.

The second section looked at a concrete policy modelling example to test this assumption. It showed that the very first negotiation and discussion with the user community to identify their questions was highly user-driven, interactive, and iterative. It required communicative skills, patience, willingness to compromise on both sides, and motivation to make both ends meet – the formal world of modellers and the narrative world of policymaking in practice.

Often, the user community is involved in providing data for calibrating the model. It is not an easy issue to confirm the existence, quality and availability of data and check for formats and database requirements. As the quality of the simulation in the eyes of the user will very much depend on the quality of the informing data and the quality of the model calibration, much time and effort need to be spent in coordinating this issue with the user community.

Last but not least, the user community has to check the validity of simulation results and has to believe in their quality. Users have to be enabled to understand the model, to agree with its processes and ways to produce results, to judge similarity between empirical and simulated data etc.

Summarising, in our eyes, the User Community view might be the most promising, but definitely is the most work-intensive mechanism to assess the quality of a simulation. It all depends on who the user community is and its composition. If there is more than one member, the user community will never be homogenous. It is difficult to refer to a "community" if people have radically different opinions.

Furthermore, there are all sorts of practical contingencies to deal with. People might not be interested, or they might not be willing or able to dedicate as much of their time and attention to the study as is needed. There is also the time dimension: the users at the end of a simulation project might not be the same as those who initiated it, because of job changes, resignations, promotions and organisational restructuring. Moreover, the user community and the simulation modellers may affect each other, with the modellers helping in some ways to construct a user community in order to solve the practical contingencies that get in the way of assessing the quality of the simulation, while the user community may in turn have an effect on the modellers (not least in terms of influencing the financial and recognition rewards the modellers receive).

If trusting the quality of a simulation indeed means trusting the process that produced its results, then we need to address the entire interaction process between user community, researchers, data, model, and findings as the relevant assessment mechanism. Researchers have to be aware that they are co-designers of the mechanisms they need to participate in with the user community for assessing the quality of a social simulation.

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Modelling cultural shift: Application to language decline and extinction

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Abstract—**Cultural shift is present in many aspects of human history. Here we present a model developed to study the particular case of language shift when a minority language is in competition with another language, which is perceived by the population as being socially and economically more advantageous (Isern and Fort, J. R. Soc. Interface 2014). We show that this model can describe satisfactorily the decline on the fraction of Welsh speakers over the last century. We also apply our language shift model as an interaction term into a reaction-diffusion equation and use it to predict the spread of retreat of the area of prevalence of the Welsh language. We find that the predictions are consistent with observational data.**

I. Introduction

THROUGHOUT human history we find numerous cases of cultural shift, where a society undergoes a change in some of its social or cultural traits, by adopting a more advantageous trait. Examples of cultural shift might include technical changes (such as the adoption of agriculture, or the industrialization process), changes in religious believes, or the adoption of a new language. Particularly, here we will focus on the study of local language shift during the last century, and the geographical retreat of the area of influence of minority languages being replaced by a new dominant language seen as more advantageous [1].

In general, cultural shift can be due to a local innovation (such as the evolution of Romance languages from Latin [2]) or due to the transmission of a cultural trait from a neighboring region [3]. In linguistics, the evolution of a new language is a process that takes thousands of years [4], whereas the acquisition of a neighboring language can happen at much shorter timescales [5]. In addition, nowadays improved communications and globalization processes have accelerated the processes of language replacement [6], [7], having a substantially negative impact in language diversity. Indeed, currently about 96% of the population speaks only about 4% of the languages in the world [8], and about a 90% of the present languages might become extinct, or in process of extinction, by the end of the century [9].

Because of the importance of the decline in language diversity, as well as the interest of the language shift dynamics by itself, in recent years, several studies have proposed different mathematical and computations models to describe the ongoing processes of language shift [10]. In 2003, Abrams and Strogatz [11] developed a simple two-population model to describe the competition for speakers between two languages, A and B, and which has been the basis for several other studies on linguistic shift [12], [13]. The dynamics of the competition is expressed in terms of the temporal change in the fraction of the population speaking each language as follows [11]

$$\begin{cases} \dfrac{dp_A}{dt} = \gamma\left(s p_A^{\alpha} p_B - (1-s)\, p_A p_B^{\alpha}\right), \\ \dfrac{dp_B}{dt} = -\gamma\left(s p_A^{\alpha} p_B - (1-s)\, p_A p_B^{\alpha}\right), \end{cases} \tag{1}$$

where p_A and p_B are the fractions of speakers of each language, with $p_A + p_B = 1$, γ is a parameter that scales time, $s \in (0,1)$ reflects the status of language A relative to B, and α determines the relative importance of the population fractions in attracting speakers to language A.

This model was applied to describe the decline of minority languages in competition with more advantageous languages. In particular, they applied the model to cases where a minority language is spoken regionally in a country where the official language a different language, which is seen as socially and economically more advantageous [11]. As a consequence, the minority language loses speakers on behalf of the other language, since the shift is seen as an advantageous strategy. In this context, p_A corresponds to monolingual speakers of the high-status (official) language, and p_B to fraction of the population that can speak the regional language (either as monolinguals or bilinguals). Therefore language A has the higher status, $s > 0.5$.

Here we want to model the same kind of situations, but with special attention to the geographical aspect of the language shift process. That is, we want to estimate the

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speed of advance of the border between linguistic areas, since not only the fraction of speakers of the high-status language increases over time, but also its area of influence expands. However, we will not develop our models here applying (1) because, even though Abrams and Strogatz obtained good fits for the periods they studied, (1) presents several problems when extrapolating beyond these periods. As an example, for the case of the Quechua language modelled in [11], (1) predicts that only when the fraction of speakers of the high-status language (Spanish) is higher than 25% will the language shift start; otherwise, it would be the Spanish speakers who would learn Quechua; a result that is in opposition to historical events [7], [9]. In contrast, for other languages, such as the Welsh language, (1) predicts that, for very low proportions of minority speakers, the languages shift process would be reversed, which is historically unrealistic (see a detailed mathematical discussion on these issues in [1]).

Therefore, here we present an alternative model to (1) that can also describe satisfactorily the historical data on the decline of endangered minority languages, but without the problems affecting (1) [1]. We use this new model as interaction term in a reaction-diffusion equation in order to explore the geographical aspect of language shift and to estimate the speed of retreat of the border between linguistic regions. We will apply our model to the case of the Welsh language, and see that we obtain estimates consistent with historical data.

II. MODEL

We want to define a model that can estimate the speed at which the border between two linguistic regions advances, when the speakers of one of the languages cease to speak it in favor of the neighbor language, which they perceive as having a higher status. We will first present an equation to describe the dynamics of the transfer of speakers from one language to the other, and then apply this equation as interaction term into a reaction-diffusion equation.

A. *Language shift model*

As in (1), in order to describe the dynamics of linguistic replacement, we divide the population into two groups —those who can speak the low-status languages (B), and those who cannot, and who can only speak the high-status language (A). Then, we propose to describe the temporal change of the fraction of speakers of each language, p_A and p_B, as follows [1]

$$\begin{cases} \dfrac{dp_A}{dt} = \gamma p_A^{\alpha} p_B^{\beta}, \\ \dfrac{dp_B}{dt} = -\gamma p_A^{\alpha} p_B^{\beta}, \end{cases} \tag{2}$$

where γ is a parameter that scales time, and the parameters $\alpha, \beta \geq 1$ are related to the attraction or perceived value of each language. Since $p_A, p_B \leq 1$, α and β may be regarded as a measure of the difficulty of language A to attract speakers (α), and the resistance of language B to loose speakers (β).

Note that, as opposed to (1), the model represented by (2) only allows for the speakers of the low-status language to change language, but not the reverse shift. This simplifies the equations, solves the problems and limitations from (1), and is a reasonable assumption in cases where no linguistic policies are applied (such as with the Welsh language up to the 1970s).

In general, in order to apply (2) as an interaction term into a reaction-diffusion equation, we need to rewrite it in terms of the population density (n_i), rather than the population fraction ($p_i = n_i/(n_A + n_B)$). Assuming that the total population ($n_A + n_B$) does not vary significantly over time (a realistic assumption for the Welsh during the period considered here [14]), the temporal variation of the population density speaking each language may be expressed as

$$\begin{cases} \dfrac{\partial n_A}{\partial t} = \dfrac{\gamma}{(n_A + n_B)^{\alpha+\beta-1}} n_A^{\alpha} n_B^{\beta}, \\ \dfrac{\partial n_B}{\partial t} = -\dfrac{\gamma}{(n_A + n_B)^{\alpha+\beta-1}} n_A^{\alpha} n_B^{\beta}. \end{cases} \tag{3}$$

B. *Reaction-diffusion model with language shift*

We now apply (3) as an interaction term in a reaction-diffusion equation that describes the temporal and spatial evolution of the population number density of speakers of each language, n_A and n_B, as follows [1]

$$\begin{cases} \dfrac{\partial n_A}{\partial t} = D\dfrac{\partial^2 n_A}{\partial x^2} + a n_A\left(1 - \dfrac{n_A + n_B}{K}\right) + \dfrac{\gamma n_A^{\alpha} n_B^{\beta}}{(n_A + n_B)^{\alpha+\beta-1}}, \\ \dfrac{\partial n_B}{\partial t} = D\dfrac{\partial^2 n_A}{\partial x^2} + a n_B\left(1 - \dfrac{n_A + n_B}{K}\right) - \dfrac{\gamma n_A^{\alpha} n_B^{\beta}}{(n_A + n_B)^{\alpha+\beta-1}}, \end{cases} \tag{4}$$

where D is the diffusion coefficient, a is the intrinsic growth rate, and K is the carrying capacity. In (4), we have chosen the local *x*-axes such that the linguistic front moves in the *x*-direction.

We can simplify (4) by assuming that, for modern cases of language replacement, the total population is fairly constant in time and nearing the carrying capacity. Then, if we apply that $n_A + n_B \approx K$ into (4), we find the following expression [1]

$$\begin{cases} \dfrac{\partial p_A}{\partial t} = D\dfrac{\partial^2 p_A}{\partial x^2} + \gamma p_A^{\alpha} p_B^{\beta}, \\ \dfrac{\partial p_B}{\partial t} = D\dfrac{\partial^2 p_B}{\partial x^2} - \gamma p_A^{\alpha} p_B^{\beta}, \end{cases} \tag{5}$$

that can be expressed again in terms of population fractions, which may now be defined as $p_i = n_i / K$ for $i = A, B$.

It is possible to find the speed of the linguistic front from (5) (or (4)) by applying numerical integration. We set the initial conditions so that, initially, the grid is divided in two sections —a range of x is occupied only by speakers of language A, and the rest by speakers of language B. Running the numerical integration, we obtain a moving front, and from its position at each time step we calculate the front speed.

It is not possible to find an analytic expression for the speed of the linguistic front from (5). However, we can derive an analytic range containing the real front speed by applying variational analysis. Following the method described by Benguria and Depassier [15], we can find the following lower bound for the front speed [1]

$$c_L = \sqrt{\gamma D} \max_{\delta \in (0,1)} 2\delta \sqrt{1-\delta} \frac{\Gamma\left(1+\frac{\beta}{2}\right) \Gamma\left(\frac{\alpha}{2}+\delta-\frac{1}{2}\right)}{\Gamma\left(\frac{1}{2}+\frac{\alpha}{2}+\frac{\beta}{2}+\delta\right)}, \quad (6)$$

where the gamma function is defined by the following integral $\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt$, for $x > 0$ [16].

It is also possible to find an analytic upper bound following the variational analysis in [17], which is expressed as follows [1]

$$c_U = 2\sqrt{\gamma D} \sqrt{\sup_{p_A \in (0,1)} [\alpha p_A^{\alpha-1}(1-p_A)^{\beta} - \beta p_A^{\alpha}(1-p_A)^{\beta-1}]}. \quad (7)$$

The bounds are obtained from (6) and (7) by searching for the maximum result of the right-hand side expression for values of $\delta \in (0,1)$ for the lower bound, and for values of $p_A \in (0,1)$ for the upper bound. Besides the limitations explained above of the Abrams-Strogatz model (1), another problem with this model is that the variational analysis above does not work (because the interaction has two terms, and their difference can be either positive or negative, depending on the values of the population fractions).

III. Results

Here we apply our spatial model with language shift, (4), to predict the speed of advance of the English linguistic front replacing Welsh in the UK. We will compare the results with the actual front speed, estimated from linguistic maps to be within the range $0.3-0.6$ km/yr [13].

We first find the values of the parameters α, β and γ from (2) that better fit the historical data on the decline of the Welsh language. We use data on the fraction of the population able (p_B) or unable (p_A) to speak Welsh in Monmouthshire for the period 1900–1980 (figure 1c in [11]). We use these data, rather than the data on all of Wales, also presented in [11], because Monmouthshire is a rather rural, area representative for most of the extension of Wales, and thus of the region where the front speed was estimated in [13]. The data from all of Wales, by contrast, contains data from the large agglomerations near Cardiff (about 50% of the population lives in 10% of the area of Wales), where the language shift dynamics may well differ from that on the rest of Wales.

Fig. 1 shows the data on the evolution of the fraction of Welsh speakers in Monmouthshire over time (squares), as well as the best fit obtained with (2) (line) . The parameter values yielding this best fit are $\alpha = 2.23$, $\beta = 1.76$ and $\gamma = 0.237$. We can see in Figure 1 that we can obtain a very good fit of the data, which even improves the best fit that can be obtained with the Abrams-Strogatz model (1), since here we obtain a lower value of the sum of squared errors ($\chi^2_{Eq(2)} = 1.41 \cdot 10^{-4}$ while $\chi^2_{Eq(1)} = 1.46 \cdot 10^{-4}$). (Reference [1] shows how (2) can be satisfactorily applied to model also the decline of other languages.)

We now apply the parameters found above into our spatial model, (5), in order to find an estimation of the front speed both numerically and analytically. To do so we will consider two realistic values of the diffusion coefficient, $D = 5.08$ km^2/yr and $D = 6.72$ km^2/yr. Both are estimated from $D = \langle \Delta^2 \rangle / 4T$ [18] and using values of the generation time ($T = 25$ yr [13]) corresponding to modern human populations. Then, the first value of the diffusion coefficient is estimated from mobility data on modern populations in the Parma Valley, Italy, during the twentieth century ($\langle \Delta^2 \rangle = 508$ km^2 [19], [20]), and thus coetaneous with the data in Fig. 1. The second value is estimated from mobility data in Catalonia, Spain, during the eighteenth and nineteenth centuries ($\langle \Delta^2 \rangle = 672$ km^2 [21]).

We present the predicted front speeds in Table I for the two values of the diffusion coefficient. The second column corresponds to the results of the numerical simulation, and thus, the exact front speed of the linguistic front for a system whose dynamics may be described by (4). Comparing these values with the speed range estimated from data, $0.3-0.6$ km/yr [13], we see then that we obtain good agreement between model and observations.

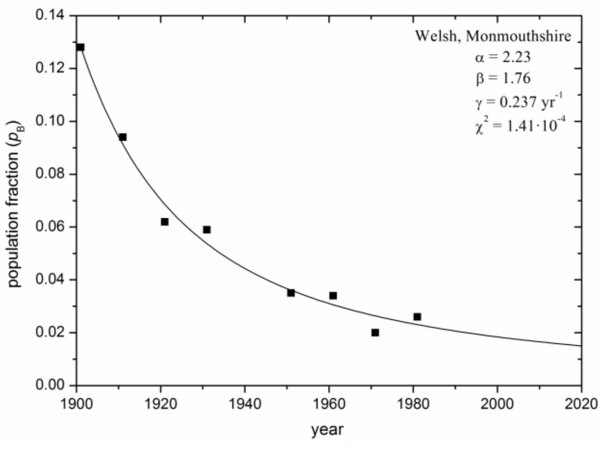

Fig. 1 Decline of the proportion of Welsh speakers over time (squares) and best fit (line) obtained with (2). Adapted from [1].

TABLE I.
NUMERICAL (c) AND ANALYTIC (c_L, c_U) PREDICTIONS OF THE ENGLISH LINGUISTIC FRONT REPLACING THE WELSH LANGUAGE

D **(km^2/yr)**	***c*** **(km/yr)**	**c_L (km/yr)**	**c_U (km/yr)**
5.08	0.557	0.356	0.934
6.72	0.641	0.409	1.750

In addition, the last two columns in Table I contain the values of the lower and upper analytic bounds calculated using (6) and (7), respectively. We see that, as expected, the exact solution lies within those bounds. But, what is more important, we see that the ranges obtained are also fairly consistent with the observed data values, and thus, we can use (6) and (7) to find a first approximation of the expected front of linguistic replacement without the need to apply numerical integration.

IV. CONCLUSIONS

We have presented a model that has been developed to describe the dynamics of language shift in a region where the speakers of a native language are under the influence of a neighbour language regarded as being socially and economically more advantageous [1]. Applying the model to the case of the Welsh language, we find that it is able to reproduce satisfactorily the decline in the fraction of Welsh speakers over time.

We have also applied our language shift model as an interaction term in a reaction-diffusion model in order to estimate the speed at speed at which the more advantageous languages spreads geographically, increasing its range of prevalence and, in consequence, diminishing the area of influence of the minority language. We have tested our model with historical data on the retreat of the area of influence of the Welsh language, obtaining a good agreement between model and observations.

In the context of present-day linguistics, our model can be used as a tool to assess how endangered a minority language is, and thus be able to design actions to control and/or reverse the destruction of language diversity. However, on a wider context, the model presented here could be applied to the study of other cases of cultural shift, present or past, where an advantageous cultural trait is spread, overcoming the prevalence of a local trait.

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From Anarchy to Monopoly: How Competition and Protection Shaped Mafia's Behavior

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***Abstract*—Mafia-like organizations are highly dynamic and organized criminal groups characterized by their extortive activities that impact societies and economies in different modes and magnitudes. This renders the understanding of how these organizations evolved an objective of both scientific and application-oriented interests. We propose an agent-based simulation model – the *Extortion Racket System* model – aimed at understanding the factors and processes explaining the successful settlement of the Sicilian Mafia in Southern Italy, and which may more generally account for the transition from an anarchical situation of uncoordinated extortion to a monopolistic social order. Our results show that in situations of anarchy, these organizations do not last long. This indicates that a monopolistic situation shall be preferred over anarchical ones. Competition is a necessary and sufficient condition for the emergence of a monopolistic situation. However, when competition is combined with protection, the resulting monopolistic regime presents features that make it even more preferable and sustainable for the targets.**

I. Introduction

Mafia-like organizations are remarkably prosperous organizations originating in Southern Italy at the end of the XIX century, if not earlier, and now widely spread all over the country and the rest of the world. They are highly dynamic and organized criminal groups that impact societies and economies in different modes and magnitudes [1, 2]. However, their origins are not yet well understood, mainly due to the lack of information, which is in part a consequence of their secret nature.

Two alternative explanations of the origins of the Sicilian Mafia (henceforth *the Mafia*), one of the most known and successful mafia-like organization, have been proposed so far.

On the one hand, the Mafia has been considered as a specific way of thinking and behaving, and its origins are explained referring to the concept of *mafiosity*, a set of attitudes and values, i.e., a *subculture*, widespread in the Sicilian society [3–9].

An alternative explanation that has recently gained large support among scholars proposes two main factors explaining the origins of Mafia, (1) the *land reforms* and (2) the *property rights*. These factors were involved in the Sicilian transition from feudalism to pre-capitalism in the XIX century and in the typical market structure of the Sicilian region at that time [10–15].

Following to this view, the Mafia phenomenon developed when the State was weakly represented in the Sicilian region. Owing to the debate on the Italian Unification, the citizens kept their eyes wide open on Rome. Consequently, widespread criminal activities were freer to engage in repeated raids against properties and production, thereby creating a chaotic or anarchical situation all over Sicily.

Those criminal activities mainly consisted in the imposition of a predatory *taxation* on landowners, i.e., the extortion racket. The victims were forced to pay under the threat of harmful retaliation. Only if they did pay, they suffer no harm. Extortive activities were *uncoordinated* and the victims were exposed to the predatory requests of many *competing roving bandits* [16]. This situation induced landowners to hire reputable violent criminals to control banditry and protect their land and production [13].

This need for *protection*[1] increased the practice of *protection racketeering*, which is defined as "an institutionalized practice whereby tribute is collected on behalf of a criminal group that, in exchange, claims to offer (...) protection" [18, p. 140]. The activity of protection racketeering has been identified as the Mafia's typical activity [1, 12, 19, 20], which led Gambetta [12] to define it as "The Business of Private Protection."

Schelling [20] noted, however, that protection racket activities cannot tolerate co-existing extorters. Targets are less likely to pay more than one extorter per time. Successful racketeering seems to require a *monopolistic regime*[2]. Monopoly, in contrast to an anarchical situation of uncoordinated extortion, creates a sort of social order through which, once individuals accept to pay one extorter, they "do not need to worry about theft by others" [16].

Consequently, it becomes crucial to understand what are the factors leading to the achievement of monopolistic situations and what are the benefits that they may provide over anarchical ones. Another important issue is that of exploring what factors may lead to monopolistic situations that are more desirable for the societies in which extortion activities are endemic.

In our view, the understanding of how mafia-like organizations may have evolved from uncoordinated groups of *roving bandits* into real *governments of the underworld* is an objective of both scientific and application-oriented interests. On the

[1]There are different types of protection that extorters may provide to their victims, such as protection against themselves, against other rival extortionists, against business competitors (for a recent analysis of Mafia protection, see also [17]). In this work, we refer only to protection against other extortionists who would tax the same targets.

[2]By monopoly, we refer here to the presence on the territory of only one criminal organization practicing protection racketeering.

one hand, it aims to contribute to the general study of the bases and origins of social order [16, 21]; on the other, it aims to understand what makes mafia-like organizations so prosperous and successful: in Italy, criminal organizations of this type produce a huge tax-free capital, which is calculated to approximate 7% of the country's GDP in 2007 [22].

Hence, the present study proposes an agent-based simulation model – the *Extortion Racket System* model – aimed at understanding the factors and processes explaining the successful settlement of the Sicilian Mafia, which may more generally account for the transition from an anarchical situation of uncoordinated extortion (i.e., widespread banditry) to a monopolistic social order. The model will test the effects of the transition from a primitive and anarchical form of extortion to a monopolistic government of the underworld, both on the racketeering system and on the whole population.

The model involves the interplay between two types of agents – Extorters and Targets – and reproduces a situation in which rival extortive systems exist and compete with one another. Each extorter behaves according to an extortive policy that consists of the extortion level (i.e., the amount of the targets' endowment requested as extortion money) and punishment severity (i.e., the amount of punishment effectively inflicted by the extorter on the target that did not pay the extortion request). The extorters' goal is to extort the targets in their domain and to expand such domain by competing with other extorters, thereby providing a sort of *weak* protection to their targets. Alternatively, the extorters may reproduce a *strong* protection, in which they provide a more active shelter to their targets. The model enables the verification of the effects of competition among extorters on the extortion systems themselves and on the targets, as well as the observation of the separate and combined effects of both types of protection.

The Extortion Racket System model aims to test the following research questions:

1) How to explain the transition from an anarchical and uncoordinated extortive situation to a monopolistic one? What are the minimal factors that suffice to bring about a monopolistic regime?
2) What is the effect of either regime, anarchical and monopolistic, on the targets?
3) What is the effect of either regime on the extorters? In particular, what is the effect of the monopolistic regime on the profile and behavior of the surviving extorters?

We hypothesize that (1) a monopolistic regime is required for an extortion racket system to be successfully and steadily settled; (2) a monopolistic regime is preferred by the targets over an anarchical one; (3) the competition among extorters plays a key role in the transition from an anarchical and uncoordinated extortive situation to a monopolistic one; and (4) the strong protection enables the selection, among those competing, of the relatively most sustainable extortive system to become the monopolist.

As we will see, our results show that competition among extorters for defining and enlarging their domains leads to a monopolistic situation that generates advantages for both the targets and the extorters compared to an anarchical situation. In anarchical situations, the burden on targets is always greater than when a monopoly of any type is achieved. Moreover, anarchical situations of non-regulated extortion are shown to be not sustainable in the long-term since they are characterized by high rate of punishment, resulting in the rapid death of all targets and consequently of extorters. Results also show that when competition is combined with a strong protection, in which extorters that proved successful actively discourage their competitors from victimizing their own targets, advantages for the latter follow. In particular, a preferable monopolistic situation for the targets is achieved compared to the one achieved by competition alone: the presence of strong protection both speeds up the achievement of a monopolistic situation and favors the transition to a government of the underworld, in which the extortion burden and the level of punishment on targets decreases, while the number of survival targets increases.

The paper will unfold as follows. In Section II, we describe the Extortion Racket System model aimed to check the research questions we posed above. Next, we discuss the results we have obtained so far in Section III. Finally, we provide some conclusions as well as some ideas for future work in Section IV.

II. Model Description

This simulation model represents a world populated by *extorters* and possible *targets* of extortion.

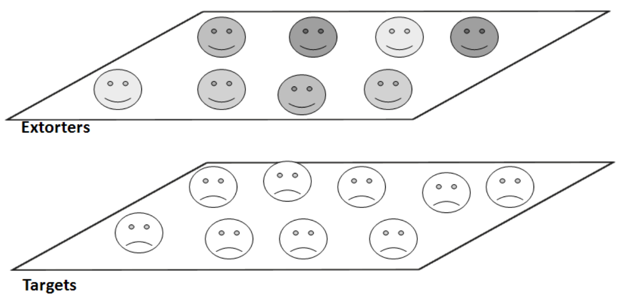


Fig. 1: Two-layer simulation model structure.

To help visualize our model, we structure it in two layers (see Figure 1). The top layer is populated with extorters ($E = \{e_1, \ldots, e_n\}$, where n is the total number of extorters in the model ($n = |E|$)), while the bottom layer with targets ($T = \{t_1, \ldots, t_m\}$, where m is the total number of targets in the model ($m = |T|$)). The extorters interact among themselves and with the targets for a specified number of *rounds*.

The extorters' basic activity is to extort targets and their goals are: (1) to receive extortion payment from as many targets as possible, and (2) to expand their domains as much as possible by providing protection to their targets.

Each extorter behaves according to its own extortive policy that remains unchanged over time. Each policy can be seen as an extorter's profile and consists in the combination of two traits: *extortion level* and *punishment severity*.

The extortion level refers to the amount of the targets' endowment requested under a more or less frightening menace, while the punishment severity represents the amount of punishment effectively inflicted by the extorter on the target in case of non-payment. Punishment is costly both to the target receiving it and to the extorter inflicting it as the extorter spends resources to inflict the punishment.

We characterize an extorter as an agent having the following set of attributes, see Table I.

TABLE I: Extorter's agent attributes.

Attributes	**Description**
Wealth	Accumulated extortion received.
Targets	List of targets to extort.
Enlargement Probability	Probability of incorporating a new (randomly selected) target in the extorter's domain.
Protection Provision	Flag indicating whether the extorter tries or not to protect its targets from other extorters.
Extortion Level	Percentage of the target's income demanded as extortion.
Punishment Severity	Percentage of the target's income inflicted as punishment.
Cost of Fighting	Percentage of the extorter's wealth inflicted as cost on the opponent extorter.
Cost of Punishing	Percentage of the punishment inflicted paid as cost by the extorter.

Targets are entrepreneurs that operate businesses (e.g., supermarkets, building companies, retail shops), which generate regular earnings. Their aim is to minimize the amount of earnings spent in paying extortion and in receiving punishment when not complying with the extortive request. Targets are agents with the following set of attributes, see Table II.

TABLE II: Target's agent attributes.

Attributes	**Description**
Wealth	Accumulated income.
Income	Earning received at each round.

Each target keeps also a record of the punishments and successful protections received from each of the extorters it interacted with. This piece of information is used by the target for ranking the extorters whenever it cannot afford paying all extortion requests (see Equation 1). Initially, the targets have just an estimation of the information, which they update whenever they have direct interactions with the extorters.

In the initialization simulation stage, the same number of targets is assigned to each extorter. The targets assigned to an extorter are referred to as the extorter's *domain*.

Assignment is performed according to the Pseudo-Algorithm 1, in which a new target randomly selected (line 4) is assigned to each extorter with a probability that varies according to the number of extorters already assigned to extort

Pseudo-Algorithm 1 Initial definition of the extorters' domain.

```
1: repeat
2:    for all extorter do
3:       while target not assigned do
4:          Select a target randomly
5:          if (target is not assigned to this extorter) then
6:             probability ← 1 / Number extorters assigned to
               this target
7:             if (random number < probability) then
8:                Assign target to this extorter
9:             end if
10:         end if
11:      end while
12:   end for
13: until all targets are assigned to more than one extorter
```

that specific target (line 6 – 9). This happens until all targets are assigned to more than one extorter (line 13).

This assignment procedure is aimed at reproducing an anarchical situation, characterized by all targets initially having more than one extorter demanding payment, and all extorters initially having the same number of targets to extort. The underlying idea is that prior to the Mafia consolidation, as evidence shows, there was no clear territorial separation among groups. Extorters needed to keep, defend, and expand their domains by competing with other extorters for the same limited resources (i.e., targets).

Each extorter's profile, consisting of the extortion level and punishment severity, is also defined in the initialization stage. The extortion level is randomly selected by applying a uniform distribution from 0% to 100%; also punishment severity is randomly selected on a uniform distribution, but the possibilities are limited between the extortion level value assigned to the extorter and 100%. For instance, if the extortion level randomly assigned to an extorter is 60%, then the punishment severity will be randomly selected from 60% to 100%.

Once completed the initialization stage, extorters and targets interact for several rounds, following the steps illustrated in Figure 2.

Each round begins with the targets receiving their incomes that result from regular business activities. This income varies among targets representing different businesses' type and size. In stage 1 (Figure 2), each extorter is assigned its own list of targets to extort, which represents its domain; however, it is also endowed with a given probability (*Enlargement Probability*, see Table I) to increase its domain by one new target. Once defined its new domain, extorters define how much to extort from each target (*Decide Extorting*, see Figure 2), which corresponds to the target's income multiplied by the extorter's extortion level. Then in stage 2, extorters make their extortive request to their targets (*Demand Extortion*, see Figure 2).

In the third stage (*Decide Paying Extortion*, see Figure 2), each target checks whether they can afford paying all the

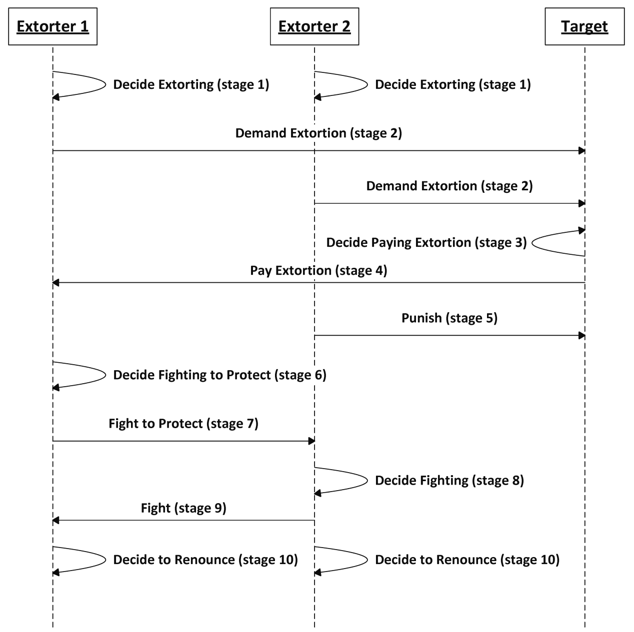


Fig. 2: Sequence diagram of the agents' interaction.

demanded extortions (i.e., they check whether their income is greater than or equal to the sum of all the extortions received). If so, it proceeds straight to stage 4 as it can afford paying all the extortion requests; otherwise, the target is forced to establish a preferential order among extorters. In order to rank them, the target assigns each extorter demanding extortion with a *convenience value* calculated according to Equation 1.

$$C_i = Ext_i + \left(\left(\sum_{j=1, i \neq j}^{n} Pun_j \times probPun_j \right) \times probProt_i \right) \quad (1)$$

where,

- i and $j \in E$.
- C_i is the *convenience value* assigned to extorter i.
- Ext_i is the amount demanded as extortion by extorter i.
- Pun_j is the punishment inflicted by extorter j in case it does not receive the extortion payment.
- $probPun_j$ is the probability of the target being punished by extorter j in case of non-payment of extortion. This probability is calculated based on the outcomes of previous interactions of this target with the same extorter j, considering those interactions in which the target has not paid the extorter j.
- $probProt_i$ is the probability of the target being protected by extorter i in case the latter is paid. This probability is calculated based on the outcomes of previous interactions with the same extorter i in which the latter successfully protected the target from extortions.

This convenience value is based on a simple algorithm aimed at minimizing the target's losses when selecting which extorters to pay. It combines the extortion demanded by the evaluated extorter and the potential protection service that the extorter may provide against other extorters. Based on the extorters' convenience value, the target sorts the extorters list in ascending order. It means that the target prefers to pay the lowest extortion and to receive the lowest punishment by all the unpaid extorters.

Then in stage 4, the target pays all or as many extorters it can afford to pay (*Pay Extortion*, see Figure 2), starting from the top to the bottom of its ranking extorters conveniences' list.

In stage 5, those extorters that did not receive payment decide whether to punish or not the targets that have not paid extortion (*Punish*, see Figure 2). The inflicted punishment reduces the target's wealth, but also imposes a cost on the punisher (*Cost of Punishing*, see Table I). Once punished, the target updates the extorters' punishment probability ($probPun_j$, see Equation 1). The incentive for punishing is the increased probability of the extortion's success in the next round.

Stages 6 and 7 depend on whether the *Provider Protection* extorter's attribute is enabled (see Table I). If so, the extorter goes through these stages; otherwise, it proceeds to stage 8, which means that the extorter does not provide strong protection to its targets.

In stage 6, extorters with the Provider Protection attribute enabled that received extortion payment (henceforth *protectors*) face a new decision, namely whether or not to fight against other extorters that tried to extort the same target (henceforth *opponents*) (*Decide Fighting to Protect*, see Figure 2). Fighting, which reproduces what we call strong protection, results in a reduced probability that one's targets will receive others' extortion demands in the future, and in a reduced risk that they will pay any of these [23]. The protector decides to fight only weaker or equally strong opponents, according to Equation 2.

$$\frac{wealth_p}{wealth_{max}} + \frac{numTarget_p}{numTarget_{max}} \geq \frac{wealth_o}{wealth_{max}} + \frac{numTarget_o}{numTarget_{max}} \quad (2)$$

where,

- $wealth_p$ and $numTarget_p$ are respectively the wealth and the number of targets of the protector extorter.
- $wealth_o$ and $numTarget_o$ are respectively the wealth and the number of targets of the opponent extorter.
- $wealth_{max}$ is the maximum of the protector and opponent extorters' wealth.
- $numTarget_{max}$ is the maximum of the protector and opponent extorters' number of targets.

If the protector decides to fight (*Fight to Protect*, see Figure 2), then in stage 7 both extorters suffer a reduction in their wealth (*Cost of Fighting*, see Table I) according to the Lanchester's N-Square rule [24, 25]. This rule states that when fighting, both extorters (protector and opponent) lose wealth, but each extorter loses wealth proportionate to the adversary's wealth. This means that the wealthier extorter has a greater impact on the less wealthy one, and there is no winner in such situation as both lose. The incentive for the protector to fight against its opponents is that of increasing the wealth difference between itself (stronger) and the opponent (weaker). This increased difference may then force the latter to give up the target or die (i.e., successful protection). The emergent effect of strong protection is that of building a reputation of reliable protector.

In stage 8, unpaid extorters decide whether or not to fight against opponents (*Decide Fighting*, see Figure 2). This fighting decision is also based on Equation 2 in which the extorter decides to fight only weaker or equally strong opponents. The incentive for fighting is a resulting larger wealth difference from opponents, to the point that these might possibly quit the market. The long-term emergent effect is instead a reduced number of competitors, and finally a monopolistic situation in which both the targets and the extorters are better off than they are in an anarchical and uncoordinated regime. In stage 9, if the extorter decides to fight (*Fight*, see Figure 2) the cost of fighting is calculated also on the basis of the Lanchester's N-Square rule.

Finally, in stage 10 each extorter decides whether or not to renounce (*Decide to Renounce*, see Figure 2) the targets it unsuccessfully tried to extort. Renouncing means that the extorter will remove the targets from its domain. Three conditions must be satisfied for renouncing a target:

1) the extorter did not receive payment from the target;
2) the extorter was attacked by a protector of that target; and
3) the extorter did not attack anyone to protect that target.

If the extorter succeeds in leading others to renounce a target, or, otherwise stated, in protecting it, the target will keep track of this information and will update the protection probability concerning that extorter. This piece of information will obviously affect the target's ranking of future extorters (see Equation 1).

At the end of each round, the extorter dies if its wealth is not higher than 0 or if it has no targets to extort. In the former case, its targets will be redistributed to the extorters that fought for them. The target dies if its wealth is not higher than 0.

III. Results and Discussion

This section describes a simulation experiment aimed at answering the posed research questions and check the validity of our hypotheses presented in Section I. The simulation experiment includes three treatments, as shown in Table III.

These treatments vary by just one feature. The *no-competition* treatment differs from the other two because extorters do not compete among themselves. By contrast, the *competition & no-strong-protection* and *competition & strong-protection* treatments differ as to the provision of the strong protection service to the targets. In the former treatment, extorters provide no active protection service to the targets: paid extorters do not fight against other possible extorters; in the latter treatment, the paid extorters have the option to provide active protection to their targets.

For each treatment, the simulation model was run 50 times with different random seeds and targets, but with the same set of extorters' profile randomly chosen once at the begin of the experiment. The input parameters used in the simulations are: extorters' profile (see Table IVa), extorters' attribute initial values (see Table IVb), and targets' attribute initial values (see Table IVc).

This work has been realized within the FP7 European Project GLODERS and the input parameters' values have been inferred from empirical work conducted in Sicily by the GLODERS' partner affiliated with the University of Palermo [26, 27]. These data were collected through interviews of extorted entrepreneurs, judicial documents and confiscated Mafia documents analyses (e.g., the *Libro Mastro*, an accounting Mafia's book). These analyses corroborate the assumption that

TABLE III: Experimental treatments.

Treatment	Description
No-Competition	Extorters do not compete among themselves, meaning that they do not fight. Extorters demand extortion to the target and punish those that do not pay.
Competition & No-Strong-Protection	Extorters that receive extortion do not protect (*Protection Provision* disabled, see Table I) the extorted target from other extorters. Extorters that are not paid, first punish the targets that did not pay, and then decide whether to fight or not in order to increase the probability of expanding their domain.
Competition & Strong-Protection	Extorters that are paid may fight in order to protect their extorted targets (*Protection Provision* enabled, see Table I) and increase their chance of being paid in the future. Extorters that are not paid decide whether to fight or not in order to increase the probability of expanding their domain.

TABLE IV: Input parameters.

(a) Extorters' profiles used in the experiment.

Extortion Level	Punishment Severity
70%	90%
30%	40%
80%	100%
90%	100%
40%	50%
60%	70%
80%	90%
100%	100%
20%	20%
50%	70%
60%	90%
10%	60%
20%	90%
30%	70%
70%	80%
50%	50%
10%	20%
40%	100%
100%	100%
90%	90%

(b) Extorters' attributes initial value.

Attributes	Value
Number of Extorters	20
Wealth	1000
Enlargement Probability	10%
Targets	422
Cost of Fighting	3%
Cost of Punishing	33.3%

(c) Targets' attributes initial value.

Attributes	Value
Number of Targets	2000
Wealth	1000
Income	Initialized with a base value chosen between 300 and 1000 using a uniform distribution. At each round, it varies this value from 90% to 110%

the punishment severity inflicted by the Mafia in case of non-payment is often greater than the extortion demanded, as well as that the Mafia extortion request differs depending on the type of business extorted.

The analyses of the treatments are based on a set of output metrics described in Table V, which values are calculated as the average of the results of the 50 simulation runs carried on for each treatment.

TABLE V: Output metrics.

Metric	**Description**
Number of Extorters	The number of extorters active on the simulation.
Number of Targets	The number of targets active on the simulation.
Speed to Monopoly	The number of rounds to achieve monopoly.
Extortion Burden	Proportion of the targets' income spent on paying extortion.
Extortion x Punishment	Proportion of demanded extortions that triggered punishment.
Losses due to punishment	Proportion of the targets' income lost because of punishment.

Here is a summary of the main results. Figures 3a – 3d show the graphics of the dynamics of the *no-competition* (dotted line) and *competition & no-strong-protection* (solid line) treatments.

Due to the lack of competition among extorters in the *no-competition* treatment, targets face an anarchical situation in which they are exposed to requests from all possible extorters, causing their death, and consequently that of all extorters approximately at round 700.

In this treatment, targets' death is ignited at the beginning of the simulation as each target receives on average four extortive requests (this number is specific for the settings in Tables IVa – IVc and it may vary according to the ratio between targets and extorters). Thus targets that cannot bear to pay all of these demanded extortions are punished, and consequently many of them die, as the steep decrease in the number of targets of Figure 3b shows (from 2000 to around 500 targets in the initial rounds). In the subsequent rounds, the proportion of targets' income used to pay extortion increases (see Figure 3c), and the targets become incrementally unable to pay all of the extortive requests; this in turn inflates the number of punishments (see Figure 3d), and consequently the number of targets' deaths. As the number of targets diminishes, some extorters see their domains shrinking until they get to zero, what also causes their death. The situation evolves by the remaining extorters enlarging their domains, what slowly leads to the death of all the other targets and subsequently of the extorters.

The *no-competition* treatment represents a situation of predatory extortion, in which the extorters do not create any long-term relationship with their victims. They attempt to extort them, without caring about their survival. Moreover, they use violence as deterrence. Our results show that anarchical situations of non-regulated extortions are not sustainable in the long-term since they are characterized by predatory extortions and high levels of punishments, resulting in the rapid death of all targets and consequently of all extorters. Hence, as claimed by [16, p. 568] "In a world of roving banditry there is little or no incentive for anyone to produce or accumulate anything that may be stolen and, thus, little for bandits to steal.".

Instead, competition allows the situation to evolve from an anarchic violent situation to a regime of one stationary bandit (see the *competition & no-strong-protection* treatment in Figure 3a) who monopolizes the taxation (i.e., extortion), thus allowing for the emergence of a more acceptable situation for the targets. In it, only a portion of their income is stolen through extortion (see Figure 3c) and they do not have to worry about the theft of others [16][3]. In this sense, competition acts as a sort of weak or soft protection, in which targets, though victimized by one bandit, are at least freed from all others.

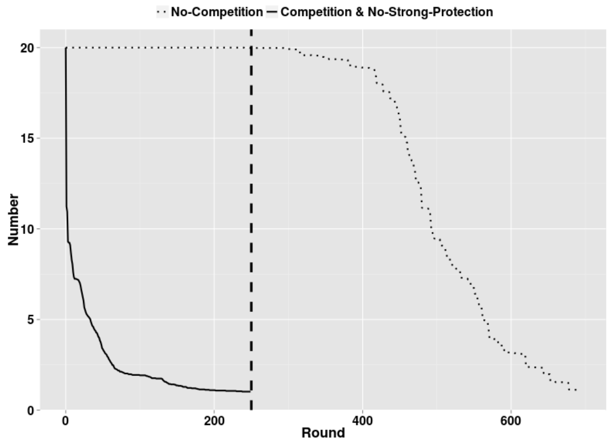
At the same time, competition selects among extortive systems, sorting out the successful ones. What makes an extorter succeed and survives competitors? The probability of obtain payment from targets. In turn, such a probability is determined by the extortion level: when this is reasonable [see 10], the targets are able to sustain the costs. Hence, no state of generalized violence, causing the death of all the targets, is triggered. Competition is an important factor of protection in two ways: (1) it brings about a monopolistic regime, which is more tolerable for targets than anarchy; (2) it leads to the selection of the most successful competitor, which turns to be the most likely to be paid, or, ultimately, to the extorter that makes the most acceptable requests. Competition among extorters seems a sufficient condition for a basic form of social order to settle.

Let us now compare the *competition & no-strong-protection* treatment's results with the *competition & strong-protection* ones.

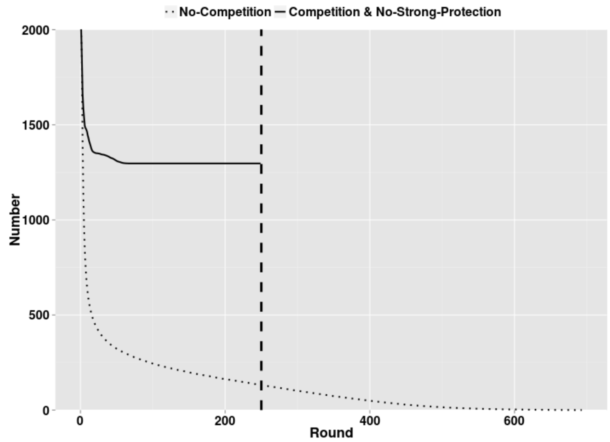
Figure 4a depicts the evolution of the number of extorters in the *no-strong-protection* (dotted line) and *strong-protection* (solid line) treatments. In both, the situation evolves from an anarchical into a monopolistic situation, determined by the survival of only one active extorter. In the former treatment, however, the monopolistic regime is reached in a shorter period of time, occurring approximately at round 90, while in the latter treatment, the same regime needs around 250 rounds to emerge. This time difference derives mostly from the fact that the activity of protection provision raises significantly the initial number of fights (see Figure 4e and Table VII) between extorters in comparison to the *no-strong-protection* treatment and consequently the number of extorters' death.

Besides reducing the frequency and severity of violence and

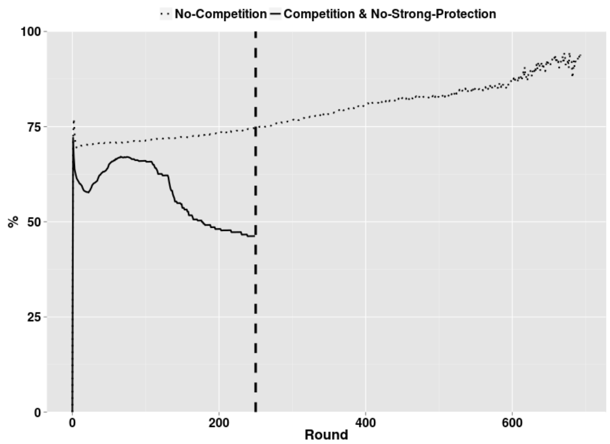
[3]Once a monopoly is achieved, the monopolistic extorter may have an incentive to increase the extortion demand, which may create a favorable environment for the emergence of other competing extorters leading to the competition dynamics once again. Even though this is an interesting aspect to analyze, this work focuses only on the process leading to monopoly achievement, not in its evolution after the achievement.



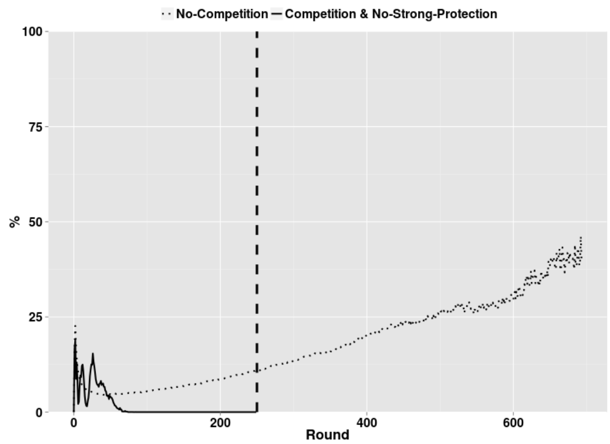
(a) Number of Extorters.



(b) Number of Targets.



(c) Proportion of target's income spent on paying extortion.



(d) Proportion of extortions demanded that resulted in punishment.

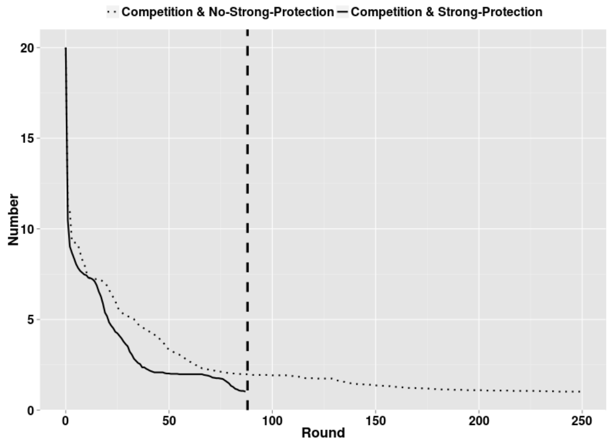
Fig. 3: Dynamics of *no-competition* (dotted line) and *competition & no-strong-protection* (solid line) treatments. The vertical dashed line in the graphics indicates the moment in which a monopolistic regime is achieved in one of the treatments. By this, we mean a situation in which there is only one active extorter in the environment. The *x*-axis unit of all the graphics indicates the number of simulation rounds.

the time needed to reach monopoly, strong protection has further positive effects on targets. As shown in Figures 4d and 4f, strong protection results in a reduced, respectively, frequency and severity of punishment inflicted on the targets that refused to pay. It therefore makes the number of surviving targets increase (see Figure 4b), and leads to an increasing amount of resources targets are left with, after they have paid extortions (see Figure 4c). Additionally, Figure 4c also shows that after the monopoly has been achieved, the level of extortion requested is higher with strong protection than without. This seems to indicate that strong protection makes the extortion burden more tolerable for targets, and the power of successful extorters more stable.

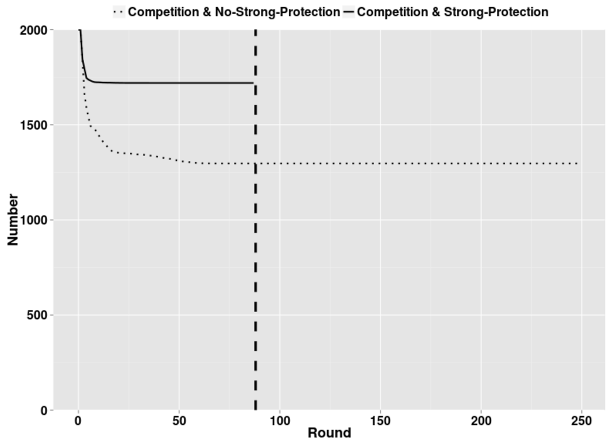
Analyzing numerically the effects of only competition vs competition plus strong protection with respect to the metrics affecting targets' welfare, we observe a statistical significant improvement for all of them (see Table VI, column Student's T-Test p-value). An interesting finding noticeable in Table VI is that not only the targets benefit from active protection provided by extorters, but also the monopolistic extorter benefits from it, as its wealth is 55.43% larger in the latter treatment.

Entering in more details about the monopolistic extorters, Tables VII and VIII show the ranking of extorters beginning from the extorter that survived longest to the extorter that survived the least, respectively in the *no-strong-protection* and *strong-protection* treatments. The main difference between these treatments is the number of punishments inflicted to the targets that resist paying extortion, which is always significantly lower in the protection treatment than in the non-protection treatment. Exceptions are the last 8 extorters, which in both treatments have a short life, only 2 rounds, showing that there is an early elimination of extorters with an exceeding extortive demand (higher than or equal to 70%).

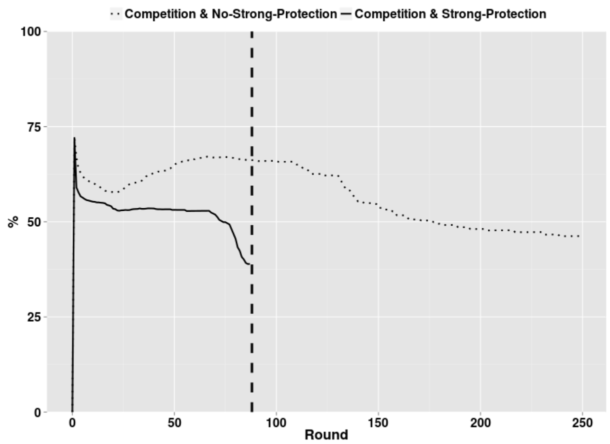
Another interesting difference between these two treatments



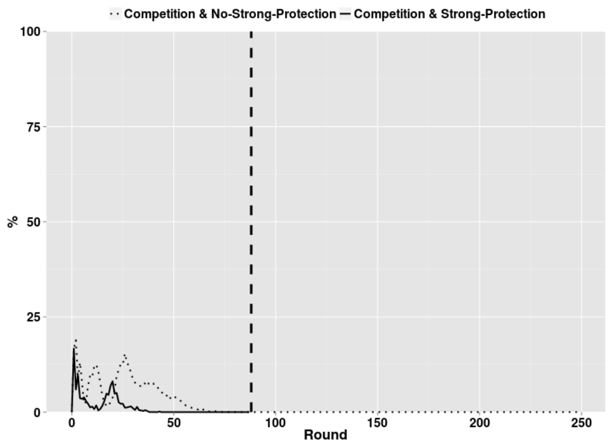
(a) Number of Extorters.



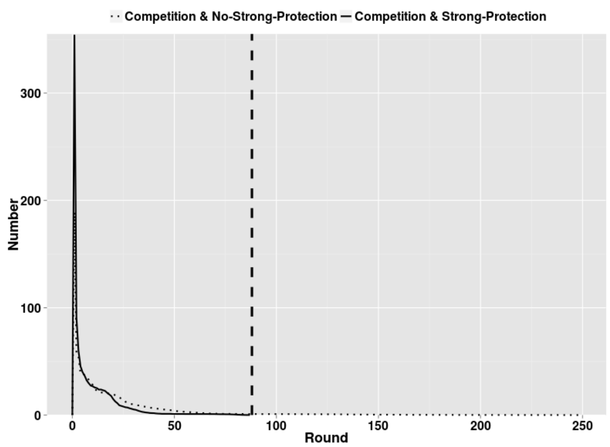
(b) Number of Targets.



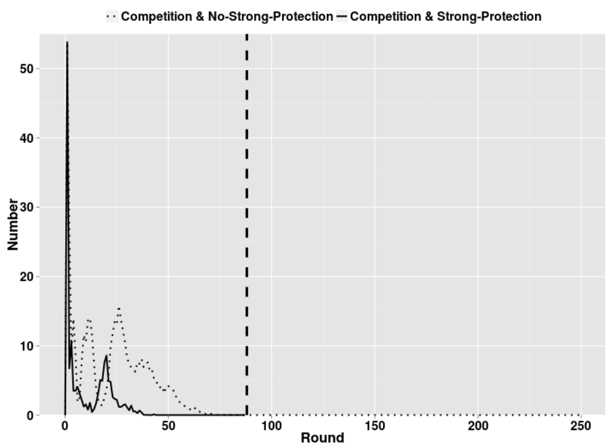
(c) Proportion of target's income spent on paying extortion.



(d) Proportion of extortions demanded that resulted in punishment.



(e) Number of fights among extorters.



(f) Severity of punishment inflicted.

Fig. 4: Dynamics of *competition & no-strong-protection* (dotted line) and *competition & strong-protection* (solid line) treatments. The vertical dashed line in the graphics indicates the moment in which a monopolistic regime is achieved in one of the treatments. By this, we mean a situation in which there is only one active extorter in the environment. The *x*-axis unit of all the graphics indicates the number of simulation rounds.

TABLE VI: Output metrics considered for the analysis of the model.

Metric	Competition & No-Protection		Competition & Protection		Student's T-Test
	Mean	Standard Deviation	Mean	Standard Deviation	p-value (α = 0.05)
Number of Alive Targets	1,296.52	61.62	1,719.68	35.22	2.2×10^{-16}
Total Wealth of Alive Targets	99,959,199.00	15,759,955.00	178,787,543.00	535,7493.00	2.2×10^{-16}
Wealth of the Monopolistic Extorter	64,198,555.00	16,581,454.00	99,790,153.00	381,1173.00	2.2×10^{-16}

TABLE VII: Rank of extorters in the *competition & no-strong-protection* treatment.

Rank	Extortion Level	Punishment Severity	Number of Punishments	Extortion x Punishment
1	40%	100%	432.1	0.59%
2	60%	90%	1533.8	4.05%
3	50%	50%	1978.26	21.91%
4	50%	70%	2918.34	3.43%
5	40%	50%	1246.96	4.02%
6	30%	70%	404.88	1.95%
7	30%	40%	490.88	2.84%
8	60%	70%	723.46	36.17%
9	20%	90%	74.34	0.81%
10	20%	20%	239.96	3.59%
11	10%	60%	30.1	0.87%
12	10%	20%	68.62	2.03%
13	100%	100%	442.5	24.98%
14	80%	100%	423.06	23.86%
15	90%	90%	438.74	24.81%
16	70%	80%	393.92	22.19%
17	100%	100%	442.96	25.00%
18	90%	100%	438.22	24.72%
19	80%	90%	429.52	24.23%
20	70%	90%	361.28	20.34%

TABLE VIII: Rank of extorters in the *competition & strong-protection* treatment.

Rank	Extortion Level	Punishment Severity	Number of Punishments	Extortion x Punishment
1	40%	100%	43.2	0.04%
2	30%	70%	114.2	0.12%
3	50%	70%	843.94	3.36%
4	60%	90%	845.72	3.74%
5	40%	50%	679.26	2.96%
6	30%	40%	246.32	1.53%
7	20%	90%	18.62	0.12%
8	50%	50%	410.08	17.56%
9	20%	20%	122.16	2.05%
10	10%	60%	9.62	0.33%
11	60%	70%	321.14	18.22%
12	10%	20%	15.42	0.58%
13	100%	100%	442.5	24.98%
14	90%	90%	423.18	23.87%
15	80%	100%	439.88	24.82%
16	70%	80%	393.88	22.19%
17	100%	100%	442.96	25.00%
18	90%	100%	438.28	24.73%
19	80%	90%	429.22	24.21%
20	70%	90%	361.12	20.33%

is the ranking position of high punishers, which is always lower in the *strong-protection* treatment than in the *no-strong-protection* treatment. This means that in the former treatment the most violent extorters (i.e., those that punish more severely) are eliminated earlier than in the case when *strong-protection* is not available, thus significantly reducing the targets' losses (i.e., amount of wealth spent on paying punishment, see Figure 4c).

IV. Conclusion and Future Work

The Extortion Racket System model is aimed at understanding how social order may emerge from anarchical situation of uncoordinated extortion (i.e., widespread banditry). It focuses on the factors and processes that may lead from an anarchical and chaotic situation to a monopolistic social order, in particular, it is aimed at answering some research questions, by testing the following 4 hypotheses: (1) a monopolistic regime is required for an extortion racket system to be successfully and steadily settled; (2) a monopolistic regime is preferred by the targets over an anarchical one; (3) the competition among extorters plays a key role in the transition from an anarchical and uncoordinated extortive situation to a monopolistic one; and (4) the strong protection enables the selection, among those competing, of the relatively most sustainable extortive system to become the monopolist.

Our results show that in situations of anarchy, extortion racket systems do not last long: they dissolve soon because they cannot sustain the rebellion and consequent death of their targets (Hypothesis 1). Moreover, the level of extortion paid by the targets is always lower whenever a monopoly of any type is achieved. This results in a situation in which both the monopolistic extorter and the targets are better off: targets do not need to worry about the thefts of other extorters, they are left with a certain capital after paying the extortion, and therefore have an incentive to save and to invest, thereby increasing future income that the extorter can benefit from. Monopolistic situation shall then be preferred over anarchical ones, because as claimed by Olson [16, p. 568] "In a world of roving banditry there is little or no incentive for anyone to produce or accumulate anything that may be stolen and, thus, little for bandits to steal." (Hypothesis 2).

Moreover, results show that competition is a necessary and sufficient condition for the emergence of a monopolistic situation (Hypothesis 3). However, when competition is combined with strong protection, the resulting monopolistic regime presents features that make it more preferable and sustainable for the targets than the one emerging from competition alone. The strong protection of the subjects against other possible extorters favors the rapid emergence of a government of the underworld in which a peaceful order is provided (since less punishment has to be used to convince targets to pay) and more resources are left to the targets (Hypothesis 4).

In future work, we intend to enable agents to improve their performance by dynamically adapting their extortive demands and punishment severity (i.e., their profile) to the context in which they interact. Additionally, we may enable them to form coalitions instead of only competing among themselves, which may enable the representation and analysis of different types of mafia-like organizations, such as *'Ndrangheta* and *Camorra*. We also may enable the entry of new extorters that may challenge the dominance of a monopolist in order to validate the dominant resistance against new comers.

APPENDIX
GLOSSARY

Follows a glossary with the definition of the most important concepts used in the paper.

- *Anarchy* is characterized by a target having more than one extorter demanding extortion payment.
- *Monopoly* is characterized by the presence on the territory of only one extortion system practicing racketeering.
- *Extortion Level* is the amount of the targets' endowment requested as extortion money.
- *Punishment Severity* is the amount of punishment inflicted by the extorter on the target that did not pay extortion.
- *Fighting* is a situation in which an extorter attempts of harming or gaining power over another extorter.
- *Competition* (or weak protection) is the fight started by an extorter that *did not* receive extortion payment.
- *Protection* (or strong protection) is the fight started by an extorter that *did* receive extortion payment. Strong protection provides a more active shelter to its targets compared to competition (weak protection).

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The Emergence of Institutions for the Management of the Commons

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***Abstract*—In this paper we present an abstract replication of institutional emergence patterns observed in common pool resource (CPR) problems. We used the ADICO grammar of institutions as the basic structure to model both agents' strategies and institutions. Through an evolutionary process, agents modify their behaviours and eventually establish a management institution for their CPR system, leading to significant benefits both for them and for the commons as a whole. We showed that, even if our model has a high level of abstraction, by taking an evolutionary perspective and using the ADICO structure we are able to observe common institutional patterns. We confirm that institutions do indeed contribute to the sustainable management of common pool resource systems.**

Keywords: Common pool resource, institutions, norm, emergence, evolutionary modelling

I. Introduction

Four decades of research have shown that Hardin's *Tragedy of the Commons* [5], although frequently occurring in open access resources, can be avoided thanks to the building of carefully-designed endogenous institutions [1], [12], [13]. However, the specific processes leading to institutional change are often difficult to study in the field due to the large number of factors potentially involved, and because such processes often occur on temporal scales beyond the scope of most social science research [18]. Laboratory experiments may offer a way out of the problem, and they indeed significantly contribute to our understanding of the dynamics of common-pool resource (CPR) situations [14]. Nevertheless, the number and nature of factors that can be reasonably tested in the lab is limited. For instance, it is difficult to design experiments involving long-term interactions among participants or doing studies needing large samples of subjects. For these reasons, the development of commons management institutions needs also research going beyond what is reasonably to achieve in the lab or in the field.

Agent-based models (ABM) represent an interesting alternative to both methods. Their main advantage is that they allow to design virtual experiments using more flexible set of conditions than what is feasible in the lab and to analyse their long term dynamics more easily than what is possible in the field [2], [18]. Using ABMs, it is indeed possible to design complex models that are able to capture the effect of a large number of factors on CPR management. The outcomes may be subsequently compared with empirical findings to test the models ability to reproduce patterns and dynamics observed in the real world [8], [19], [21].

In this work, we present an ABM designed to replicate patterns of institutional emergence commonly observed in the field. It is based on the "grammar of institutions", first introduced by Crawford and Ostrom [3], and takes an implicit evolutionary approach to explain the dynamics of CPR management institutions as emerging from the beliefs and actions of users. This is in line with what we have learned from both commons research, including Ostrom's work [12], [13], [16], and institutional economics, with a specific reference to North [10], [11].

In our model, agents representing CPR users are endowed with a set of behavioural strategies based on the ADICO grammar [3], but can also learn by copying others or by exploring new possibilities. Moreover, when unsatisfied with the current state of affairs, they can engage in collective action in order to collectively manage their resource through an institution defined as an ADICO rule. Although in the first phases of its development, the current model is already able to replicate common dynamics of institutional emergence and allows us to reach a better understanding of the process underlying the development of CPR management institutions.

The structure of this paper is as follows. Section II introduces the definition of institutions that will be used in the paper and provides background on common pool resource management problems. Section III defines our ABM allowing the emergence of institutions for CPR management. Section IV discusses simulation results. Finally, Section V gives the concluding remarks.

II. Background

A. Common-Pool Resource Systems

Common-pool resources are natural or man-made resources shared among different users [12]. This produces competition that often (although not necessarily) leads to their degradation or even to destruction. Many natural resources fall in this category and are today "chronically" overused. Examples are forests, fisheries, water basins, biodiversity and even the atmosphere.

Formally, the expression *common-pool resource* refers to a class of goods defined by two characteristics: a difficult *excludability* of potential beneficiaries and a high degree of *subtractability* (i.e., rivalry of consumption) [16]. Thus, the CPRs share characters with both private and public goods, namely a high subtractability with the former ones and a low possibility of exclusion with the latter ones. This makes the management of CPRs especially complex: as in the private good case, the consumption of resource units (e.g., extraction of timber from a forest, of water from a basin, etc.) by one user reduces the total quantity of units available to the other ones; as in the public good case, it is difficult to prevent any user from continuing to subtract units from an endangered resource (e.g. the ocean fisheries). This led Hardin to picture the commons problem as a social dilemma in his famous article *The Tragedy of the Commons* [5]. Formally, this can be seen as a n players version of the Prisoner's dilemma or, more properly, as a CPR game, as first proposed by Walker and colleagues [22]. In both cases, no user has rational incentives to limit his/her consumption and, hence, the possibility to avoid the resource degradation or destruction is extremely low.

Subsequent authors followed Hardin in presenting CPR management as a social dilemma and in formalizing it using different variations of the games above [4], [16]. These all share the idea that the rational equilibrium of the game is well below the collective optimum theoretically achievable by restricting resource use to a sustainable level. Nevertheless, in contrast with theoretical predictions, empirical research has shown that successful management of the resources can be achieved by building endogenous institutions [1]. More specifically, the "tragedy" is avoided thanks to institutions that define clear exploitation rights and create incentives to prevent resource overuse. In other words, the tragedy of the commons is the tragedy of open-access resources, not necessarily of well managed CPRs.

Being institutional building the main way out of the dilemma, the question becomes how to favour this process. Empirical research trying to answer this question has been summarized in Ostrom's "diagnostic approach" [15], which includes a large number of factors potentially affecting the outcome of interaction in CPRs situations. Nevertheless, selecting which factors are actually relevant in a given situation remains a non-trivial task. What is still missing in guiding this choice is a clearer picture of the mechanisms behind the emergence of institutions in CPR situation. ABMs represent an appropriate tool for this endeavour thanks to their capacity of linking the micro and macro-levels of social behaviour [6], [21]. However, a rigorous characterization of institutions becomes crucial to fully exploit the analytical capacity of these models.

B. Institutions

In economics, institutions are usually defined as "the set of rules actually used by a set of individuals to organize repetitive activities that produce outcomes affecting those individuals and potentially affecting others" [10].

Institutions enable interactions, provide stability, certainty, and form the basis for trust. They may however, keep people stuck in unsustainable behaviours or lead to biased power relations. If institutions fail to fulfil stability or to enable sustainable decisions, there are grounds for institutional (re)design [9], [13].

Institutional (re)design refers to the devising of new social arrangements, by examining existing arrangements and changing them if necessary [17]. In order to design institutions, one should be able to understand and analyse the institutional rules. Similarly, institutional frameworks such as Ostrom's *Institutional Analysis and Development* (IAD) framework were developed to study institutional change on the basis of a systematic analysis of the different components of a socio-ecological, system and their relations [13].

The IAD decomposition of a social-ecological system is presented in Fig. 1. Its key component is the 'action arena', in which participants interact and perform appropriation and provision activities. Besides the participants (who have access to resources and information among others), the action arena also includes action situations where the actual activities (or 'games') take place.

The activities in the action arena lead to patterns of interaction and outcomes that can be judged on the basis of evaluative criteria illustrated on the right side of Fig. 1. The action arena is influenced by attributes of the physical world (e.g., climate), the attributes of the community in which the actors/actions are embedded (e.g., demographics, shared beliefs), and the set of rules that govern actor behaviour. The rules of the game (i.e., the institutions) are a major influence actual on the structure of behaviours and interactions. Therefore, in the IAD framework much attention is given to institutions, which are structured using the *ADICO grammar of institutions* [3], [13].

C. The ADICO Grammar of Institutions

ADICO structures institutional statements into five components: <u>A</u>ttributes, <u>D</u>eontic, a<u>I</u>m, <u>C</u>ondition, and sanction (<u>O</u>r else). This structure summarizes institutional statements, facilitating the understanding of the formation and evolution of institutions [13].

a) Attributes: Attributes describe the participants in the situation to whom the institutional statement applies. For example, an attribute of an ADICO can be a 'student'.

b) Deontic Type: This components is used to distinguish between 'prescriptive' and 'non-prescriptive' statements. Deontic operators are *obligated*, *permitted* and *forbidden*. When an institutional statement has the deontic type 'obliged' the person *must* perform the action associated to the institution. For example, "a student is obliged to attend 50% of class A in order to be able to sit the exam". On the contrary, for institutions with the deontic type 'forbidden', actors are not allowed to perform the action associated to the institution. For example, "a student is not permitted to take a course twice". The deontic type 'permission' constitutes the action related to the institution or grant rights to participants with certain properties to perform an action. For example, "a student with GPA above 9 is permitted to take more than 100 credits per semester".

c) aIm: The aim component describes the action or outcome to which the institutional statement applies. In order

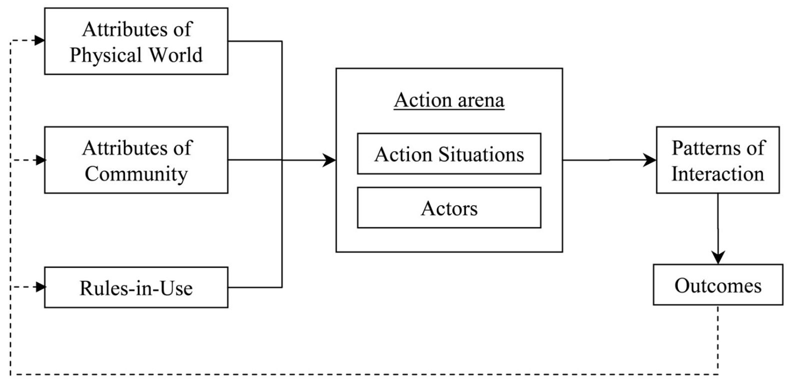

Fig. 1. The components of a social system in the IAD framework [16].

for an institution to influence behaviour, individuals must have a choice concerning its 'aim'. In other words, prescribing an action or outcome only makes sense if its negation is also possible. In the above mentioned examples of institutions, "take course", "sit exam" and "take credit" are the aims of those institutional statements.

d) Condition: Conditions are the set of parameters that define when and where an ADICO statement applies. If there is no condition stated, it implies that the statement holds at all times.

e) Or else: 'Or else' is the consequence of non-compliance to an assigned institutional statement. A common type of 'Or else' is a sanction.

According to the ADICO decomposition, an institutional statement can be divided into three different categories namely: rules, norms and shared strategies.

1) **ADICO**
A *Rule* is the most complete form of institutional statement, covering all five components of ADICO. In other words, rules have attribute, deontic type, aim, condition and 'or else'.
2) **ADIC**
A *Norm*[1] is an institutional statement without an explicit and unique 'or else' component.
3) **AIC**
A *Shared strategy* is an institutional statement where there are no sanctions or deontic type. These kind of statements represent behavioural patterns shared between individuals in a system.

In our model, as we will explain later, we assume that the emerging institutions are norms (of the ADIC type) meaning that agents are obliged to comply with the established institutions but they will not receive an explicit sanction for non-compliance.

[1]Referred to as 'social norm' or even 'moral' or 'ethic code' in multi-agent systems literature.

III. An ABM of Emerging Institutions

A. Model Overview

The model is implemented in Netlogo [23]. It takes the ADICO sequence as a starting point to allow institutions to emerge and evolve in an abstract CPR system. We use the ADICO structure in two different ways. First, we assume that the agents select and follow *individual strategies* structured by the 'A', 'I' and 'C' components of ADICO. Strategy change follows an evolutionary dynamics where unsuccessful agents *copy* other agents or randomly explore new possibilities (*mutation*).

Second, the ADICO sequence is used to structure the management institution that affects the behaviour of all agents. Note that the current model covers only the 'A', 'D', 'I', 'C' components of the ADICO structure but has no sanction. This means that it would be formally more proper to refer to it as a *norm*. However, since in the current version all agents comply with the institution, the distinction is practically irrelevant and we will continue to talk about "institutions". Future developments will include the possibility of rule-breaking for agents and sanctioning, hence including also the 'O' component.

The main feature of the model is that the institution derives bottom-up from agents' strategies through a voting system and can change through time following the evolution of agents' strategies.

B. Model Components

The model consists of the following components:

- Agents: the agents are nodes in a social network defining their neighbourhood. The network is defined in two different ways: (1) random network, (2) small-world network.
- Resource: there is only one resource that is shared between agents in the simulation. The agents gain energy by taking units from the resource. The resource is renewable; in each time step it (re)grows at a rate given by a logistic function with two parameters: the carrying capacity K and the reproduction rate r, which represents the maximum proportional increase of the resource in one time step. The specific function used is a standard

discrete-time logistic. The increase ΔR of the resource R at time t is given by:

$$\Delta R = rR\left(1 - \frac{R}{K}\right) \tag{1}$$

At the beginning of the simulation the resource is set at carrying capacity, while it subsequently changes depending on the amount harvested by agents and on equation (1).

- ADICO components:
  - A. The relevant statements apply to the single agent in case of individual strategies and to all agents in case of the establishment of an institutional rule.
  - D. The deontic is relevant only for the institution (since it is a rule, not a strategy) and is always of the 'obliged' type, which means that agents always follow their strategies or the institutional rule.
  - I. We assumed that all the actions an agent can possibly take are stored in a list. These actions are related to the common resource exploitation. The actions also influence the amount of energy the agents gain. For simplicity, we also assumed that the number of units extracted from the resource is equal to the energy gained by the agent. For example, `eat5` implies that the agent gains 5 units of energy, while the resource is decreased by 5 unit. There is also one action that does not influence the resource, but reduces the amount of agent energy (`eat-5`). This action is included in the action list to represent possible losses that an agent may face through inappropriate behaviour (e.g., fishers losing their boat while trying to fish during a storm).
  - C. We assumed that all the conditions an agent can possibly consider are stored in a list. The conditions specify when and where the agent is allowed to perform its selected action. At a given point in time, each agent has only one action-condition pair.
  - O. As written above, we assumed that all agents follows the rule when an institution is in place. As a consequence, this component becomes non-relevant.
- Institution: in the current model, only one institution at a time can rule the system. This institution, is established by a voting system. Throughout the simulation, the institution changes if the number of agents not performing well (i.e., energy level < 0) is higher than a certain threshold (Tab. I, `threshold for institutional change`). Furthermore, the institution can only change at certain time intervals given by the `institutional emergence time` parameter.

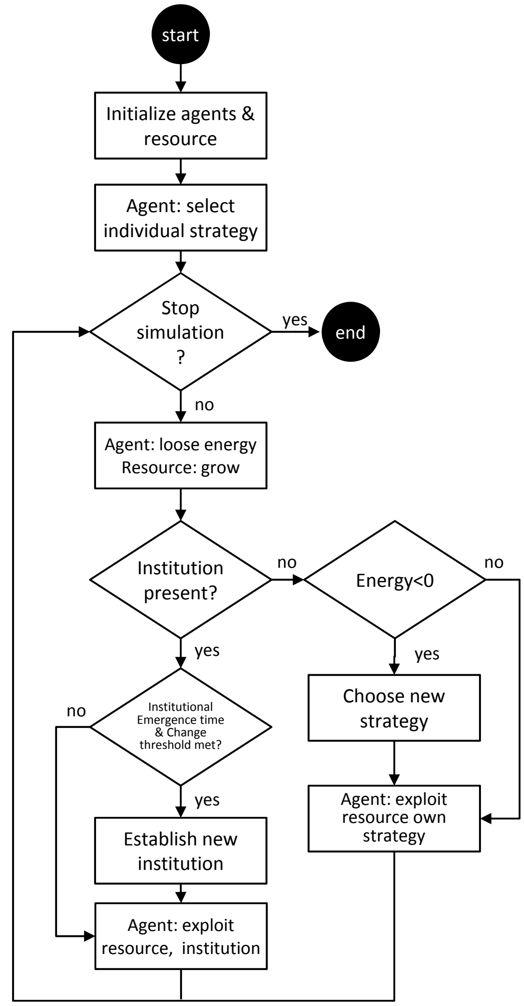

Fig. 2. The simulation procedure

C. Simulation Procedure

The simulation, depicted in the flowchart in Fig. 2, is described below:

- Model setup:
  1) each agent randomly selects a strategy, i.e. a combination of action-condition (AIC);
  2) the resource is initialized equal to the carrying capacity.
- Procedures occurring in every time step:
  1) the resource grows as explained above
  2) agents loose energy according to the `energy consumption` parameter
  3) agents gain new energy by exploiting the resource
  4) each agent checks its current energy level; if it is below 0, it chooses a different action-condition combination using one of the following two procedures:
     – mutation: with a given probability (Tab. I, `mutation rate`), the agent chooses the new action-condition pair (each one separately and randomly) as at the beginning of the simulation;

TABLE I
EXPERIMENTAL SETUP

Parameter	Values
actions	eat [$(n \times 2), 1 < n < 10$], [-5]
conditions	(ticks mod 3) = 0, (ticks mod 2) = 0, energy <= 0, (ticks mod 20) = 0, (ticks mod 250) = 0, true
initial amount of resource (k)	5000 – 20000 (step 10000)
growth rate (r)	0.1 – 0.5 (step 0.2)
number of agents	100
energy-consumption	1 – 10 (step 5)
mutation rate	0.01 – 0.1 (step 0.05)
threshold for institutional change	0.4. 0.6, 0.8, 1
institutional emergence time	50, 100, 200, 500, 1000
number-of-links	2
rewire-prop	0.05

   – copying: the agent chooses the action-condition of the most successful agent in his neighbourhood.

- Institutional change procedures occurring every `institutional emergence` time step:
  1) If a certain proportion of agents (`threshold for institutional change`, Tab. I) has energy below zero, there is call for institutional change. The most frequently used action-condition pair is selected as a new institution. From this point, the agents must comply with the institution, rather than performing their own action-condition pairs.

The simulation end after 2000 ticks or when the resource completely runs out.

D. Simulation Setup

The goal of this preliminary model is to see whether it is possible to replicate the qualitative dynamics of empirical CPR systems using an abstract model of institutional emergence and evolution. More specifically, we compared the outcomes of the CPR system under the institution and no-institution conditions. The underlying question is whether the agents and the resource are better off, when collectively selected institutions are present.

Tab. I shows the experimental setup, including the values used for the parameters introduced in the previous section. The parameter sweep resulted in 3240 runs which were repeated 100 times, which led to a total of 324,000 runs. Half of these runs allowed an institution to emerge, while the other half were without this possibility. For each run, the average energy of the agents, the average amount of resource, and the final selected institution were recorded.

IV. RESULTS

A. Resource and energy

The introduction of the institution affects positively both the amount of resource in the system and agents' energy. This remains true also controlling for the other simulation parameters (Tab. II and III). All parameters except the mutation rate have

TABLE II
OLS ON THE AMOUNT OF RESOURCE REMAINING AT THE END OF THE SIMULATION

	Estimate	Std. Error	t value	Pr(> $\|t\|$)
(intercept)	-4626.0191	38.1777	-121.17	0.0000
institution	3516.6743	15.8985	221.20	0.0000
K	0.5148	0.0013	403.87	0.0000
r	14135.1495	46.7691	302.23	0.0000
energy consumption	-56.1966	2.1591	-26.03	0.0000
institutional emergence time	-1.1240	0.0226	-49.71	0.0000
mutation rate	9.6372	215.9067	0.04	0.9644
threshold institutional change	-3530.4305	35.5500	-99.31	0.0000
R^2	0.4966			
$F(7, 320752)$	4.52e+04			0.0000

TABLE III
OLS ON THE AMOUNT OF AGENTS' ENERGY AT THE END OF THE SIMULATION

	Estimate	Std. Error	t value	Pr(> $\|t\|$)
(intercept)	-607.8326	16.1403	-37.66	0.0000
institution	58.8458	6.7214	8.76	0.0000
K	0.0915	0.0005	169.87	0.0000
r	3767.1631	19.7725	190.53	0.0000
energy consumption	-238.5417	0.9128	-261.33	0.0000
institutional emergence time	-2.5759	0.0096	-269.47	0.0000
mutation rate	-49.3257	91.2786	-0.54	0.5889
threshold institutional change	-60.1269	15.0294	-4.00	0.0001
R^2	0.3913			
$F(7, 320752)$	2.945e+04			0.0000

a significant effect on both dependent variables. The resource carrying capacity and renewal rate positively affect both the amount of resource available and the agents' energy, while the energy consumption negatively affects them. Especially interesting is to note that both the institutional emergence time and the proportion of agents needed to change the institution negatively affect both indicators, which means that the harder it is to build the institution the worse is the outcome for both the agents and the resource.

Although, the agents on average are better off when institution building is allowed, they do not necessarily reach an optimal situation. In most cases, the selected institution actually led to a condition when the available energy was below what the agents could have theoretically obtained from the resource; in some cases it was even below the energy gathered under the same parameter configuration in the no-institution condition. This is clear in Fig. 3, which shows the average amount of energy and resource at the end of the simulation under all the different institutional arrangements selected by agents.

To simplify the analysis, we selected two examples of resource condition characterized by difficult resource management (low carrying capacity and high energy consumption) and easier management (high carrying capacity and low energy consumption) respectively. Note that the extreme abundance

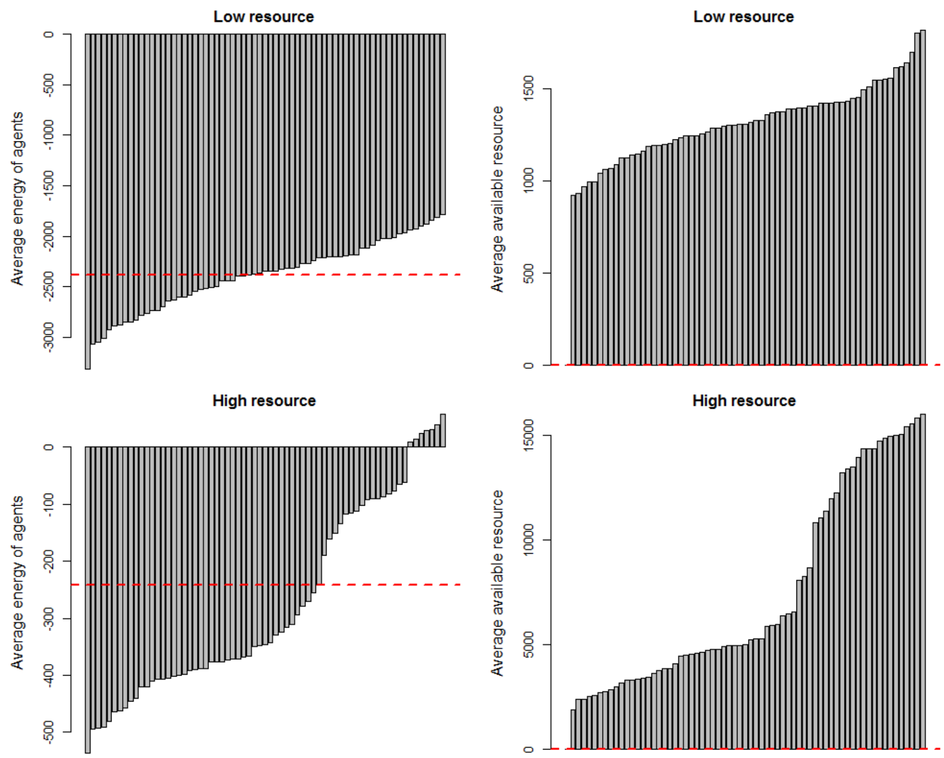

Fig. 3. Average energy of agents and resource left at the end of the simulation under various institutional arrangements in low and high resource conditions. Low resource is defined as $K = 5000$, $r = 0.1$ and energy.consumption = 10. High resource is defined as $K = 20000$, $r = 0.1$ and energy.consumption = 1. The dashed red lines represent the average energy and resource under the same parameter configurations in the no institution condition.

condition ($K = 20000$, $r = 0.5$) was not included in the analysis since the management of the resource under an open access rule was effective enough and agents never implemented a stricter institutional rule (see Tab. IV below).

Under all the selected institutions, the state of the resource at the end of the simulation was instead better than the no-institution case (Fig. 3). This is quite interesting since it implies that in no case the agents selected an institution making them using the resource more than in the open access situation. It is also worth noting that, under most of the selected institutional arrangements, the difference between the open-access and the regulated condition was quite dramatic, with the resource exploited at low to sustainable levels under all of the selected institutional arrangements and few signs of overuse. Especially relevant is the quasi-optimal use of the resource in the low resource condition, with withdrawal often approximating the maximum sustainable yield keeping the resource at intermediate levels under a majority of the selected institutions.

B. Institutions

On average, agents created an institution 2/3 of the times when the institutional emergence option was enabled. Notably, they only succeeded in doing it when the proportion of agents needed to change the current institution (the threshold for institutional change parameter) was lower 1. In other words, under the unanimity rules the process of institutional building never succeeded. The institutional emergence time parameter instead only showed a relatively small effect. Finally, the agents never created an institution when $K = 20000$ and $r = 0.5$, i.e., when the resource was so abundant and rapidly replenishing that no institution was actually needed to reach the survival level.

It is interesting to note how agents adapted their institution to the environment. Tab. IV shows the most common institution for each combination of K, r and energy consumption. The amount of energy "eaten" tends to increase with both the resource availability and the agents' requirements, while the modal institution becomes the "open access" one (["" ""]) for the highest values of K, r, especially under low energy consumption requirements.

To better analyze the changes in the institution due to different resource availability, we separated the institutional rule recorded at the end of the simulation into its *aim* and *condition* statements. Fig. 4 presents the resulting distribution under both a relatively low and a relatively high resource availability.

When the resource is scarce, agents tend to select relatively high withdrawals at distant intervals. This strategy clearly allow the resource to replenish between two different consumption steps. This said, the relatively even distribution of different institution visible in the upper row of Fig. 4 testifies the difficult adaptation of agents to a scarcity situation, where easy solution is available to have at the same time enough

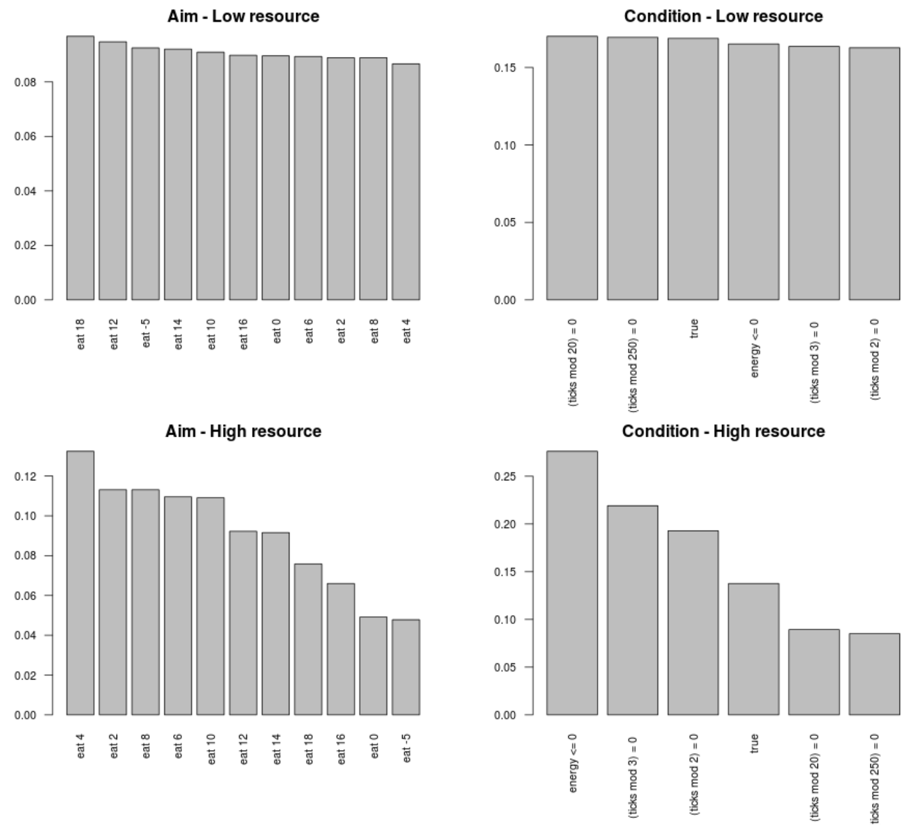

Fig. 4. Distribution of the Aim and Condition statements under low and high resource condition. Low resource is defined as $K = 5000$, $r = 0.1$ and energy.consumption = 10. High resource is defined as $K = 20000$, $r = 0.1$ and energy.consumption = 1.

energy for all and a resource kept at sustainable levels.

On the contrary, when the resource is abundant, relatively small but frequent withdrawals are consistently selected. In a majority of the cases, agents are simply allowed to consume a small amount of resource either when their energy becomes zero (condition: "energy $\leq$ 0") or even in every time step (condition: "true"). This allows them to maintain an optima level of energy without degrading the resource at a level beyond its renewal capacity.

V. Discussion and Conclusion

In this paper we presented a preliminary model based on the ADICO grammar of institution showing that an institution emerging through collective behaviour without centralized planning can help the management of common pool resources. Consistently with much empirical findings [1], [12], [13], we found that, in systems where institutional building was possible, both the agents' payoffs and the resource condition improved in comparison with situations where the agents were only allowed to follow their own strategies.

This result is consistent with the work of Smajgl and colleagues, who also model rule changes in social systems using the ADICO structure [20]. While Smajgl considered the selection of agents actions and global rules as two separate behavioural mechanisms in the system, we see emerging rules as ones that are the results of repetitions and commonality in individual strategies. Furthermore, agent behaviour and decision making in [20] is defined through internal and external variables such as incentives, motivation, goals and environmental conditions.

In the model presented in this paper, agents are simpler entities, which either randomly choose new behaviours or copy others. Another distinction between these two researches is that, while the resource dynamics in [20] only followed simple rules and presented no inter-temporal links, we explicitly modelled the resource change over time using prevailing bio-economics models and studied how these changes influence the emergence and evolution of rules.

Despite a much higher level of abstraction and the fact that we took an implicit evolutionary (copying, mutation, etc.) perspective, our results remain fully consistent with both Smajgl's ones and the ones of commons research [1]. Notably, we were still able to observe institutional dynamics similar to the ones found in empirical settings and to confirm that institutions do indeed contribute to the sustainable management of common pool resource systems. Especially interesting was the capacity of agents to adapt their institutions to resource availability. For instance, the fact that agents selected institutions allowing them to harvest only at distant intervals of time bears a clear resemblance with discussions going on during CPR experiments, where time-based strategies allowing the resource

TABLE IV
MODAL INSTITUTION FOR EACH COMBINATION OF K, r AND ENERGY CONSUMPTION

K	r	energy consumption	selected institution
5000	0.10	1	[” eat 2” ” energy <= 0”]
10000	0.10	1	[” eat 2” ” (ticks mod 2) = 0”]
20000	0.10	1	[” eat 18” ” energy <= 0”]
5000	0.20	1	[” eat 4” ” (ticks mod 3) = 0 ”]
10000	0.20	1	[” eat 2” ” (ticks mod 2) = 0”]
20000	0.20	1	[”” ””]
5000	0.50	1	[” eat 12” ” energy <= 0”]
10000	0.50	1	[”” ””]
20000	0.50	1	[”” ””]
5000	0.10	5	[” eat -5” ” (ticks mod 2) = 0”]
10000	0.10	5	[” eat 12” ” true”]
20000	0.10	5	[” eat 10” ” (ticks mod 2) = 0”]
5000	0.20	5	[” eat 10” ” true”]
10000	0.20	5	[” eat 10” ” (ticks mod 2) = 0”]
20000	0.20	5	[” eat 10” ” energy <= 0”]
5000	0.50	5	[” eat 12” ” (ticks mod 2) = 0”]
10000	0.50	5	[” eat 12” ” true”]
20000	0.50	5	[”” ””]
5000	0.10	10	[” eat 12” ” (ticks mod 2) = 0”]
10000	0.10	10	[” eat 8” ” true”]
20000	0.10	10	[” eat 10” ” (ticks mod 3) = 0 ”]
5000	0.20	10	[” eat 10” ” (ticks mod 2) = 0”]
10000	0.20	10	[” eat 4” ” energy <= 0”]
20000	0.20	10	[” eat 10” ” true”]
5000	0.50	10	[” eat 4” ” true”]
10000	0.50	10	[” eat 16” ” energy <= 0”]
20000	0.50	10	[”” ””]

to replenish were more often discussed and selected under the most challenging conditions [7].

Finally, it is worth noting that the model discussed in this paper represents only a starting point in our research on the mechanisms leading to institutional emergence and that there are many dimensions that can still be added to the model. First, as highlighted by Poteete and colleagues [18], although norm emergence has been studied to some extent, the emergence of rules is an area of research that requires special attention. By building a model using the ADICO structure, we focused our attention to the dynamics (or emergence) of rules. This means that, to be able to study rules in a more realistic way, we should at least add cheating and sanctioning mechanisms to our model. Following Ostrom's argument about the process of norms (ADIC statement) evolving into rules (complete ADICO statements including sanctions), we decided that a reasonable first step was to allow norms to emerge in the system with all agents abiding them. Nevertheless, future versions of the model will allow agents to decide whether they would comply with the institution or follow their own individual strategies through simple learning mechanisms. Finally, the current model allows only one institution to emerge at a time. In future versions, coexistence of various institutions and their possible conflicts will also be an interesting area to explore.

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Simulating pedestrians through the inner-city: an agent-based approach

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***Abstract*—This paper describes an agent-based model for the simulation of pedestrian movement in city centers for various types of visitors. It takes into account preferences of different types of pedestrians. The model is tested and calibrated using GNSS data of pedestrians collected during a field experiment in the city of Delft. Although the model as presented here is not yet fully validated it showed to be able to generate plausible patterns of movements making the model potential useful for urban design studies.**

I. Introduction

To design, plan and manage the use and accessibility of inner-city centers insight in the movement behavior and utilization of the public space is essential. This paper presents an agent-based model which simulates movements of the people in city centers based on their spatial preferences. So far, few frameworks exist that included the knowledge on pedestrian movement which preferences for places to visit [1], [2]. From a viewpoint of urban planning and design this combination may be of great value, as such a model gives the opportunity to explore various scenarios related to the design of city centers, road networks, and access points to cities. Future changes in urban structure may be checked in the model on possible effects on pedestrian behavior.

Most agents-based models which simulate movement behavior of pedestrian focus on applications in the field of crowd management [3], or the movement of tourists in nature areas [4], [5]. Only a few agent-based simulation models are known that concentrate on the behavior of pedestrians in city centers who are shopping or sightseeing, one exception of is the work of [6], [7].

In this research we present an agent-based simulation in which 3 different types of users are being distinguished, accounting for the majority of inner city users: inhabitants, regional visitors, and visitors from outside the region [8]. Inhabitants mostly combine non-leisure activities with leisure, either knowingly or not. This is the group having the most differentiated agenda but will mostly spend the least time in the city center. The regional visitor has one main purpose and that is shopping. Visitors from outside the urban region tend to spend more time with the more touristic activities like sightseeing. Like [9] also noticed, this group, the more touristic oriented leisurist, claims to do "very vaguely formulated activities such as sightseeing, wandering about, taking in the city and getting among the people". With the goal of modeling this behavior, more is needed than these vague notions of activities. Other research is more detailed and point out how this group is attracted to the obvious tourist attractions but are also is interested in shopping. Although maybe not the main purpose of the visit, most touristic visitors go shopping during their trip [10].

The goal of the research presented here is to explore the use and accessibility of streets in city centers by using an agent-based model which explicitly represents the individual behavior of people roaming around the city trying to fulfill individual desires. The simulated patterns are verified by comparing them with tracking data collect using GNSS devices during a field experiment in the city of Delft. It tries to go a bit beyond models by explicitly including attractiveness of areas, streets, and facilities in a decision-making model.

II. Methodology

The model is based on the assumption that pedestrian movement behavior is defined by two aspects: 1) a goal oriented behavior which influences the agents to choose places to visit and 2) the movement behavior which determines the routes to follow in order to visit the places it wants to visit. The movement behavior of the agents depends on the type of visitor and the activities its wants to carry out. The movement behavior may vary from a "wandering" type of movement in which the followed route is chosen to accomplish a satisfying experience till an purely optimizing behavior aimed to reach the place(s) to visit as quick as possible.

The most important assumptions of the presented model are:

- People are constrained in space and time;
- people move forward until a crossing is reached. Crossings are points where people make decisions about the route to take;
- pedestrians avoid to move on the same part of the network multiple times as much as possible;
- destinations may change as a function of their current position and are therefore often determined on an ad-hoc basis;
- pedestrians may have different levels of knowledge on the area, based on different sources. This will influence the behavior and show different levels of distance- or effect minimizing behavior;

- route choice is influenced by the characteristics of the network as well as different elements of attractions;
- agents operate independent of other agents i.e. aspects as overcrowding are currently not take into account.

A. *elements of the model*

Based on this the basic elements of the model are defined as follows:

- agents representing pedestrians;
- access points;
- a representation of the network;
- representation of decision points i.e. crossings;
- specific areas of interest for the various agent types i.e. shopping areas, cultural areas etc.;
- preference rules.

The agents represent individual pedestrians belonging to a certain group i.e. inhabitants, urban region visitors, or visitors from outside the region. Each agent type has different preferences about the network and their preferred destinations as well as a varying time budget.

Access points mark locations where agent start and end their movements. Mostly they represent parking lots or public transportation hubs. Each access point seeds a predefined number of agents distributed in time on to the network.

The network represents the street network of an inner-city. Each node in the network represents a crossing. Each edge in the network is characterized by values indicating the attractiveness for that street based on four types of functions: tourist attractions, shops, drinking and dining facilities, and cultural attractions. Additionally edges have an id, name, and a zone identifier which is used to demarcate areas of interest for the three groups of agents.

B. *decision-making*

The decision-making of the agents is implemented following a two-step procedure:

- After being “released” from their access point agents take an optimized (shortest) route over the network to their preferred areas of interest. The characteristics of the individual edges is not taken into account during this phase. If more than one preferred areas of interest is available to an agent group one of them is chosen randomly.
- When an agent reaches the area of interest it starts to exhibit roaming behavior based on the attractiveness of the network edges. At each crossing a value is calculated indicating the probability the agent will choose this road:

$$P_{ae} = h_{ae}(Azone_{za} * \sum_{f=1}^{n}(w_{af} * Aedge_{ef}))$$

Where P_{ae} is the probability of agent a to take edge e, $Azone_{za}$ is the attractiveness of zone z to agent a, h_{ae} is the history factor, w_{af} is the weight agent a assigns to function f, and $Aedge_{ef}$ is the attraction value for edge e for function f. The history factor h depends on the number of times an agent passes an edge and is currently simply defined as a exponentially decreasing function.

TABLE I
INITIAL WEIGHTS FOR THE AGENTS

type	shops	tourist.	cult.	drinking dining
inhabitants	0.5	0.0	0.9	0.5
reg. visitors	0.9	0.0	0.2	0.4
other visitors	0.4	0.9	0.1	0.2

Each agent moves around in the city center until its time-budget is used. The time budget is determined by drawing from a normal distribution based on measured time people spend in the city during the field-experiment that people spend in the city center. Larger differences exist between local inhabitants who spend on average 4500 seconds in the city center than for example visitors from outside the region who spend on average about 8200 seconds in the city.

III. Preliminary Results

A case study of the municipality of Delft is used for this research. In 2009 a tracking research has been carried out. Students of Delft University collected GPS recordings of visitors starting from 2 parking garages near the center. A brief interview was carried out to determine the type of visitor. The participants were given a GPS-tracking device. Due to urban-canyoning effects and people continuously walking in and out shops, the quality of the GPS-tracking data varied. Assigning pedestrian to specific streets was therefore not very accurate. Instead a kernel density analysis was carried out to generate heatmaps indicating the density of visitors for the various areas in the center. For example Fig. 3 shows the most visited areas by inhabitants.

The ABM was implemented in GAMA, an agent-based development environment specifically designed for geographical systems [11]. For the model a network data set containing all streets as well as all crossings of Delft was compiled. Based on a field visit each street was assigned an attractiveness value for each of the 4 aspects (shops, tourist attractions, cultural attraction, and drinking and dining facilities) (see for example Figs. 1 and 2).

The weights each agent assigns to the attractiveness of a specific function w_{af} was initially based on first estimations according table I and needs to be calibrated. As starting points the location of the parking garages near the center were used, which are the same as used for the GPS-tracking research. The number of agents leaving each parking garage was also based on the data of the field experiment.

Fig. 4 shows the results of the simulation for inhabitants. Currently these results are preliminary. However a quick visual comparison shows that the simulated patterns coincides with the measure pattern of Fig. 3 although the extend in which the pedestrian move seem to be more spread out. To thoroughly test the presented approach currently a sensitivity analysis is carried out as well as and calibration and an extended Monte

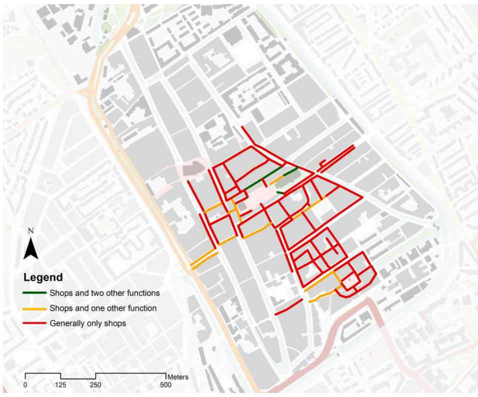

Fig. 1. Streets with having a high attractiveness for shopping

Fig. 2. Areas indicated with a high attractiveness for cultural activities

Fig. 3. Recorded GPS tracks of inhabitants visiting the city center of Delft

Carlo analysis to account for the probabilistic nature of the model.

IV. Conclusion and discussion

Although the model up till now have not been calibrated and validated yet it already shows that it is possible to generate plausible pedestrian movement patterns for specific types of visitors of city centers with the use of existing GPS-tracking data. Patterns of movement emerge from relative simple decision-making based on attractiveness of individual

Fig. 4. Simulated movement of local inhabitants visiting the city center of Delft

roads and area to agents. A point-to-point based decision making procedure seem to realistically capture movement behavior of pedestrians in a situation were people exhibit a more exploration based behavior aimed on gathering "best experiences" in the city. The agents are currently implemented as purely reactive agents. This means that *a-priory* knowledge about for example the best shops and attractions are not known to the agent. So no means of developing intentional behavior is currently possible something which especially might influence the movement patterns of inhabitants as they are assumed to show a more goal directed behavior to shopping or visiting points of interest. A next step in the development of this model therefore could be to give agents knowledge on a larger area than only the crossings. This will enable agents to combine goal oriented behavior with the *ad-hoc* exploration of the city center thus broadening the pallet of possible movement strategies.

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Computational Environment Behavior Research: Case Studies of Sustainability and Population Collapse in a Northern Arizona Region

Keywords: Computational Social Science, Agent Based Modeling Simulation, Anasazi, Coupled human-environment systems, Biocomplexity in the Environment, Deep ecology, Environment-Behavior Research, Mixed Methods, Simulation.

While most would call Environment-Behavior Research a discipline and work to defend it's existence, I prefer to take an "Environment-Behavior" perspective into my research, teaching, and practice endeavors. This way I need waste little time in defending the field per se. While my interests originally focused upon seeking defensible justifications for "value added by design" relative to schools, residential developments, and commercial complexes with an eye toward greater levels of expected success in long term sustainability for the human communities and cultures that inhabited them with stable and flourishing natural ecosystems – over the years the focus has shifted more and more deeply toward capturing the essences of and working toward collective capacities to simulate "coupled human-natural systems."

Using Agent-Based Modeling Simulations we can capture from the "bottom-up," in the form of simple algorithms the essence of some system of interest, by capturing the essential behaviors of the key players and/or components within that system. These algorithms (computations) are then allowed to interact with one another, resulting in a new model system that can be explored. Agent based modeling is well suited for analysis of dynamic systems of heterogeneous, adaptive "agents." Complex, adaptive, systems such as these are difficult if not impossible to capture using more traditional modeling tools like axiomatic mathematics, statistical methods, or even qualitative/descriptive methodologies.

For nearly a decade our research group has been working toward integration of socio-spatial elements of culture, and/or cultural landscapes into an earlier model of the Anasazi in a Northern Arizona Region that was primarily environmentally deterministic. To date this research has indicated that earlier hypotheses, seemingly un-testable, about ideological and cultural factors not included in original models being responsible for the abrupt dissolution of the Anasazi culture are more than mere conjecture – they are highly plausible.

However, as models/simulations grow ever more complex and numerous, problems have emerged with regard to interchangeability of models among researchers, re-use of earlier existing models, and solid data tracking into the design of model components and construction of modeled causal networks. Beginning with a description of the Long House Valley (Arizona) and Mesa Verde (Colorado) Anasazi research teams, their models, their development, and a short discussion of experimental results from these research teams and present plans for future work the discussion here will turn to matters of methodology and rigor. Using the Anasazi model for a Northern Arizona region as a case study, we will explore the process of taking an existing model as a piece of earlier research, reverse engineering it, and designing an extension utilizing insights gained through the Perspective of Environment-Behavior Research. An extension that, like all environmental designs and public policy developments, is geared toward user needs – in that instance the Archaeologists, Dendroclimatologists, Computer Scientists, Anthropologists, Epidemiologists and Sociologists/Public Policy Analysts that comprised the original Artificial Anasazi Model.

In the process of achieving those goals it became clear that a new generation of models is needed, and indeed there is a great deal of work being done all around the globe by researchers, as the emergence of the new field "computational social science" indicates, in this area. However – looking at this new field of "computational social science" and the other sub-disciplines popping up – it seems undeniable that the same deficiencies will re-create themselves in this new social science perspective as with it's environmental science version. The need for the Perspective of Environment-Behavior Research is clear – not so much in the form of our pre-existing body of substantive works – but by way of the collective insights we in EBR have gained over these past 4 decades.

My present work centers on designing the methodologies and protocols that can pull together the many diverging skeins within Agent Based Modeling Simulation (especially those that pertain to development of deeper understandings of sustainable systems at all units of analysis). Pull them together so that the current team of researchers can begin to develop a new class of model that combines Agent Based Modeling Simulation + 3d GIS through "Middleware" development (a third component, not yet in existence) – so that researchers in Architecture and Planning can begin to dialogue with and through the work of other researchers in the many fields that come together to a degree never before considered within the global community of researchers focused on this type of research. In particular – the problem that needs the most work is the one that EB has labored so long and hard itself to master. Development of valid and/or trustworthy research designs and subsequent results for problems in the real world that involve persons and the environment.

While significant advances are being made in development of protocols for Agent Based Modeling with regard to standardization of basic model structure descriptions (OOD) and toward standardization/synchronization of modeling components (Mr. Potatohead), a significant gap still remains in to create an appropriate "ecological context" for next generation Agent Based Modeling research; that of providing satisfactory documentation/citation protocols. This paper suggests the addition of a third component to complement Standardized Model Descriptor protocols [1] and Standardization and/or Coordination of Object Oriented Model Designs so that components and/or algorithms might be interperable (e.g.: Mr. Potatohead development[2] pattern protocols). This third component would provide linkages into the respective literatures, or other verifiable sources, upon which model designs are based.

ABM researchers who wish to emulate scientific research designs must meet the requirement that experiments be repeatable, and that they be (in principle) open to challenge. Agent based modeling simulations in general fail to track backwards into the literatures on, or documented descriptions of the actual entities, that our models are purported to capture. This represents a dimension of scientifically legitimate inquiry[3] that ABM simulation research designs must begin to satisfy.

For several reasons the time has ended when models circulate only within circles where data sources are common knowledge. ABMS are becoming more complex, researchers are working toward components becoming interoperable and used in construction of and/or modification of other models and increasingly across disciplines, and ABMS couplings with GIS may likely become the standard. Without the development of protocols for properly "citing" sources (as is standard in scientific research and publication) the emergent ABMS boom will unquestionably bog down and become mired within legitimate protestations that its assertions are little more than pseudo-science that will be difficult, if not impossible to counter.

Our research team's utilization of NVivo, a software package for the analysis and synthesis of qualitative data, to provide data tracking from literatures, interviews, and/or observations for the successful modification of the original Artificial Anasazi Model[4] (Gumerman, Dean, Epstein, Axtell, Parker, Swedlund, and McCarrol) to incorporate "ideological and cultural factors not present in the existing model" is presented as an example of what is needed to bridge this gap.

Beginning with a description of the Long House Valley (Arizona) and Mesa Verde (Colorado) Anasazi models, their development, and a short discussion of experimental results from these research teams - followed by a description of why and how the original model was modified and presentation of new experimental results. Next the reverse engineering of the existing LHV Anasazi model, interviews of original team members, evaluation/choice of hypotheses to be tested in new version of model, and research into literatures of anthropology, archeology, ethnography, psychology, sociology, environment-behavior research, CAS, ABMS and philosophy were utilized and tracked (using NVivo) from their sources into the process of "program modification specification," development of UML code, Java code, and debugging will described in detail.

Concluding remarks discuss the pro's and con's of the protocols followed, outline a conceptual design for new tools to fill the gap that was found between data analysis and synthesis software such as NVivo and high level symbolic programming protocols such as UML, and suggest this as an opportunity for additional collaborative research and development. Collaborative research and development where not everyone need be a programmer or mathematician – but everyone must

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1 e.g.: "Overview, Design Concepts, and Details" , or ODD (Polhill, Parker, Brown, Grimm; 2008)

2 The "Mr. Potatohead" framework is a "conceptual design pattern" (CDP) that represents key elements of Agent Based Models (ABM) for Land Use/Land Cover Change (LUCC) research – and demonstrates how multiple models can be represented and compared within a single meta-model.

3 Kuhn, T. S. (1996). The structure of scientific revolutions; Popper, K. R. (1968) The logic of scientific discovery; Voss, J. L. (2000) Transcending Geographies of Paradox: coextensive essences of phenomenological and scientific inquiry.

4 This model was jointly developed by the Brookings Institution and the Santa Fe Institute by George Gumerman, Jeff Dean, Miles Parker, Alan Swedlund, Joshua Epstein, Robert Axtell, and Stephen McCarrol. It it a model of the Anasazi of the Long House Valley in North Eastern Arizona – capturing land use patterns, changes in ecological context (weather, water table), demographics, settlement patterns, and maize production from 800 to 1350 AD. The model seeks to explain LUCC, demographic + settlement changes, and eventual abandonment of LHV in 1300.

be interested in solving complex problems beyond the capacities of any individual discipline to do alon

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Diffusion of ideas, social reinforcement and percolation

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***Abstract*—This paper analyzes how social structure and social reinforcement affect the diffusion of an idea in a population of human agents. A percolation approach is used to model the diffusion process. This framework assumes that information is local and embedded in a social network. We introduce social reinforcement in the model by softening the condition to adopt when the number of adopting neighbors increases. Our numerical analysis shows that social reinforcement severely affects the output of the process. Some ideas with an original value so low that it would never get diffused can be spread due to the strength of social reinforcement. This effect also interacts with the structure of the network, with a more sizeable impact on small worlds with a low rewiring probability. Also, social reinforcement completely changes the effect of clustering links, because sequential adoption of neighbors can make one agent adopt at later stages.**

I. Introduction

The success or failure of an idea depends not only on the goodness of the idea but also on the diffusion process. There are many examples in history of ideas that were dismissed at first and much later proven right. As many ideas spread through social contact, the social structure of individuals is likely to be determinant in the diffusion process. The present paper performs a theoretical study of the influence of social reinforcement on the diffusion of ideas in a population of human agents.

There is an ongoing debate in recent literature as to which social network structure is optimal in terms of diffusion [1]. The first strand of literature builds upon [2] "weak ties hypothesis". According to this idea, long ties between otherwise unconnected neighborhoods facilitate the spread of information, as they reduce the redundancy of the diffusion process [3].

The second strand of literature builds on the work by [4] and argues that close social structures promote trust, and thus facilitates information sharing and transmission. Thus, networks with overlapping neighborhoods (highly clustered networks) are better suited to promote diffusion [5].

The empirical evidence to support both theories is wide and strong. In recent works, Damon Centola has argued that none of them can be generalized to "whatever is diffused", but depends on whether the process is a simple or a complex contagion process [6], [7], [8], [9]. In simple contagions, only the first contact with an infected agent determines whether or not an agent is infected. In such a case, information in closed neighborhoods is redundant, and long ties can bridge distant neighborhoods and allow for information to travel through the network. In complex contagions, on the other hand, transmission depends on interactions with multiple infected agents. Thus, clustered neighborhoods are not redundant anymore, but provide with multiple sources of reinforcement that can promote transmission. Accordingly, they finds that complex contagion processes diffuse better in clustered networks like small-worlds [10] or lattices than in random networks [11].

In this paper we will argue that it is not only the nature of the diffusion process but the distribution of "incredulity" or resistance to contagion of agents, that determines the performance of different network structures. In order to do so, we build upon a percolation framework to study the interplay of individual preferences and social reinforcement, in order to have a theoretical benchmark that can help understanding the role of structural factors such as clustering in diffusion processes. We consider that ideas are diffused by word-of-mouth [12] by friends in a complex way. We find that for uniform distributions of incredulity, the strength of weak ties hypothesis can still apply for complex contagion processes. On the other hand, for incredulous populations the reinforcement mechanism is more important and clustered networks do better than random ones.

The structure of the paper is as follows. Section II introduces the basic model and the extension with social reinforcement. In Section III we introduce a different distribution of agents. Finally, in Section IV we present some conclusions.

II. Basic percolation model and social reinforcement extension

A. Basic percolation

In this article we study the diffusion process of new ideas on a population that presents a social network structure. Ideas are identified by their value, represented by a number $v \in [0, 1]$. Agents are heterogeneous and they are characterized by a minimum quality requirement (MQR) for adopting a new idea. The higher the MQR -the more "incredulous" an agent is- the higher the value he requires of an idea in order to adopt it. The MQR of agents is a random variable which is uniformly distributed, $q \sim U[0, 1]$. This modelling framework corresponds to the so-called percolation model [13].

In a percolation model of diffusion one agent adopts the new idea at any given time t (time is discrete) if the following three conditions are met:

- the agent has not adopted before t,
- the agent is informed, which only occurs if at least one neighbor has adopted at time $t - 1$,
- the value of the idea is higher than the MQR of the agent, that is $q < v$.

Without a social structure the percolation model behaves as a well-mixed population of consumers. In a well-mixed population, agents are not embedded in a social network and they have perfect information. As soon as the idea enters the "market", the willing to adopt agents adopt it while the rest don't. As the MQR is uniformly distributed $q \sim U[0, 1]$, a proportion $100 \times v_0\%$ of the population will adopt an idea of value $v_0 \in [0, 1]$. This case can be represented in our model with a complete network, where every agent is connected to every other agent. In a complete network, a single early adopter will inform the whole population of agents about the existence of the idea.

B. Network structure

In a percolation setting, agents become informed of the existence of the idea through her neighbors. Thus, the structure of the social network where the agents are embedded can be determinant of the outcome of the process [6]. Previous studies have considered percolation processes in regular networks as a two dimensional lattice [14], [15], [16] or a completely random network [12] . These networks do not offer an accurate description of a social network [17], although their simplicity can be useful for their implementation and the interpretation of the results.

In this paper we propose the use of the small world algorithm [10] for the modelling of the social structure as in [18]. This provides with a family of networks, an interpolation between regular lattices and completely random networks. The algorithm starts with a regular ring lattice and rewires every link with probability μ. This parameter allows to fine tune the randomness of the network.

The small world algorithm produces a network structure that reproduces two well-known properties of social networks. On the one hand, they have a high clustering coefficient. That is to say, that the probability of two nodes to be connected together is higher if they share a mutual neighbor. This is a typical characteristic of social networks, where friendship groups are tight communities, and friends share many connections. On the other hand, small worlds have a low average path length. This is the so-called "six degrees of separation" theory introduced by [19], according to which every person in the world is separated from every other person by a very small number of connections such as friendship.

Varying the rewiring probability μ of the small world algorithm produces networks with varying average path length and clustering coefficient (Figure 1). The case

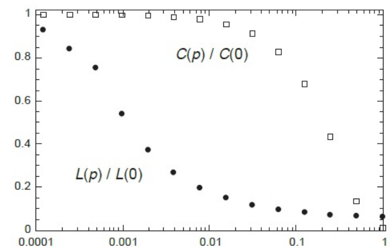


Fig. 1: Clustering coefficient $C(p)$ and average path-length $L(p)$ as a function of the rewiring probability in small world networks [10].

with $\mu = 0$ is the one-dimensional regular lattice, and the case with $\mu = 1$ is the random network, also known as Poisson network or Erdos-Renyi model. The "typical" Small World is the one with rewiring probability $\mu = 0.01$, presenting an average path-length almost as low as the Poisson network, while still having a clustering coefficient which is comparable with the one-dimensional regular lattice.

C. Social reinforcement

The difference between the basic percolation model and the social reinforcement extension lies in how the MQR of agents is calculated. Let q_t be the MQR of an agent at time t. In the basic percolation model this threshold remains constant over time, with $q_t = q_0 \ \forall t$. Thus, the number of adopting neighbors does not play any role in adoption decisions. Nothing changes for an agent if she knows about the new idea from one or many neighbors: the number of adopting neighbors does not have any weight, and additional adoptions are only redundant information. We extend this model by introducing a local social reinforcement effect. We include a new factor in the expression of the value of an idea, according to which decisions are influenced by the number of adopting neighbors. Adopting neighbors can "advocate" in favor of the idea, so as to increase the likelihood of its adoption.

The updated MQR is defined to satisfy the following hypothesis of the model. Let $q \in [0,1]$ be the MQR of an agent, $a \in \mathbb{N}$ the number of adopting neighbors and $\gamma \in [0,1]$ a parameter expressing the social reinforcement intensity. The functional form $f(q,a,\gamma)$ is chosen such that:

1) it is decreasing in the absolute number of adopting neighbors, $\frac{\partial f}{\partial a} < 0$;
2) it is decreasing in social reinforcement, $\frac{\partial f}{\partial \gamma} < 0$;
3) with only one neighbor adopting it is equal to the initial MQR q_0;
4) without social reinforcement ($\gamma = 0$) it is equal to the basic percolation model.

The first condition implies that neighbors give positive information about the idea: the more neighbors adopt, the easier it is for an agent to adopt. The second condition means that social reinforcement is a positive force for adoption. With the same number of adopting neighbors, the updated value of MQR will be lower for higher social reinforcement intensities, so adoption will be easier. The first decision to adopt for an agent is after the first adoption in her neighborhood. In order to compare our results with the benchmark percolation case, we need the MQR of agents to be their initial value with only one neighbor adopting (third condition). Finally, the fourth condition allows us to keep the benchmark percolation as a particular case of the extended model. The functional form in Equation (1) fulfills all four conditions.

$$\begin{aligned} q_t^i &= q_0^i \cdot \left(\frac{1}{\#\ neighbors\ of\ i\ that\ have\ adopted}\right)^{\gamma} \\ &= q_0^i \cdot \left(\frac{1}{a_t^i}\right)^{\gamma} \qquad (1) \end{aligned}$$

D. *Simulation results*

In this section we study the percolation model extended with social reinforcement by mean of batch simulation experiments. For the social network structure, different instances of the small world model [10] are considered, which are identified by a rewiring probability $\mu \in \{0, 0.001, 0.01, 0.1, 1\}$. We consider $N = 10,000$ nodes representing potential adopters, with $k = 4$ neighbors on average. We simulate the model in different settings represented by the rewiring probability μ (network structure), the idea initial value v_0, and the social reinforcement intensity γ. The MQRs of agents are random draws from a uniform distribution, $q \sim U[0,1]$. For each setting we run $R = 50$ simulations, and look at the average value of the diffusion size together with its standard deviation across the different runs. In all simulations the diffusion process is initialized with 10 early adopters, the seeds of the simulation.

Results of the simulations are reported in Figure 2. Without social reinforcement ($\gamma = 0$), the social structure creates "information failures" compared to the well-mixed population with perfect information. Some willing to adopt agents never become informed of the existence of the idea because none of their neighbors have adopted it. Thus, the final diffusion size is lower than the linear demand (dashed line).

We first observe that in the diffusion regime of percolation (above the threshold represented by the sharp increase in diffusion size), the social reinforcement factor adds to the diffusion levels of the basic percolation model. Moreover, the number of adopters can even surpass the linear diffusion level of a well-mixed population. This is because with social reinforcement agents get to have a subjective valuation of the idea which is above its initial value v_0, and possibly above their minimum required quality even if the initial value was below it.

A second but possibly more important change is for the position of the percolation threshold. For the Poisson network ($\mu = 1$), an increasing social reinforcement intensity does very little, since the position of the threshold is almost unaffected across the different panels in Figure

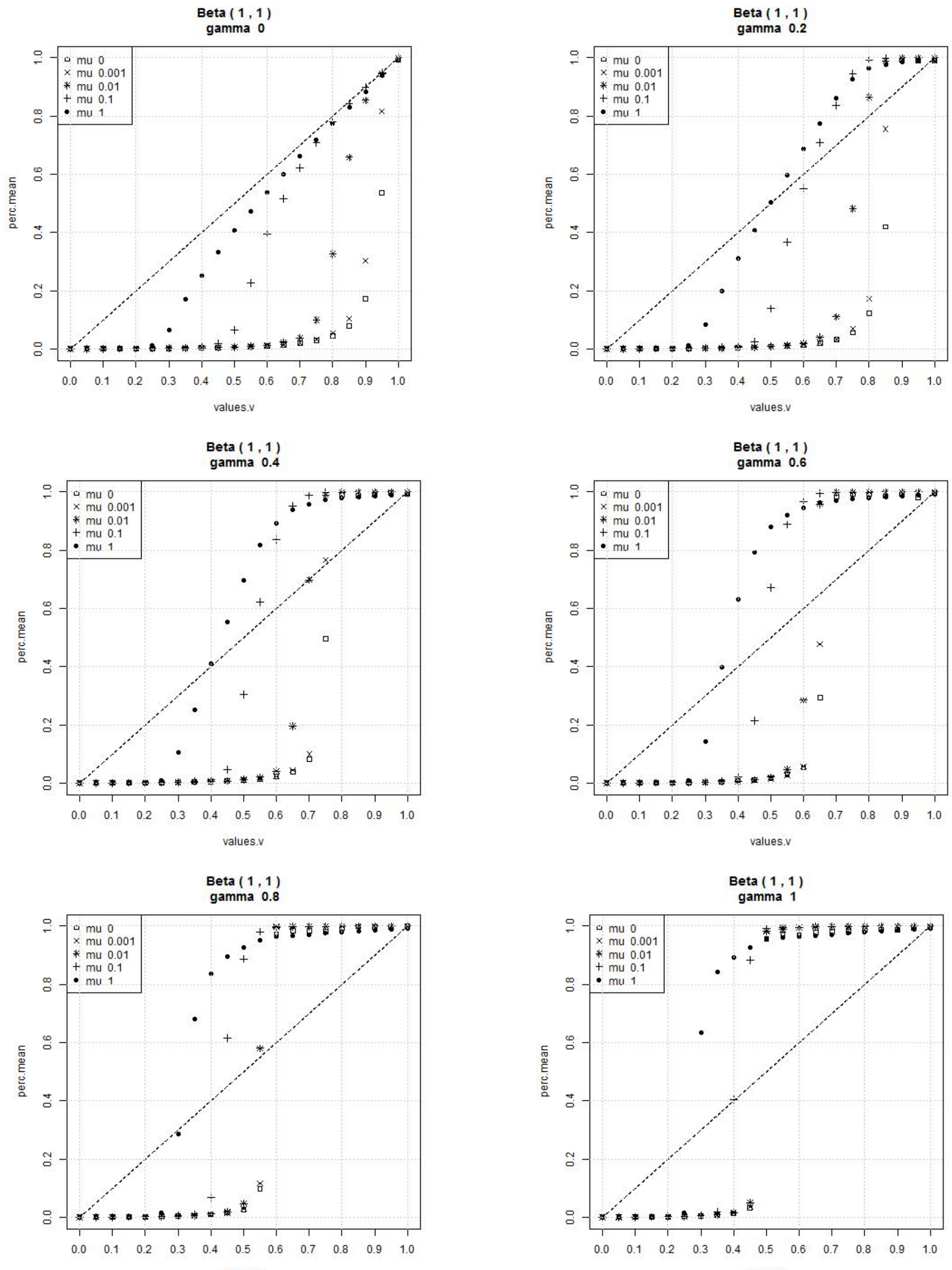


Fig. 2: Diffusion size in different small world networks for different initial values $v_0 \in [0, 1]$ of the diffusing idea (horizontal axis) in different conditions of social reinforcement intensity $\gamma \in [0, 1]$ (different panels). Reported values are averages over 50 simulation runs. The network size is $N = 10,000$ nodes, with 10 early adopters (seeds).

2. The opposite is true for the regular one-dimensional lattice and for Small World networks with $\mu = 0.001$ and $\mu = 0.01$, that see their thresholds moving substantially to lower values as γ increases. For instance, the typical Small World network with $\mu = 0.01$ has a threshold equal to 0.2 without social reinforcement,[1] which goes down to about 0.7 with $\gamma = 0.4$ and to 0.6 with $\gamma = 1$.

The thresholds to percolation do not just decrease, they also seem to change their nature. Without social reinforcement (Figure 2) the threshold from non-diffusion to diffusion regimes is a second order transition: there is a sharp but continuous change in the number of adopters. With social reinforcement (Figure 2), on the other hand, the threshold looks more like a first order transition: the number of adopters jumps from almost zero to almost full diffusion. This can be the result of a critical mass scenario. As soon as there is a sufficient number of adopters, the social reinforcement forces the process to cascade to complete diffusion. This effect only happens in highly clustered networks ($\mu = 0.01$ or lower). Without social reinforcement clustering hampers diffusion, since most links are redundant and cannot be used to reach new sources of information. With social reinforcement, though, another effect arises: shared friends may lead an agent to adoption by increasing her subjective value of an idea. Assume for instance that at a time t agent i, Margaret, sees Bill, one of her neighbors, adopting the idea. Still, the initial value of the idea is below Margaret's minimum required level, $v_0 < q_r^i$. At time $t+1$ another of her neighbors, Elinor, or agent j, adopts. This happens exactly because their common friend Bill had adopted the period before. Elinor had a lower minimum requirement level than Margaret, which happens to be such that $v_r^j < v_{t+1} < v_r^i$. Now, with two neighbors adopting, the value of the idea for Margaret becomes high enough as to be above her minimum requirement, $v_{t+2} > v_r^i$. This is how the triadic structure of their mutual friendship makes it possible for Margaret to adopt at a later stage, which would have not happened in a different social structure. Figure 3 shows an example of this dynamic.

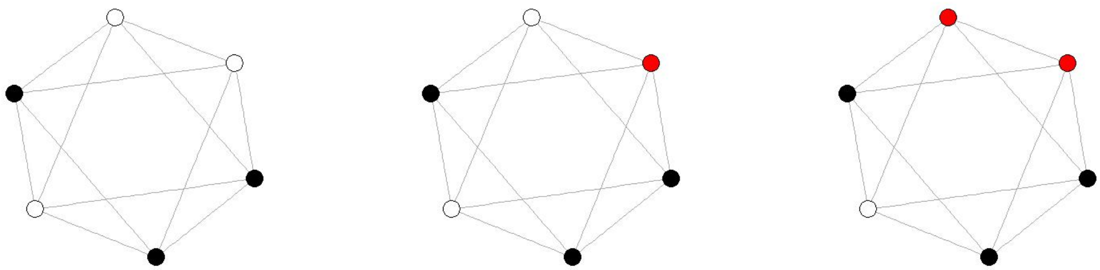
[1] The theoretical value is about 0.82, according to [20].

Finally, Figure 2 shows that increasing social reinforcement intensity reduces the differences between network structure. While without social reinforcement ($\gamma = 0$) there are differences in the final size of diffusion for $v_0 \in [0.3, 1]$ approximately, with a high social reinforcement ($\gamma = 1$) this range is reduced to $v_0 \in [0.3, 0.5]$. This result has important implications for policies aiming at introducing some new behavior or idea: when agents can be convinced by their friends, it is not so important to know the social network structure. In a well-mixed population, perfect information implies that every agent instantly knows about any new idea. In a network setting, this situation is represented by a fully connected network, where every agent is neighbor of every other agent. In this case, social reinforcement would lead to full diffusion even for small values of the idea.[2] Thus, it is important to know that there is some kind of network structure in the process. It is not so important, however, which structure this is as long as it is not a perfect information setting.

III. Non-uniform distributions

Most studies on complex propagation consider that agents are homogeneous in their resistance to contagion [6], [11]. In the previous section, we relax this assumption by assuming a uniform distribution of MQRs. Nonethe-

[2] If an idea of value v_o is introduced, a proportion v_o of the N agents would immediately adopt it, that is a total of $N \cdot v_o$ agents. In the following step, the MQR of the remaining agents has been decreased by $\frac{1}{N v_o}^{\gamma}$: at the end of the second step, $v_o (v_o N)^{\gamma}$ agents have adopted. The process continues so that after the s step, $v_o^{1+s\gamma} N^{s\gamma}$ agents have adopted. If $N > frac1v_o$, then $lim_s (v_o^{1+s\gamma} N^{s\gamma} = \inf$, so the process reaches full diffusion.



(a) The white nodes represent the willing to adopt neighbors.

(b) A willing to adopt agent adopts (red node).

(c) The clustering links make social reinforcement more intense for non-willing to adopt agents.

Fig. 3: The effect of social reinforcement on clustered neighborhoods

less, the outcome of the diffusion process is highly dependent on the specific distribution considered.

The marginal effect on the MQR of an having an additional neighbor adopting is described in Equation (**??**). The first adopting friends induce a large decrease in the MQR, while after a large number of friends have adopted the influence of an additional adopting neighbor is negligible. Moreover, the effect on one more friend adopting is larger for large values of q_o^i. Thus, in this section we will concentrate on a case where agent have high initial MQRs.

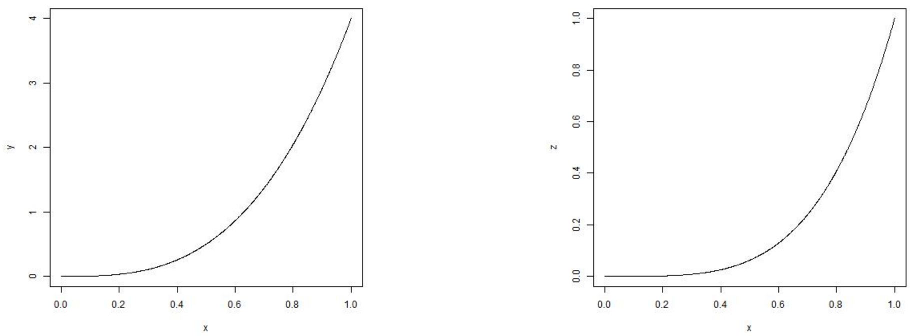
$$\begin{aligned} q_t^i &= q_0^i(1/a_t^i)^\gamma \rightarrow \Delta q_t^i \\ &= q_0^i \Delta(a_t^i)^{-\gamma} \\ &= q_0^i(-\gamma(a_t^i)^{-gamma-1}\Delta(a_t^i) \\ &= -\frac{q_0^i\gamma}{(a_t^i)^{\gamma+1}}\Delta a_t^i \end{aligned} \tag{2}$$

As the effect of social reinforcement is higher upon more reluctant or incredulous agents, we analyze here the diffusion process in an incredulous population. Figure 4 shows the density of a $Beta(\alpha = 4, \beta = 1)$ distribution. All values drawn from this distribution will be bounded to $[0, 1]$ as in the uniform distribution $U[0, 1]$, although they will be biased towards high values close to one. That way, a distribution $Beta(4, 1)$ represents a population where most people are incredulous, or unwilling to adopt the idea, and a few people are enthusiastic early adopters. This is a realistic population that would provide an s-shaped adoption curve over time [21].

A. Simulation results

As in the previous section, we use batch simulations to compare the behavior of the diffusion process under different conditions. We compare five network structures from the samll world algorithm [10] with rewiring probabilities $\mu \in \{0, 0.001, 0.01, 0.1, 1\}$, $N = 10,000$ nodes and $k = 4$ initial neighbors. The MQRs of agents are now drawn from a $q \sim Beta(4, 1)$ distribution. For every setting of value of the idea $v_o \in [0, 1]$, social pressure $\gamma \in [0, 1]$ and rewiring probability μ we study the mean diffusion size over $R = 50$ runs with 10 seeds or initial adopters.

Results of the simulations are depicted in Figure 5. Increasing the social reinforcement intensity γ increases the number of adopters, as some of the unwilling to adopt are convinced. It also decreases the percolation thresholds, the minimum value of the idea v_o that gets



(a) Density function

(b) Cummulative distribution

Fig. 4: Probability distributions of a $Beta(4, 1)$.

some diffusion. This effect is more accused for the more regular networks, due to the reinforcement of clustering links. In the random networks, however, the thresholds are more stable. Thus, as the social reinforcement intensity γ increases, the graphics for the different networks overlap as in Figure 5, for $\gamma = 0.4$. If we continue to increase γ, the clustered networks will overperform the random Poisson network.

IV. Conclusions

Introducing social reinforcement in a percolation model of diffusion adds to the size of diffusion. In the case of ideas that would otherwise not be diffused, social reinforcement allows for some spreading in the population. It also reduces the differences between network structures. Without social reinforcement, clustering links are redundant: if the number of ties is limited, they restrict the access to new sources of information. Nonetheless, when the opinion of neighbors can influence the adoption process, clustering links can force agents to cascade to adoption.

In simple propagations no social reinforcement is present ($\gamma = 0$) and thus the size of diffusion is determined by the number of willing to adopt agents that the idea can reach. That is to say, the diffusion is determined by the dimensionality of the network, how many agents can be reached with every new step. As random networks have the higher dimensionality, they are the most efficient structures to spread an idea. In the small world algorithm, clusters come at the expenses of bridges: the more clustered the network is, the lower its dimensionality as clustering links are redundant.

For complex propagations clustering links are not redundant anymore. Indeed, they provide an additional support for the social reinforcement mechanism. Once a first neighbor has adopted, the probability that a second neighbor adopts increases with clustering coefficient. In the limit case, a random network, the probabilities of different neighbors adopting are independent. Thus, introducing social reinforcement affects the diffusion in the random network vaguely. It increases the number of adopters, as some of the unwilling to adopt are convinced, but leaves the percolation thresholds essentially unmoved. On the other hand, the interaction of social reinforcement with the structure of highly clustered networks alters both the number of adopters and the thresholds of the shift from a non-diffusion to a diffusion regime. Moreover, there appears to be a change in the nature of these thresholds, from a second order transition to a first order (discontinuous) transition. The interplay of clustered networks

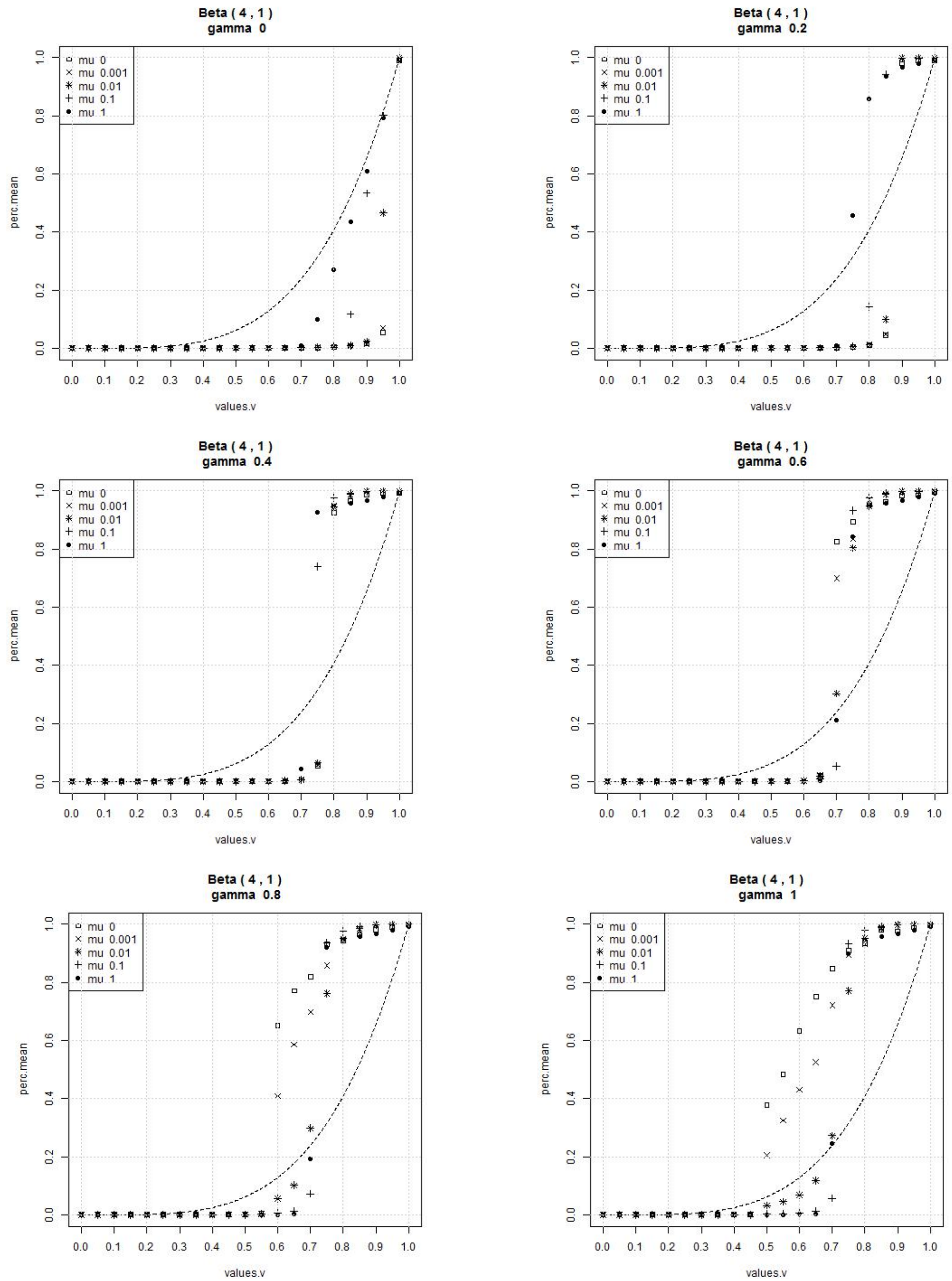


Fig. 5: Diffusion size in different small world networks for different initial values $v_0 \in [0, 1]$ of the diffusing idea (horizontal axis) in different conditions of social reinforcement intensity $\gamma \in [0, 1]$ (different panels). Reported values are averages over 50 simulation runs. The network size is $N = 10,000$ nodes, with 10 early adopters (seeds). The initial MQR values in the population follows a $Beta(4, 1)$ distribution.

decreasing their thresholds while random ones remain more stable results in an homogenization of the results for the different networks. For high intensities of social reinforcement, it is important to know that there is a social network underlying the process of diffusion, but not so important to know which network it is. Nonetheless, even with this uniformization of the network structures random networks still come as the most efficient structures to enhance diffusion.

In this setting, random networks get higher shares of diffusion both for simple and complex propagations, contrary to the findings of [6], [9], [8]. Nonetheless, changing the distribution of "incredulity" throughout the population of agents can confirm their results. Our study confirms that clustering can be favorable or harmful for diffusion, depending on the setting. Nonetheless, the determinant of which network structure is more efficient for spread is not only the nature of the process (a complex or a simplex propagation), but also the characteristics of the population in which it diffuses.

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Economic Sustainability in Relation to Demographic Decline of Celtic Agglomerations in Central Europe: Multiple-Scenario Approach

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Abstract—**Our research attempts to discuss the applicability of social simulation as a tool for exploration the late Iron Age society in both the fortified agglomerations known as the oppida and open settlements within their surroundings, especially from the point of view of the population change and related sustainability of economic production. This paper presents a model of the resilience of the food production system under the dynamically changing (increasing and/or decreasing) population. The models represent a multiple-scenario approach: the scenarios describe different aspects of the oppida occupation (population dynamics in terms of its increase or decrease, food production strategies, landscape changes or economic interactions between oppida and their hinterlands). Within a modelling process different methods are integrated: (1) cellular automata (for the representation of landscape and its changes), (2) system dynamics (population dynamics, economic strategies and ecological and societal rules), and (3) the agent-based component (livestock management).**

I. Introduction

On a transition from middle to late Iron Age period we encounter a transformation of the central European society which was represented especially by the new settlement forms – the oppida. They appeared as a part of an economically advanced environment, together with a distinctive intensification of settlement patterns. When they emerged, being understood as "deliberate foundations rather than a gradual evolution", they represented complex systems with multiple functions. However, no issue is as complex and variable at the same time as the oppida and range of their activities, functions and social hierarchies (for the discussion on some of them, see [1]. The central European sites share the dynamics of their occupation: according to the archaeological record the population density increased from the beginning of the occupation (half of the 2nd century BC), peaked around the end of the 2nd century / beginning of the 1st century BC, and then, within two generations or so, it decreased again. This decrease seems to have been quite rapid and the final population might have been even five times smaller than during its highest density. This probably massive change in the first half of the 1st century BC was not restricted to the oppida only, but reflected also on the settlements in the countryside even in wider European context [2]. Causes for gradual trend of depopulation can be seen in several factors both endogenous and exogenous: political factors (e.g. massive emigration in reaction to the military events), economic / commercial factors (e.g. difficulties on long distance commercial routes), organizational factors (e.g. insufficient workforce to perform necessary tasks caused by previous famine or plague) or ecological / subsistence problems. However, their analysis is obstructed by the overall lack of detailed archaeological data. In this situation building of explanatory models is the only valid way of exploring the complexity of past societies.

This paper presents a method to ascertain the resilience of the food production system (i.e. the carrying capacity) of the oppida under the dynamically changing (increasing/decreasing) population. The model integrates multiple parts with different methodology: the cellular automata and system dynamics components are used to explore and test various general theoretical hypotheses related to the functioning of the settlements within a particular landscape environment and the ecological and economic rules that are shaping them, the agent-based component enables enhancing the model with individuals (agents) having variety of behavioural patterns (e.g. households living in a particular environment). The models are based on domain knowledge and general palaeodemographic patterns of birth-rates, mortality and migration. We intend to demonstrate the ability to move from a static data set (archaeological and environmental records) to dynamic modelling that incorporates feedback mechanisms, system integration, and nonlinear responses to a wide range of input data. We developed the population dynamics model and the subsequent food production model. The simulation of synthetic population (size,

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structure and subsistence needs) is accompanied by the model of agricultural practices with the aim of investigating the sustainability of the long-term means of production and means of subsistence. Results obtained with the simulation demonstrate limits of the sustainable economy practiced by a constantly growing population under particular environmental and societal settings. This approach can help to analyse past socio-economic processes, determine possible crisis factors and understand ecological and cultural changes. The immediate or gradual impact of the success rate in the food production and its potential influences on the economic and social processes are also addressed.

II. Late Iron Age and its Economics

The economy could be explained partially as a response to environmental conditions and climate; economic development then can be seen as an adaptive system to the balance of the ecological factor. However, neither the economy nor society is determined solely by the limits of the environment [3]; social and political factors also played an indispensable role. Therefore, an analysis of the subsistence strategies during the late Iron Age is as much a social and political study as it is an economic one. As such it can eventually help to understand the dynamics of the development in the second half of the 1st century BC and explain the "collapse" of the complex system represented by the oppida and their hinterlands.

The whole Iron Age world despite its technological innovations, specialization and economic contacts, or its level of complexity, was still principally a world of the common farmer. The organization of food production and its redistribution is an essential factor for understanding the complexity of the society and for determining its limits. Every type of society has a characteristic way of the flow of resources and commodities through it, and the organization of transforming these resources to products [4]. The major aspect in the food production is the significance of agriculture as the primary source of subsistence and organization of potential surplus production. For the socio-economic development, the key aspect is the principle of redistribution of surplus between the consumption and investment. In terms of the technological and economic progress, which contributes to social complexity, the surplus needs not be spent, but accumulated for further investment. When a certain level of complexity within a society is achieved, and seasonal tasks somewhere allow engaging in non-agricultural activities and at the same time a regular supply of necessary foodstuffs from elsewhere is provided, regional differences (in terms of specialization) occur [5]. Such aspects and their mechanisms in the Iron Age are still being discussed. A traditional argument in these discussions concerning the level of complexity in the late La Tène society is that the central places were set in their environments as so called "total consumers" (e.g. [6]). That generally means that they were too "specialised" and hence engaged in other activities, so they were not capable of producing any foodstuffs. This fact should have eventually contributed decisively to the "collapse" of the La Tène society in the 1st century BC. Some of these settlements surely had to overcome or accept some environmental constrains (imposed for example by higher altitude) or were forced to adapt their subsistence practices (e.g. develop an alternative approach to the exploitation of land). There are several proofs providing support to the notion that the food production was an inseparable part of the oppidum´s life. The evidence is in fact abundant: numerous livestock, agricultural tools, storage facilities, archaeobotanical and pollen analyses etc. ([7] in print).

In the models of social complexity population dynamics and (over-)exploitation of natural resources play an important role from which wide range of social phenomena have been explained [8]. According to historic sources, exceeding the appropriate carrying capacity was not a rare occasion in history (cf. [9]) even in societies with developed market networks. Intensification of the production led to innovations in the agriculture on one hand but also to a more rapid depletion of the land resources especially where their extent was limited on the other. This prompted behaviour, which could have led to more profound social change at the end of the Iron Age in central Europe.

Our case study location is the oppidum of Staré Hradisko in Bohemia. The model is focused on the oppidum´s own agricultural production, i.e. a society pursuing agro-pastoral activities within the given temporal and spatial scale which is tested against subsistence, surplus production and carrying capacity factors. We aim to explore the dynamics of the food production and isolate possible crisis factors imposed either by environment or by unsustainability of the economic strategies pursued. The modelling questions being asked include:

1. Using what cultivation strategies can the population most effectively exploit natural resources in order to be self-sufficient?
2. What are the dynamics of production with constantly growing or declining population (subsistence –surplus – success rate-diminishing returns)?
3. What is the maximum population that can be sustained in a given environment and when is this maximum reached?

III. Scenarios and models

When thinking about the computational models of the Iron Age society and landscape, either we can start with the population data and explore the predicted site catchment, or we can use the landscape data and estimate the likely population in the given area. Our basic idea is to develop the population dynamics model firstly.

NetLogo was used for creation of agent-based and cellular-automata models. The agent-based apporoach is applic-

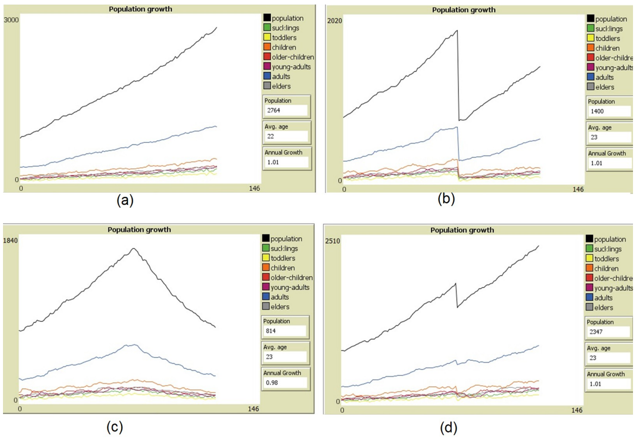

Fig. 1 NetLogo model of population dynamics: (a) baseline, (b) sudden depopulation,(c) gradual depopulation, (d) epidemic

able in case the individuals can be identified (inhabitants of the oppida in our case), cellular automata approach is suitable for land use modelling using GIS data (land allocation in our case). System dynamics modelling software Stella was applied for implementation of the aggregate models where system of stocks and flow capture both the changes of the population structure and the food production.

A. Population Growth and Decline

The population dynamics model generates the synthetic population of the settlement, including optional population decline and structural changes. Different depopulation scenarios have different reasons and consequences. Synthetic population corresponds to assumptions based on archaeological evidence.

The population dynamics is defined by the initial population, its growth rate and death rate. In our case of the oppidum Staré Hradisko in Bohemia, the initial population is estimated to be between 600-800 individuals. For establishing the appropriate birth rates and life expectancy during the Iron Age the regional model life-tables created by Coale and Demeny for the ancient Roman population [10] are the most relevant source of information about the population dynamics. We used the Model Life Tables Level 3 a 6 West. To complete missing values in the tables (as they were in 5-year intervals), the Elandt-Johnson estimation method [11] was applied. The constraints to be satisfied are approximately constant ratios of male/female and ratio of age categories. The model outputs are time series of the synthetic population data (i.e. numbers of individuals and the consumption of the population in calories) representing (1) the energetic requirements of the population, and (2) the availability of the human workforce, i.e. actual number of people in productive age in particular age/sex categories (two main categories were distinguished: "strongforce" - males and young males who can perform heavier task such as ploughing, harvesting with scythes, forest clearance etc. - and "weakforce" – females, older children and elderly, who can pursue other tasks, such as sowing, hoeing, weeding, manuring, milking, various assistance tasks etc.) for the period of 120 years.

In order to reflect the population decline of the oppidum four (de)population scenarios are formulated (see Fig. 1):

1. Sudden proportional decline (*sudden depopulation*) is a massive one-time depopulation of 30-60 percent of the inhabitants. It is naturally accompanied with the decline of workforce, livestock and food storage. It corresponds to the hypothesis of the emigration of the part of the population in the 1st half of the 1st century BC.
2. Sudden non-proportional decline (*epidemic*) is a massive one-time depopulation of 30-60 percent of inhabitants, more conspicuous in certain age groups (suckling, toddlers, children, elderly). It causes significant workforce decline during the following decades.
3. Continuous proportional decline (*gradual depopulation*) is less extensive but continuous depopulation of 3 percent of the oppidum´s inhabitants per year. It corresponds to the hypothesis of continuous emigration beginning in the 1st half of the 1st century BC.
4. For comparison, normal growth of the population (*baseline*) is defined. In this case the population grows by 2 percent annual increment (cf. [12]) up to 2500-3000 individuals. This scenario corresponds to the stable situation without any adverse events.

The increasing population trend should be reflected in models of food and fodder production (i.e. the spatial change in the field, pasture, and forest area) as well as in the numbers of livestock. The population dynamics model was implemented in NetLogo (see Fig. 1 for outputs) and reimplemented in system dynamics in order to test the model logic.

B. Food Production and Agricultural Practices

The purpose of this model is to compare agricultural strategies likely to be employed by the oppidum's population in relation to the necessary land-use area and ratio of the population engaged in agricultural work. The food production model applies population modelling outputs (i.e. time-series of synthetic population and its consumption based on caloric tables) together with authentic archaeological and environmental records of the region. The model represents the oppidum located in a gridded landscape (modelled using GIS). The individual cells are allocated topographical (slope, wetness, hydrology), land-use suitability (vegetation, soil productivity), and economic (distance from settlements, distance from water sources) variables.

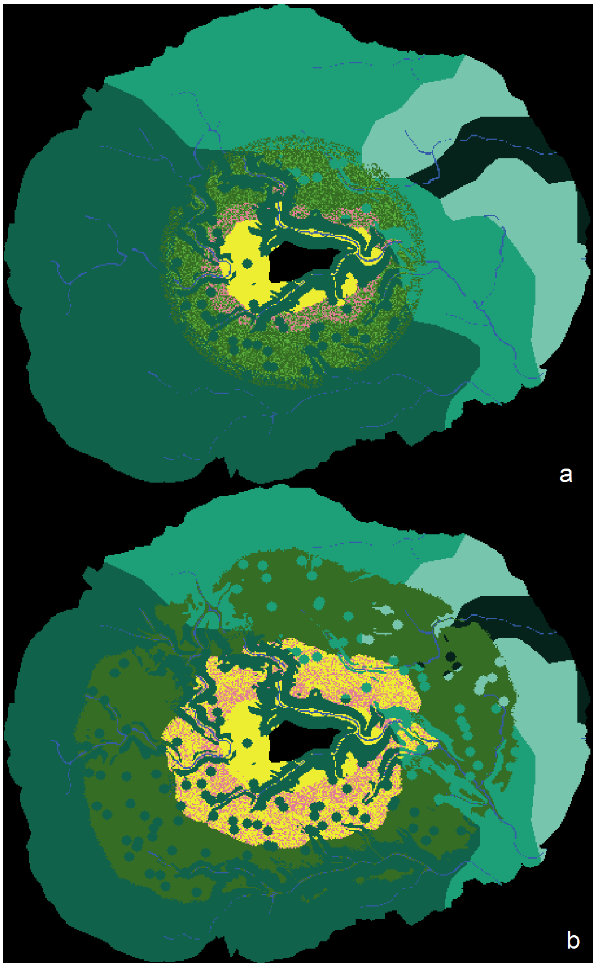

Fig. 2 NetLogo food production model: landscape around the oppidum, cereals and pulses; year 1 (a), year 120 (b)

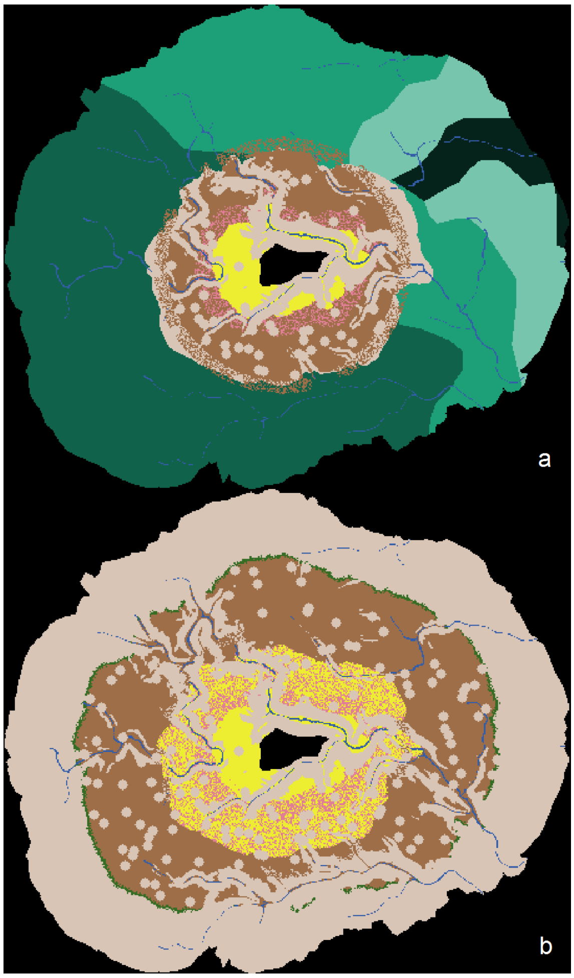

Fig. 3 NetLogo food production model: landscape around the oppidum, fields and fallows, grassland and forest pasture, year 1 (a), year 120 (b)

The evidence of agricultural activities carried out by the oppidum inhabitants can be indicated by particular material groups, archaeobotanical and archaeozoological assemblages, and settlement features (especially storage facilities) [7].

The method of Site Catchment Analysis was used for the modelling of the oppidum's hinterland. Site Catchment Analysis approach is based on models of economics and ecological energy expenditure, and provides a framework within which the economic activities of particular site can be related to the resource potential of the surrounding area. We thus needed to delimit the easily accessible area in the site's surroundings, which would have encompassed fields/fallows, pastures, meadows and managed forests. Considering the locational rules of the "least effort models" and the variable topography, the area was modelled as cost distance according to walking speed from the centre – the oppidum. This roughly corresponds to a distance of 4-5 km generally considered as a threshold for the travelling on a daily or semi-daily return.

The criteria for the prediction of fields were related to the environmental variables: topography, soils, and climate. The fields had to be placed on fairly moderate slopes - less than 5°, 5-10° and 10°-15° respectively. The pastures had to be on slopes less than 30% and within an accessible distance from the water source. Together with the other variables "soils" (quality, depth, rockiness), "topography", and "wetness" (the topographical tendency of the particular grid cell to be more or less wet) it was put together through the Multi-Criteria Evaluation analysis [13] by which different field suitability categories were created. The plots

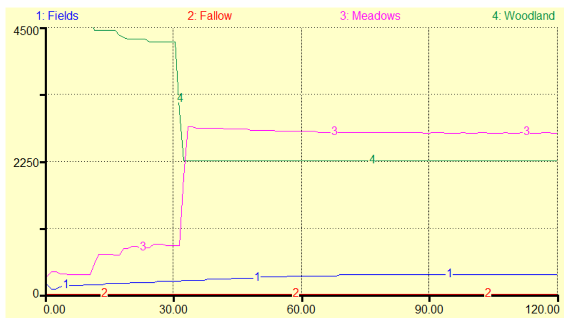

Fig. 4 Stella model of land-use units and their changes during 120 years

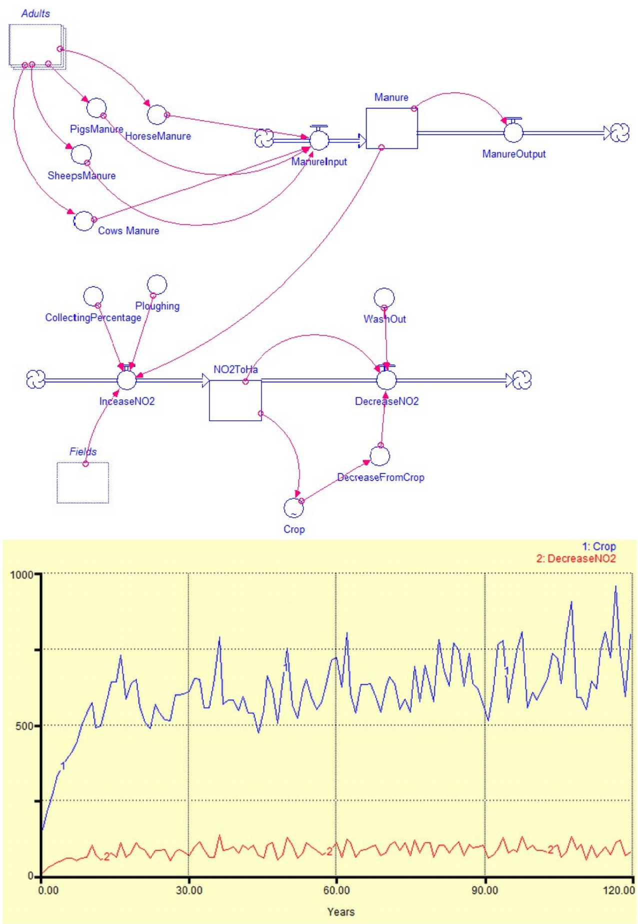

Fig. 5 Stella model of dynamics of nitrogen cycle – diagram in Stella and output

classified as unsuitable (too wet, too rocky or on slopes too steep) were excluded from the field and pasture suitability model. One of the crucial factors for the prediction of both fields and pastures was the accessibility from the settlement. Therefore most suitable areas were plotted as the most fertile zones located as close as possible to the settlement. A cost penalty was included for fields exceeding the distance of 2 km (cf. [14]). This option applies especially for more intensive regimes of land-use; the cost impact was lower for the fields under the extensive practices. Fields within distance zones could have been subjected to different land-use and management - more intensive closer to the oppidum and more extensive further away in terms of infield and outfield management). The terrains which remained can be attributed to forest pastures, forest openings and woodland.

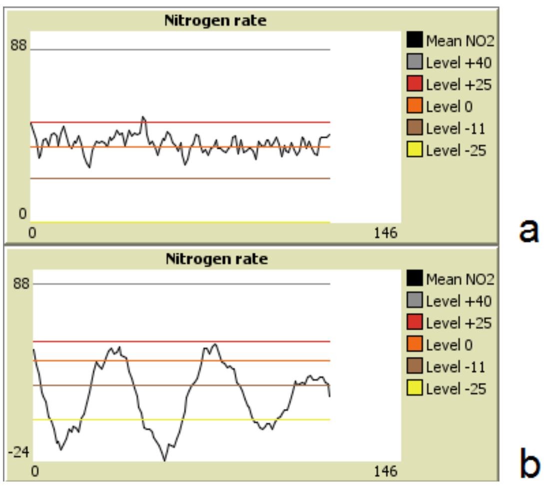

Fig. 6 NetLogo food production model: nitrogen rate for intensive strategy, with normal (a) and gradual (b) manuring

The default presumption for the model is that each household that cultivated the fields used animal traction. The actual area of fields, as well as the labour input per unit area, varies greatly according to the number of inhabitants and different arable farming strategies employed. With higher yields during an increasing intensity of cultivation, the area of fields could have decreased and vice versa. High annual harvest fluctuations are apparent in modern agricultural experiments (e.g. [15], [16]. [17]). Variable annual yields are also being regularly mentioned in the historic records (cf. [3], [18]). Therefore, using the mean yield estimation in archaeological modelling would provide only a static indication of production. A relative structure of inter-annual fluctuations in the ancient crop yields from a particular area may be established by extrapolating from modern or historical data, preferably from the same region and without estimating any absolute mean value ([16]. [19]). A general range between 500 – 3000 kg/ha (mean value 1500 kg/ha for the intensive and 1000 kg/ha for the extensive strategy respectively) [7] can be considered as the suitable variance of general yield variability, derived from the information on local environmental and climate conditions, the reconstructed scale and intensity of farming (by “intensity” it is understood the amount of labour input required to process one unit area of land) and production targets (from small subsistence needs to surplus production requirements).

The essential hypothesis supposes the continuous growth of both the population and food production. As precondition, we defined resource levels of the ecosystems (i.e. productivity of the land), productivity potential of the population exploiting these resources (i.e. labour input, technology and task management) and tested if and under what conditions certain resources could become limiting factors, and what implications could be derived from that (e.g. adoption of new subsistence strategies, new technologies, commercial contacts, social transformations, settlement abandonment etc.).

The inputs of the food production model are:

- population data for various scenarios (1 – 4),
- GIS data for the location of land-use units (maps with specifications of distance from settlement and streams, hydrology, soils, vegetation cover, slope and wetness index),
- diet specification (e.g. the ratio of cereal vs. protein part of the diet),

- strategy and work allocation settings (e.g. intensive or extensive agricultural strategy, manpower per land unit and per activity).

The following agricultural strategies are assumed to have been possibly practised by the Iron Age population:

1. *Intensive farming* on small plots: fields were manured namely by stable dung and settlement waste; they were intensively tilled by hand, and weeded. Working animals could be used for ploughing; rotation of crops (cereals, pulses) was practiced. Intensive farming strategy represents the labour demanding option, which tends to be limited in scale or to cover only the subsistence and necessary surplus needs.
2. *Extensive farming* on large plots: fields included fallows and were managed less intensively. They were manured especially by grazing animals. The plots could be usually under continuous cropping (i.e. no crops rotation) as the periods of fallow allowed for the sufficient regeneration. An extensive strategy could have been employed especially when the available land was abundant, population pressure low, labour was engaged elsewhere, or it was more preferred than the intensive production. With this strategy the potential for surplus production was higher, but could fluctuate heavily.

Both strategies could be combined in terms of infield and outfield land management in order to balance the work/land requirements.

There are different consequences and constraints. Higher cereal consumption requires more intensive growing with ploughing and manuring; intensive manuring requires higher numbers of livestock; more animals require more working hours. Total manpower has to be allocated according to the appropriate sequences of agricultural activities and their timing during the year (seeding, harrowing, ploughing, harvesting or manuring).

Typically, bigger populations have higher consumption requirements, benefit from higher manpower and manage larger areas. If additional land units were required for crop production or livestock grazing, appropriate part of the original woodland has to be cleared and thus changed into the arable land or pastures. The spreading and spatial organization of the site catchment is naturally shaped by accessibility (in model represented by friction surface modelled from local topography). If the limits were achieved, population adapts. Either part of the population leaves, or the food production and/or diet composition has to be changed. The model contains several submodels, reimplemented using system dynamics in order to test the model logic and mathematical operations:

Land-use strategies (Fig. 4.): the model reflects the change of the original, mostly forested landscape into individual land-use categories basing on the population density, number of livestock and agricultural strategy chosen.

Nitrogen cycle: (Fig. 5, 6) – the model aims to test the cycle of nitrogen in soil and its impact on the crop production under both intensive and extensive strategy. With the intensive strategy the nitrogen is applied with farmyard manure from animals stabled per nights and during the winter months. Under the extensive strategy the nitrogen is applied by livestock grazing the fallows and biomass decomposition in the grassland pastures. Two logics were applied in the system dynamics modelling – either immediate or gradual releasing of nitrogen affecting the soil fertility for the following harvest (Fig. 6.).

Livestock: the model tests number of livestock in relation to the population density, birth rates and mortality patterns (natural mortality and slaughtering rates in order to maintain the reproducibility of the oppidum´s herd) as well as the milk production and fodder requirements. Individual models are created for cattle, horses, pigs and sheep/goats respectively (Fig. 9).

Similarly to the population dynamics model, four scenarios were specified:

1. *Sudden event: lost harvest* – the crop is damaged either by floods or droughts. The consumption requirements are not covered sufficiently, therefore the population is expected to adapt to the situation.
2. *Sudden event: lost animals* – it can be caused by disease or theft. The meat and milk calories are not available and/or the ploughing oxen cannot be used, therefore the arable land is affected and the agricultural strategy has to be modified.
3. *Sudden event: fire* – the crop is destroyed including the storage (reserves from previous one or two years, seed for the next season), the populations is expected to adapt.
4. *No event (baseline)* – no unexpected events happen, i.e. the food production is not affected by inauspicious weather, fire etc. If the population grows, the food productions grew correspondingly up to the limits of the map.

The food production models apply synthetic populations data (i.e. time-series of number of inhabitants and their consumption based on caloric tables) together with authentic archaeological and environmental records with the region. As precondition, we defined resource levels of the ecosystems (i.e. productivity of the land), productivity potential of the population exploiting these resources (i.e. labour input, technology and task management) and tested if and under what conditions certain resources could become limiting factors, and what implications could be derived from that (e.g. adoption of new subsistence strategies, new technologies, commercial contacts, social transformations, settlement abandonment etc.).

The food production model captures the dynamic of agro-pastoral economy process (the oppidum's own agricultural production) in recurrent year-to-year cycles which is tested

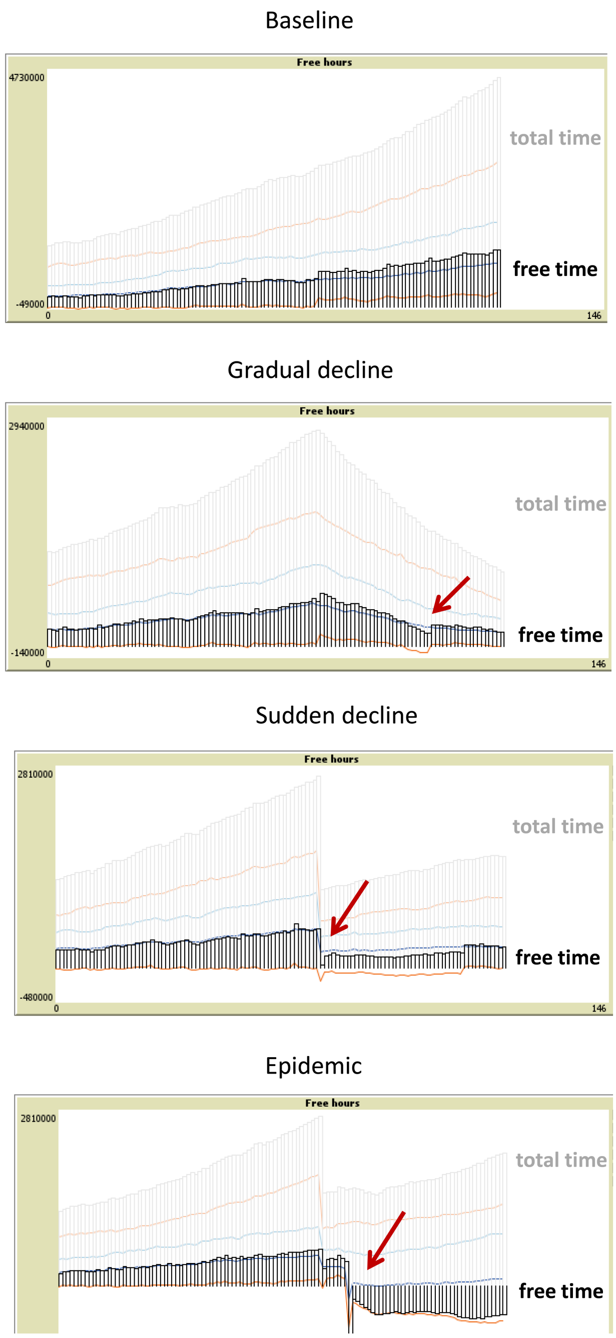

Fig. 7 NetLogo food production model: labour input for depopulation scenarios (female labour includes domestic work, as a default 10% is allocated to the "non-producers")

against subsistence, surplus production and carrying capacity factors. For each year, certain mixture of main land uses (intensive agriculture, extensive agriculture, grazing livestock and deforestation) is applied. The changes of the food storage make population to adopt to new conditions (to change the mixture of land uses). Results obtained with the simulation demonstrate limits of the sustainable economy practiced by a constantly growing population under particu-

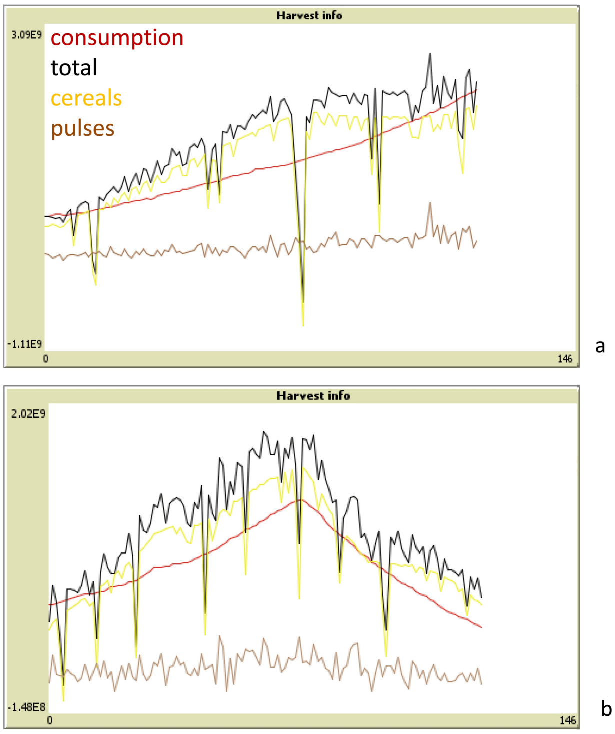

Fig. 8 NetLogo food production model: harvest for baseline (a) and gradual depopulation (b)

lar environmental settings and effect of decreasing population due to emigration and epidemics.

By including the social variables representing farmers' independent decisions to change from one economic strategy into another (or to adopt new ones) in order to cope with worsening conditions of the sustainable agricultural

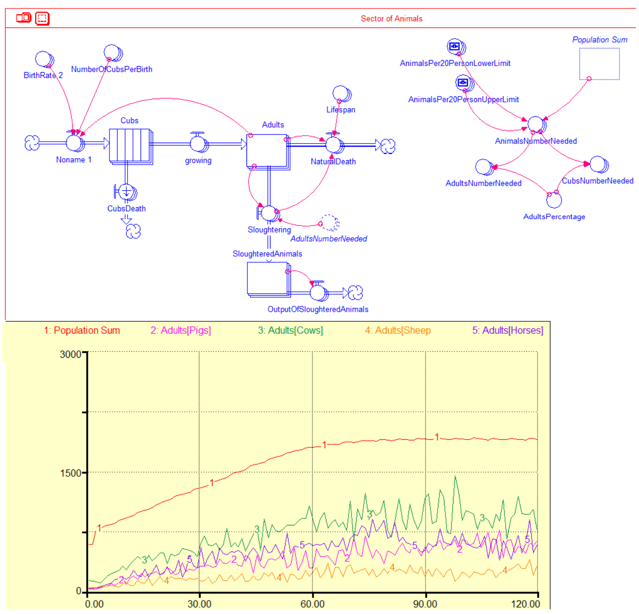

Fig. 9 Stella model of food production: livestock management

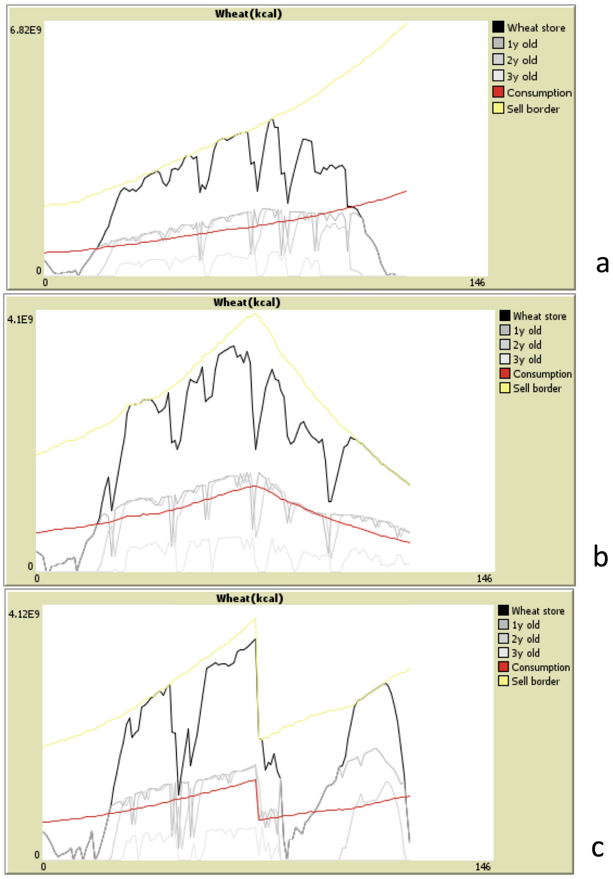

Fig. 10 NetLogo food production model: wheat storage for baseline (a), depopulation (b) and epidemic (c)

practice, the model approaches the complexity of the Celtic society.

IV. Results

A. Sustainability

Several major "events" ("destruction of crops", "destruction of storage", "livestock loss") were implemented in order to test the resilience of the agricultural system. Dense aggregated population in a *Baseline scenario* exhibits problems towards the end of the occupation due partly to the inability to cope with diminished food reserves and partly due to advanced depletion of natural resources. Profound deficit in covering the oppidum´s subsistence needs occur which has to be solved by change of agricultural strategy, external food supplies, or emigration. *Population decline scenarios* and *Epidemic scenario* on the other hand show that diminished population has higher chances to catch up with the previous sustainable level of production (Fig. 10, 11).

B. Land Use

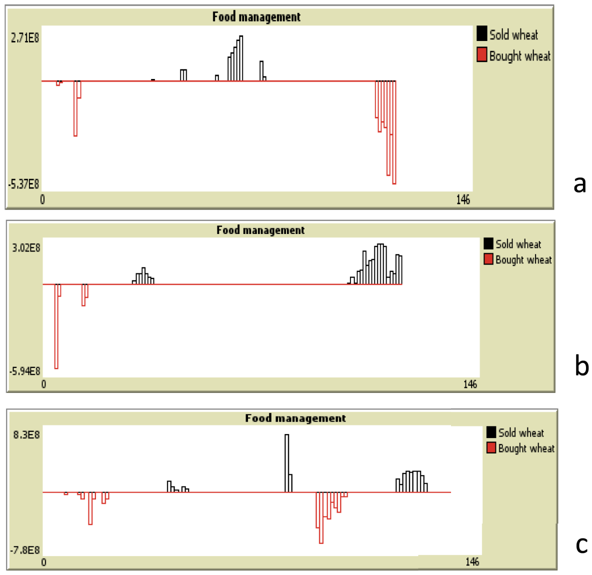

Fig. 11 NetLogo food production model: surplus (black) and deficit (red) for baseline (a), gradual depopulation (b) and epidemic (c)

Depending on the either intensive or extensive strategy chosen, the landscape is covered by the mosaics of fields and pastures gradually verging into the managed forest. With the intensive strategy the livestock has to graze in the forest or, in case of work capacities allocated to forest clearance, on grassland pastures (Fig. 2, 3, 4). With the extensive strategy the livestock is mostly left to graze the fallows. All the population decline scenarios show similar outcome to the landscape – only the infield plots are still managed intensively. Baseline scenario shows clearly the limit of the predicted catchment: by the final years of the simulation the oppidum usually runs out of the area available for pastures. In this case the possible solutions include change of economic strategy, decreasing the number of animals, enlarging the catchment or emigration. The nitrogen cycle submodels capture the influence of manuring (Fig. 5, 6).

C. Labour Input

Fig. 7 shows varying human workforce availability under the different scenarios applied. Graphs always show total time (all the working hours available within the oppidum population) and free time (hours beyond the food production tasks available for other activities such as crafts and trade). Within the Baseline scenario the amount of free time increases proportionally to the total time available. Gradual decline scenario copies the declining curve of the total population. While the free time drops within the first generation after the decline it soon catches up to the proportional amount. Both Sudden decline and Epidemic scenarios show difficulties of the oppidum population in coping with diminished working capacities of both people and animals (i.e. ploughing oxen). Epidemic scenario shows delayed impact of the disease affecting particular age groups (especially children) at the time.

Available free time amount expresses the opportunity to spend these working hours by different activities nonrelated to the food production that means more room for specialisation in crafts, trade and other social and cultural activities. This parameter thus reflects in a simple way the potential level of complexity of the oppidum´s society. The more free time the more the society can be complex and vice versa. Decrease of the free hours means more people are necessary to perform basic food production task and less people were available for other activities much less be the non-producers. Both scenarios of sudden decline and to a certain level also Gradual decline scenario reflect this potential decline of the once complex society.

V. Discussion and Conclusion

Results achieved can be discussed in the light of the framework of available data: according to the archaeological record, the settlement density in the late Iron Age in Central Europe increased over some time and then decreased again rapidly. The Population dynamics model provides realistic time series of energetic requirements, workforce availability and age distributions of population of the oppidum´s agglomeration. The modelling results showed different outcomes of the economic strategies performed by either growing or declining population.

The limits of the land-use strategies returned from the *Baseline scenario*, when the population was expected to react by adjusting their economic strategies, started acting around the population density being around 2000-2500 especially due to the depletion of resources (i.e. available field, forest and pasture plots) within the predicted catchment. When experiencing population growth, the households had to work harder in order to keep their life standards, due to the law of diminishing returns ([20] - 1). This concept refers to the fact that while the population increases exponentially, the growth of subsistence resources is only linear and generally slower. As the population approaches the carrying capacity, the production level gradually declines. This means that when reaching the carrying capacity threshold, the surplus becomes zero, and upon further population growth it becomes negative. At this point, the population faces a lack of resources for its reproduction and its density must decline ([20] - 8, 10, Fig. 1.1a) or their subsistence strategies must be adapted to the new situation. Such adaptability processes may include changing the extensive cultivation practices into more intensive land use regimes (i.e. cultivating land with higher labour input on smaller area) or a change in economic preferences to stock farming or craft industries.

What the results show is, since the adequate oppidum population (living from their own resources) was able to exploit environmental resources around the oppidum without simultaneously exhausting them, a rapidly growing number of inhabitants could – at some point - cross the limits of the sustainable agricultural production and experience several stress situations. Especially for the labour intensive scenario, the model resulted in diminishing returns from the cultivated land as the cost of farming more distant field increased. By the population peak, the gradual depletion of stored reserves resulted in a supply crisis, which must have provoked a strong social response. This evolution can be a typical development towards societal decline following the distinctive upsweep accompanied by rapid population growth especially in the environment where the market economy was not an everyday routine ([20], [21]). If the population growth would have reached this maximum value after first 80 – 90 years (due to massive immigration for example), that could be the realistic interpretation of the occupation´s decline.

However, according to the archaeological record the population started decreasing after 70-80 years (*Sudden decline*, *Gradual decline* and *Epidemic* scenarios). With such a demographic profile, the oppidum´s community could in fact practice all land-use strategies without any substantial problems apart from those imposed by natural harvest fluctuations due to weather, accidents (fire, deceasing of the livestock), and other socio-economic (raids, theft) factors.

In our models it has been proven by experiments that not all of the oppidum´s population had to be engaged in the agricultural work. There is an archaeological evidence of elite members, which, presumably, were not involved in the agricultural production. Increasing and/or decreasing amount of free time represents in fact the level of society´s complexity and its changes reflect decline of this complexity connected to the loss of the production potential. The labour shortage may also point to the necessity of using the external supplies.

VI. Future Directions

Future studies will build upon the presented models, especially on their share-ability and applicability. The applied approach can be adapted for other regions, other time periods and other economic strategies can be explored.

Our further research is focused on network analysis and network-based modelling of interactions between the oppidum and open village settlements and between individual settlements (i.e. food and raw resources circulation through social contacts). Network analysis (see e.g. [22]) is planned to be used for the interpretation of the data from the sites and for exploration of questions associated with cultural diffusion, settlement hierarchies and regional aspects.

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How real estate agents behavior affects urban growth: an agent-based model approach

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Abstract*—During the early 2000s Spanish territory has suffered major transformations due to fast urbanization. The main actors involved on this process are: urban planners, real estate agents and population. This paper presents an Agent-Based Model (ABM) which simulates the behavior of those three agents in order to better understand how the interaction of those different actors contributes to the process and produces changes in the territory in the form of urban growth. This study is applied to the Corredor del Henares, an area of 18 municipalities at Madrid Region in Spain. The paper presents the overall model with particular focus on the behavior of Real Estate Agents. Preliminary results suggest the model is capable to produce realistic scenarios and, thus, help to improve the understanding of the dynamics of urban growth in Corredor del Henares.

I. INTRODUCTION

The present paper studies the process of urbanization and urban growth in Spain. Urbanization in Spain can be described as a three-stage process involving three types of actors: urban planners, real estate agents, and population. The process starts by the choice for new urbanizable areas by urban planners following national, regional and local policies. On a second phase, real estate agents will chose where to promote new residential developments. Finally, the population will select their places to live based on their individual preferences and according to their income possibilities.

In order to better understand this urbanization process, we introduce a model that simulates this process using Agent-Based Modeling (ABM) techniques. ABM is particularly suitable for this case because it allows each of the actors' behavior to be simulated individually as well as how they, together, produce changes to the territory in the form of urban growth. ABM has been often used for urban growth simulation, mostly applied to local level (for examples, see [1] [2] [3] [4] [5] [6] [7] [8] [9]), although some few examples of application at sub-regional level can be found (see [10] [11] [12] [13]).

The present study simulates the urban growth process in the Spanish region called *Corredor del Henares*. This subregional area, composed by 18 municipalities, had a phase of very rapid urban development during the housing bubble in the late 1990s and early 2000s, in particular along the transport lines (motorway and railway) which links Madrid to Guadalajara. In addition to the strong influence of the city of Madrid, the complexity of the dynamics of urban growth in the area is increased by the large number of municipalities regulating the development as well as conflict between urban development and conservation of protected environmental areas in specific locations within the region.

The next section will present the model for urban growth in the *Corredor del Henares* with particular focus on the simulation of Real Estate Agents. Hence, the next section presents the integrated model, followed by a more detailed section on the submodel of Real Estate Agents.

II. AN ABM MODEL FOR URBAN GROWTH IN THE "*CORREDOR DEL HENARES*"

The model developed in this research consists of three independent but integrated submodels, each simulating the behavior of one of the three actors of the urbanization process in Spain: urban planners, real estate agents, and population.

The first submodel simulates the ***Urban Planner*'s** decision-making process, which consists of selecting new areas to be urbanized according to physical restrictions (i.e. protected areas, high slopes, proximity to hydrographic bodies), distance to elements of interest (i.e. roads or consolidated urban areas), and the amount of growth required to attend existing demand. These criteria are set as parameters and can be modified at initialization to generate different scenarios.

The second submodel focuses on ***Real Estate Agents*** decision making process on building new residential developments. As part of their behavior they must decide where to build new developments, how many developments must be built, their size, and their target economic group. The decision making process takes into account the legal status of the territory (defined by Urban Planners in submodel 1) as well as the areas which optimize their profits. This submodel will be further detailed in the next section.

This work was not supported by any organization

The third submodel simulates the process of residential location choice and occupation by the ***Population***. In this case, they look for the best place to move according to their economic restrictions and location preferences, such as distance to public transport network, education facilities, and so on.

The flowchart in Fig. 1 shows how the submodels are integrated, where the result of each submodel feeds into the next, in a chain-like process.

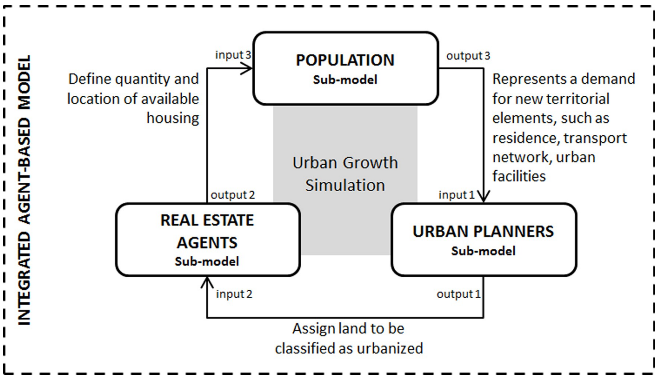

Fig. 1 Integrated decision model to simulate urban growth

III. Housing development submodel (Real Estate Agents)

As mentioned, the submodel of Real Estate Agents behavior aims to simulate the development of new residential buildings. Their aim is to maximize profit and, as such, to create new residential developments that are attractive to potential buyers. This is achieved by selecting specific locations as well as building to the standards of the targeted economic group (high, medium and low). The current version of the submodel assumes all real estate agents have the same behavior but different behaviors will be incorporated in the next stage of the model development.

The set of criteria used by agents to select a location to build residences is presented in Table 1, below, and includes attributes such as zoning, housing standard, density, and distance to specific components. Residential developments can be targeted to high, medium or low income groups.

Fig. 2 shows the flowchart of the Real Estate Agent submodel where both the available territory after eliminating restrictive areas (A) and the agent's preferences for specific geographical location (B) are considered.

The model, developed in *NetLogo* [14], allows the creation of scenarios through the weighting of different variables, such as the status of new buildings, distances to elements of interest or social similarity with neighbors, and also through the definition of the number of new residence to simulate.

IV. Conclusion

The Real Estate Agents submodel allows the user to see the distribution of new settlements as well as have an overview of the dynamics of urban growth in the region of *Corredor de Henares*. By changing setting of parameters, the model can also simulate different scenarios, such as simulating the effect of real estate agents that have interest in developing a particular area or target a particular income group.

The model is still under development, with the final submodel (population) currently being finalized. As such, the model has not yet been validated. Once the development of all individual submodels is completed, sensitivity analysis tests will be carried out for each submodel as well as for the integrated model.

Different planning and economic scenarios (i.e. housing boom, recession) will be used to test the model's outcomes and validation will be performed with data from before and after the early 2000s 'housing boom'.

Preliminary results suggest the model is capable to produce realistic scenarios and, thus, help to improve the understanding of the dynamics of urban growth in the *Corredor del Henares* region. The model has potential to support future territorial decisions in the region and, thus, fulfill the main potential of ABM applied to urban studies at a sub-regional scale.

Table I.
Variables that lead the decision process of Real Estate Agents

Computer	How variables are incorporated in the model
Zoning	Classification of urban and developable land, that must be recognized by Real Estate Agents in order to find legal areas to build new residence
Housing standard	Distribution of different type of residential buildings (high, medium and low standard) according to their square meter average price
Density	Definition of collapsed areas and the occupation capacity of the existent or new buildings
Urban Consolidated Areas	Considered an element of interest in some cases, since the demand for new residence is sometimes higher on areas closer to urban centers
Public Transport Network	The proximity to public transport network is also included in the preferences of a group of people in order to choose where to live
Road Infrastructure	New development should be close to road infrastructure in order to be more attractive to a group of population

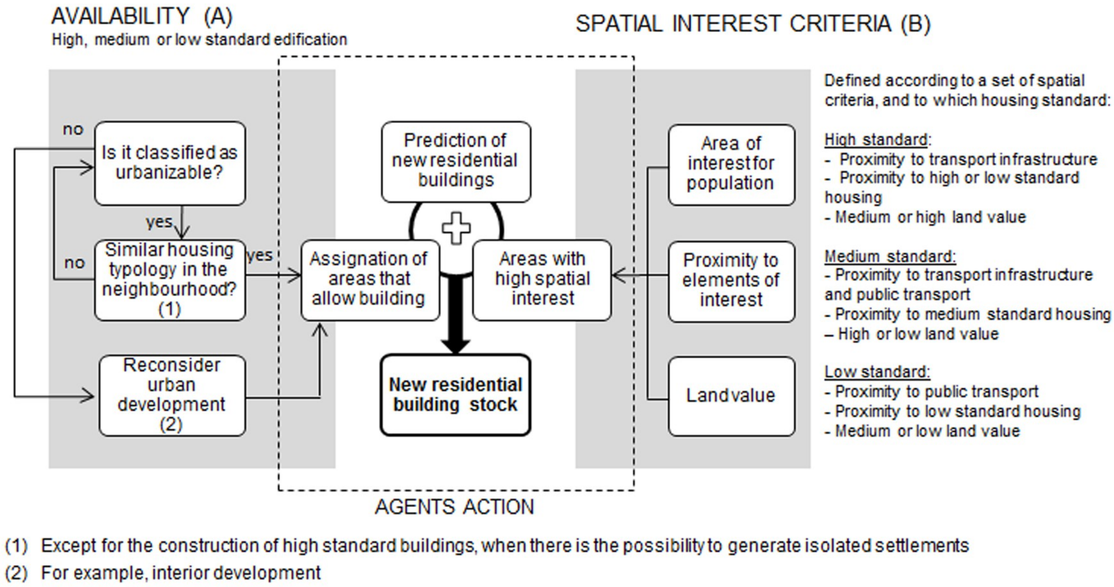

Fig. 2 Logic model of Real Estate Agents´ decision process

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Agent Activation in a Replication of the Zero-Intelligence Trader Double Auction Market Simulation

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***Abstract* - A model of a double auction market of zero-intelligence traders was replicated as an agent-based model using the same market supply and demand curves. The original results were reproduced, and these results and other behavior of the model were examined under different schemes of agent activation, both exogenous and endogenous. While the qualitative differences were typically minor, there were statistically significant differences in all the measures of all the markets in the original research and important divergence in the extended evolution of the simulation. These differences have important implications for all follow-on replications of a zero-intelligence trading model, and for the replication process in general.**

Keywords: agent-based simulation, activation, updating, model replication, standardization, market design, zero-intelligence traders.

I. Introduction

In the construction of agent-based simulations, there are a number of important design decisions that must be made, either explicitly or implicitly. Among these are model size, the presence and topology of networks among the agents, and the sequence of activation events in which agent-objects execute their methods. If the process of replicating results is to become more common, the specification of models in the research literature needs be sufficiently complete so that the same conceptual model can be instantiated by separate researchers using different code and, perhaps, a different language.

The determination of this sufficiency is an active area of research. Specifically, we examine the question of whether varying the activation scheme will result in different outcome behavior. It is most important to determine if these differences are so significant that they would affect the quality and success of the replication process.

It has been long recognized that activation can make a difference in social simulations [1], [2]. A number of recent examinations into activation for various published or suggested models have been reported [3], [4]. Collectively, this literature should motivate the examination of the impact of model design on a broad range of influential agent-based simulations. Unfortunately, the literature of such examinations is sparse.

We have chosen to re-evaluate an influential finance model – the Zero-Intelligence Trader model first published by Gode and Sunder [5]– under different activation designs to help explore the question of the importance of activation.

Finance is an area of high activity for complexity science and agent-based models. It was one of the primary motivations behind the founding of the Santa Fe Institute [6]. Agent-based models, with their many independent decision-makers, are excellent surrogates for traders in a securities market. Agents can be infused with a number of different strategies, and global information can be made available either market-wide or differentially to only select traders.

One of the simplest market models is the "zero-intelligence trader" or ZIT model. Pairs of traders are chosen from a population of traders. In the most straightforward ZIT models, traders trade a single commodity. They cannot access market-wide parameters such as the last trade price or the trade price history or even the details of their counterparty's financial position. The traders are not completely devoid of knowledge: the sellers know their own cost of acquisition, and the buyers know what future price at which they can expect to liquidate the asset. (The latter might seem a bit artificial, but is analogous to the book value of assets or the surrender value of a bond.) The simplicity of the ZIT model invites excursions on model format and design, such as studying the impact of activation.

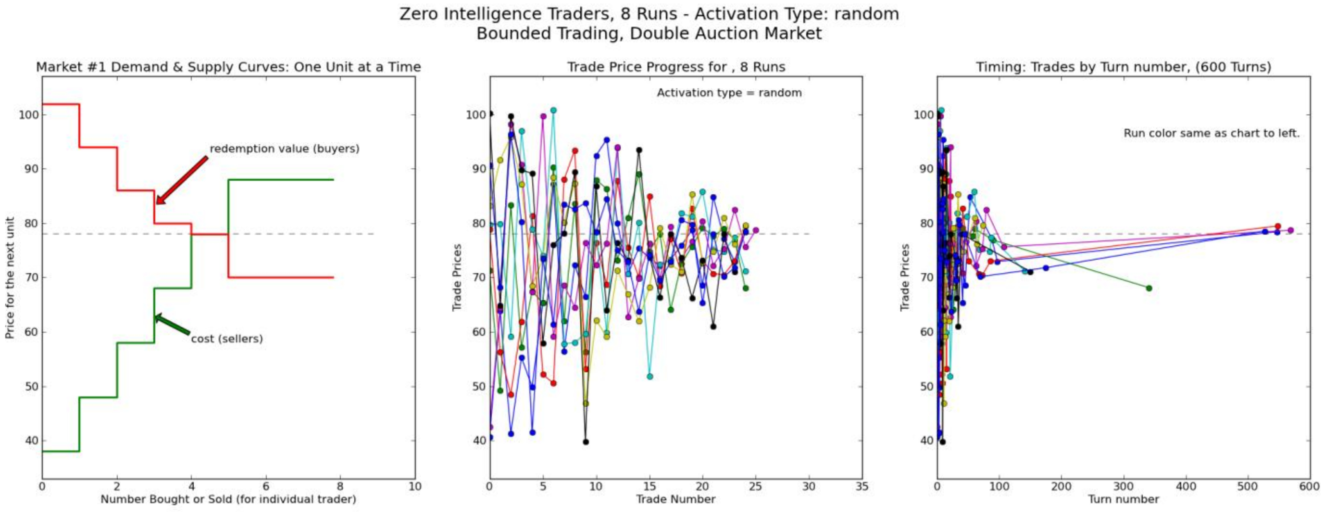

Figure 1. Market 1 Trade Price vs. Trade Number and vs. Turn

The most referenced ZIT model was introduced by Gode and Sunder [5] in an article entitled “Allocative Efficiency of Markets with Zero-Intelligence Traders: Market as a Partial Substitute for Individual Rationality.” Nearly 1200 scholarly articles referred back to Gode and Sunder over the past two decades. Researchers were initially investigating whether a rule-based double auction market simulation would show the same market success as an experimental market of actual individuals. Gode and Sunder defined success in terms of “allocative efficiency” (the even distribution of wealth) and the market would approach the theoretical maximum profit over the course of the simulation. They used graduate students incentivized by academic grade credits in an experiment to replicate profit-motivated traders. They then simulated two double auction markets to compare with the real-world experiment. A wide body of research extends the ZIT model [7], but none appear to evaluate activation.

I. BOUNDED ZIT MODEL DESCRIPTION

Both computer simulations began with a small number of traders: six buyers and six sellers. Traders trade one ‘share’ at a time. One simulation was unbounded, with the buyers and sellers making offers randomly selected between 0 and 200. The more rational simulation was termed a ‘bounded’ or constrained simulation. The buyers have a ‘supply’ curve in which the cost for their next share to be sold is determined by an escalating price curve. The sellers likewise have a redemption price, at which they may liquidate any item they buy. This redemption price curve decreases depending upon how many shares the buyers have already. After each trade, buyers and sellers calculate their profit. Buyers subtract the cost from the trade price, and sellers subtract the trade price from the redemption price. Buyers and sellers are bounded in that they are not allowed to make an offer that would lose money.

Gode and Sunder made a three simplifications to a double auction model:

- Only one unit was traded at a time.
- Once a trade took place, all outstanding offers were canceled.
- If bid and ask offers crossed (seller asked less than the best buyer bid or vice versa), the price was set by that of the earliest offer.

Buyers are informed ‘privately’ of the redemption value of each share. This value, v_i, depends on the number of shares the individual buyer has already bought. The buyer knows his own demand curve, but the market demand curve is not available to any trader. Similarly, sellers are endowed with a supply curve that represents the cost, c_i, of the i^{th} unit sold. This supply curve applies to each individual seller and the market supply curve is also not known to any trader. Each trade, therefore, created a profit. For the seller the profit is the net of the price and the cost, $p - c_i$. Similarly, the buyer’s profit is the net of the redemption value and the price, $v_i - p$. Buyers and sellers form offers at a rate and in a sequence determined by the activation scheme. All buyers have the same individual demand curve, and all sellers have the same individual supply curve. The offer for buyers is a random value between 0 and their current redemption value, v_i. The offer for sellers is a random value between their cost, c_i, and 200. This is what was meant by the bounded market. The unbounded market was also examined, but that is not considered here. (Nor is the experiment using graduate students.)

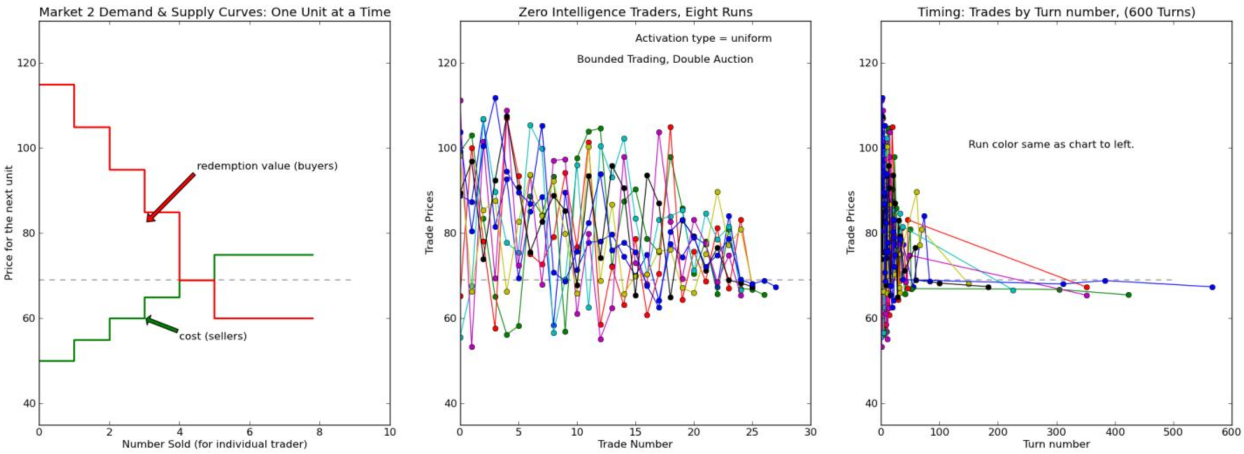

Figure 2. Market 2 Trade Price vs. Trade and vs. Turn

Gode and Sunder conducted six runs of the bounded market, with all values reset at the beginning of each run. The runs were terminated after 30 seconds. They examined five markets, or five sets of supply and demand curves. These curves were described in market-by-market graphs beside the trade price series. For the first four markets it was possible to estimate these values by inspection, but the fifth market had supply and demand curves with too fine a structure to reliably estimate. Only markets one through four were replicated here.

II. MODEL REPLICATION

Working in Python, we were able to create a double-auction model in which the traders behave in the manner described in the source article. In order to perform diagnostics it was necessary to impose some structure on the dynamic processes of the model. We introduced the concept of a turn, which we define lasting as long as one full population of traders have generated offers. A turn, therefore, is driven by events and not by computing time. This deviates somewhat from the source article, but allows side-by-side comparison of a variety of activation schemes (see below).

Once the turn in which trades take place is recorded, a price series of trades can be observed in market time instead of trade time. The Gode and Sunder paper plotted trade price per (ordinal) trade number. Thus, they did not observe the fact that later trades occurred much later in a run, after many, many offers had been made. See Figure 1 for a depiction of this dynamic behavior for Market 1.

Figure 1 also shows a number of other aspects of our market model. Instead of stopping after 30 seconds of execution, we have chosen to stop after a constant number of turns. For this graphic, we chose 600 turns, but in the full experiments we ran the market out to 5000. Even with 5000 runs there still appear to be trades taking place. That is, even after many turns and many offers are generated there is still one buyer or seller who has redemption or cost set just above or below the market-clearing price.

Figure 2 shows a market with the asymmetry in the opposite direction – a steeper demand curve and a shallower supply curve. In both cases the trades approach the market clearing price from the direction of the steepest curve. In Market 1, they approach from below because the supply curve is steeper. In Markets 2 and 3, trades arrive at the market clearing price from above because the demand curve is steeper.

Gode and Sunder were investigating how much of the rationality associated with human traders could be attributed to human decision-making motivated by profit and intelligence and how much is due to simple market discipline – the requirement that a seller can't sell below cost and a buyer can't buy above redemption value. While the bounded market's appears to be in between the random and the human market (by inspection), and the bounded market appears to converge to the same equilibrium price as the human market (determined by a regression of the bounded market curves, averaged over five runs), Gode and Sunder measured the outcome with two quantitative measures: market efficiency and wealth distribution.

In the market evolution figures the supply and demand curves for each market was determined from the reference paper, but the price time series results were from our own replication of this double-auction model coded in Python.

III. ALTERNATIVE ACTIVATION SCHEMES

In replicating this model, it was possible to postulate a broad spectrum of different activation schemes, but not all. There does not appear to be an elegant method to implement synchronous activation, in which agents' future states are stored as all agents decide, followed by simultaneous state-change. Thus, only asynchronous activation was implemented.

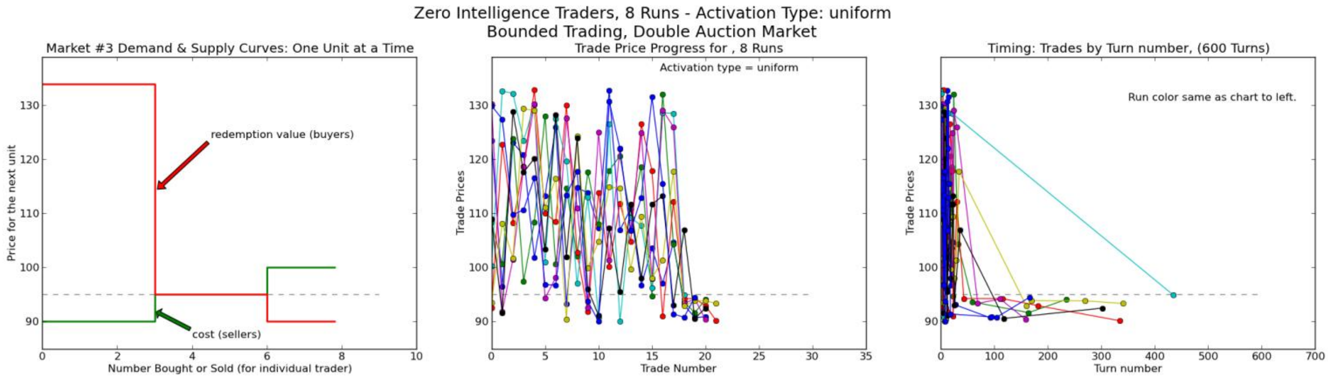

Figure 3. Market 3 (Uniform) Trade Price vs. Trade and vs. Turn

A. Random Activation

There are several suggestions in the original paper that the authors chose asynchronous random activation. Activation was just demonstrated to be important in the same year (1992) [2], [8], so it is not unexpected that Gode and Sunder would not consider elaborating on the issue.

In our instantiation, random activation merely means that traders are chosen at random from the set of all traders. These traders form an offer. A turn is defined as complete when a number of traders equal to the total number of traders has made an offer. No data points are collected at the end of one turn, and no values (other than turn number) are reset. All offers to sell or buy that are in effect at the end of a turn continue in force at the beginning of the next turn. Once a trade takes place, all other offers are canceled.

Initialization and reinitialization: On the first activation, and every time the offers have been canceled, the first trader's offer will establish the new "best offer" of that type. Thus, if a seller is chosen first, he will propose a sell price that is a uniform random variable between his cost (for this item in his inventory sequence) and the maximum of 120. A buyer will, likewise, establish the new "best buy" offer between zero and his redemption value. Trading can commence as early as the second offer.

B. Uniform Activation

Asynchronous uniform activation is executed in a manner similar to random activation. At the beginning of each turn, the array of traders is shuffled. In one turn of uniform activation, all traders will be activated. Otherwise, the trade rules are the same: offers are carried over from turn to turn, but are canceled once a trade is complete. Initialization and reinitialization are conducted in the same manner.

The trade timing plots for market 3 are shown for the uniform activation scheme. There does not appear to be any significant difference in trade timing behavior between random and uniform.

C. Poisson Activation

Poisson activation is a process in which agents are activated according to an exponential distribution with an arrival rate, λ_A. This will mean that activations for any given agent are a Poisson process. In its simplest form, a Poisson activation scheme would have all agents activated with the same λ. This, however, would merely replicate the random selection method so we explore only the case of heterogeneous values for λ_A.

Poisson activation differs from other asynchronous methods in that this variation among the agents can be based on the state of each agent or some internal parameter value. This is known as *endogenous* activation, and has been the subject of several recent studies [4], [9]. For our explorations, we chose agent wealth, which was calculated at the beginning of each turn. Thus, agent activation rates are made proportional to agent wealth values. In order to investigate the 'leveling' nature of these computer-based trading markets – a key question for the original researchers – we chose to make activation rates proportional to the absolute distance between the agent's wealth and the average wealth of the population of agents. In that way, agents that are at the extremes (rich or poor) will likely trade more often.

In order to make appropriate comparisons between Poisson activation and other activation methods, it is necessary to re-normalize all of the values of λ_A so that, on average, each turn there will be one full population of traders' activations. we accomplish this by building activation time for each agent and adding it to an 'event list'. Trader-agent activation times are drawn sequentially from an exponential distribution and each added to the previous until the times exceed 1.0. These times are then all sorted and the trader agent sequence that results from that is passed to the program as a list of activations. Offer-making proceeds in accordance with this list for a given turn. At the beginning of the next turn the values of λ_A are again calculated and another sequence is generated. The order of each turn's sequence is dependent on the current values of trader wealth and on a random draw.

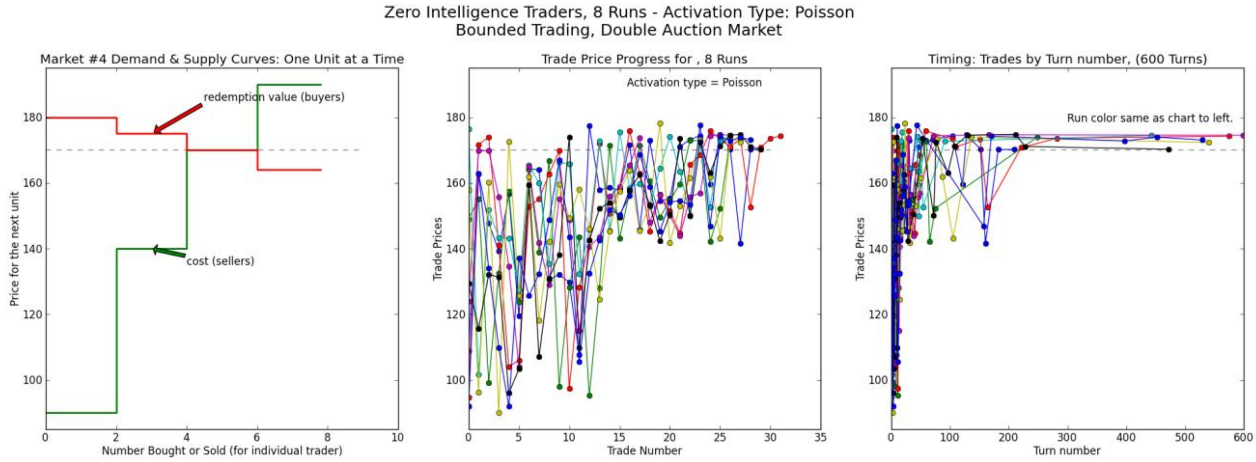

Figure 4. Market 4 (Poisson) Trade Price vs. Trade and vs. Turn

This process works well once the model is established, but at the beginning of the model no trades have taken place and, thus, traders have no wealth. In these cases the values of λ_A are merely assigned randomly (and normalized as above). Once one trader has acquired some wealth the process can proceed as designed.

The Poisson process takes advantage of the 'memoryless' feature of the underlying exponential distribution. Thus, for every trader at the beginning of each turn can treat the 'wait time' as starting anew. It does not matter, given the waiting time is exponentially distributed, how long each trader has been waiting since the last activation.

D. *Inverse Poisson Activation*

The process of activating agents faster if they are further from the average has an interesting counterpart: activation rates that favor proximity to the average. Thus, we examined a λ–setting process that slows down agent activations when the trader wealth is farther from the mean wealth. This inverse Poisson activation rate is the fourth activation scheme to be examined in the four markets.

It is important to note that the two Poisson schemes represent a conceptual departure from the other two asynchronous schemes. Both of these represent the relatively new concept of *endogenous* activation. At least one article [4] has found that this can show differences in outcome behavior when compared with the more normal exogenous activation.

IV. OUTCOME BEHAVIOR METRICS

Gode and Sunder do not rely heavily on precise quantification of the market results. This is consistent with their goal of measuring the performance of an automated market against that of a human market. They are trying to determine how much market efficiency (in profit creation and distribution) is due to the constraints of profit and loss rules and how much is due to human trading. Thus, they take the unconstrained automated market and the human market as two extremes and see where the bounded ZIT market falls. They judge that it falls much closer to the human market, but this is generally a qualitative judgment.

We chose to measure three aspects of the constrained ZIT market: its efficiency in generating wealth (or profits), its effectiveness in evenly allocating wealth among the traders, and the time it takes to reach equilibrium. Gode and Sunder used the first two measures in their paper, but left the third unexamined.

A. *Wealth Generation*

It is a straightforward matter to measure total wealth at the end of a run. One of the key (and unstated) influences on this total is the length of a run. Gode and Sunder ran a trading 'day' for 30 seconds. In our runs, we made use of the turn structure to better standardize the runs, choosing 5000 turns as a standard run.

The total wealth in the market is compared with the total *theoretical* wealth. Smith's definition of market efficiency was used [10]. Thus, the allocative efficiency of a market is the total profits earned in one run (added across all traders at the end of the run) divided by the maximum profits available. Actual human markets quickly converge to 99% efficiency. Markets only vary from this, the authors noted in 1992, when typographic errors in market orders create a distortion in the price time series. (Considering the events of the past two decades, the Gode and Sunder paper could be seen as an important early warning of such market 'errors'.)

B. *Profit Allocation*

The second metric chosen by Gode and Sunder was the profit allocation among the traders. To determine this, they calculated the cross-sectional root mean squared difference between the actual and the equilibrium profits across the traders. They defined the value a_i as the profits (or total wealth) acquired by trader i. They also calculated

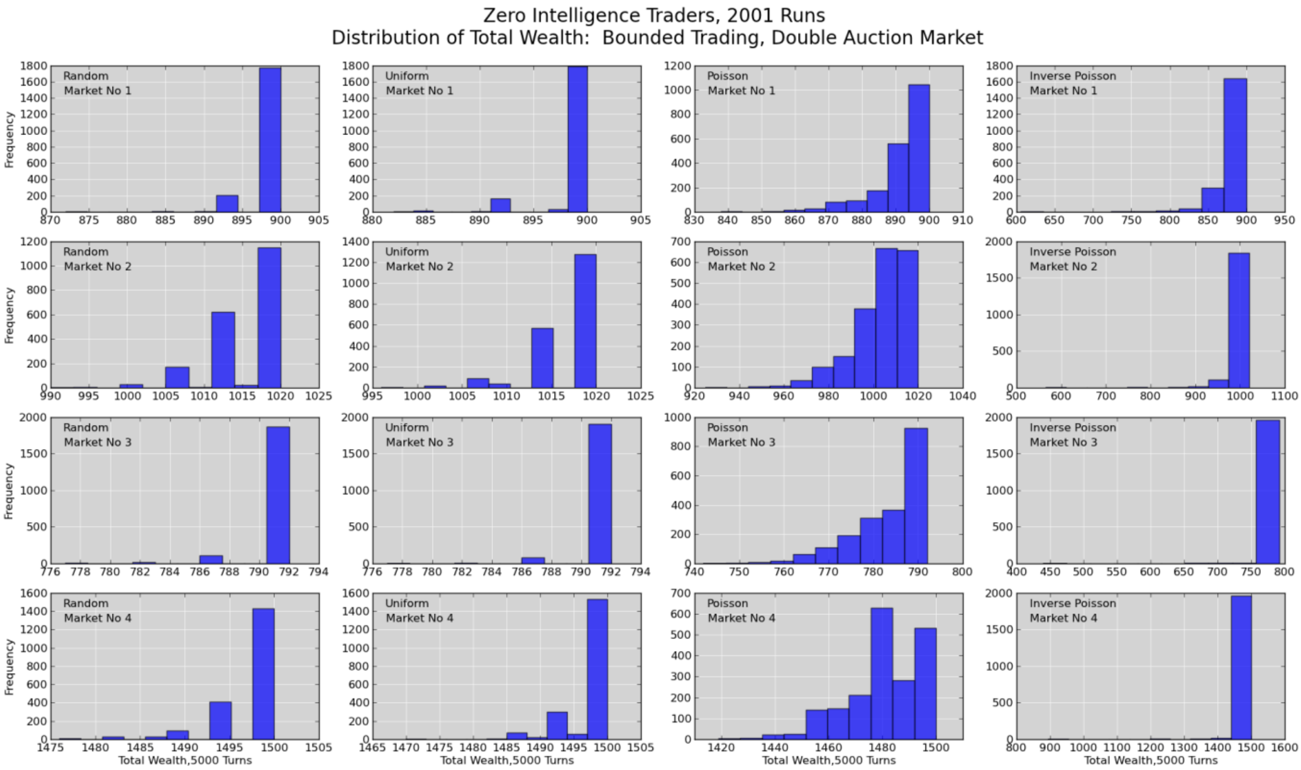

Figure 5. Total Wealth (All Traders) After 5000 Turns – Variable Scale

the theoretical profits for this trader as π_i. Thus, the dispersion across all traders becomes

$$D = \sqrt{\frac{1}{n} \sum_i (a_i - \pi_i)^2} \tag{1}$$

They left unstated how they calculated the equilibrium values. We divided equilibrium profits into those for buyers and those for sellers. We assumed buyers' equilibrium profits as the profits they could earn if they traded all the shares they could at the market clearing price. This, of course, would only include those shares with a redemption value above the market clearing price. Similarly, the sellers values of π_i was determined as the profits a seller would earn if all those shares held with costs below the market clearing price were sold at the market clearing price. Thus, to calculate *D*, it is necessary to separate the calculation of the sum into two parts. More correctly, it should be:

$$D = \sqrt{\frac{1}{n} \left[\sum_s (a_s - \pi_s)^2 + \sum_b (a_b - \pi_b)^2 \right]} \tag{2}$$

Where *s* = seller $s \in S$ and *b* = buyer $b \in B$ *and n* = the total number of traders. This separation is necessary because the supply and demand curves are not symmetrical. Sellers' equilibrium profits differ from those of buyers in essentially all markets.

C. *Time to Last Trade*

Gode and Sunder did not examine the model behavior over the long term for a variety of reasons. They were comparing simulated markets with actual human experiments. The human experiments had a finite duration because they were limited by many factors that are not present in simulations. Thus, the simulated markets were truncated and the long-term data are missing (or, in the terminology of statistics, the data were 'censored').

We expected to run the markets to exhaustion. That is, we experimented with a number of lengths of runs in the random and uniform activation types to find a reasonable point at which trading ended. We chose a run length of 5000 turns, believing this would encompass all trades for all markets and all activations. As noted in the result section, there was still censored data even at these extended runs. In fact, this represents a major difference among the activation schemes. Thus, while we didn't collect a comprehensive set of data, analysis of the turn at which the 'last trade' took place certainly achieved one of the key goals of this project – differentiating among activation schemes.

V. MODEL RESULTS

A full spectrum of experiments was run: four activation schemes across four markets. Each experiment consisted

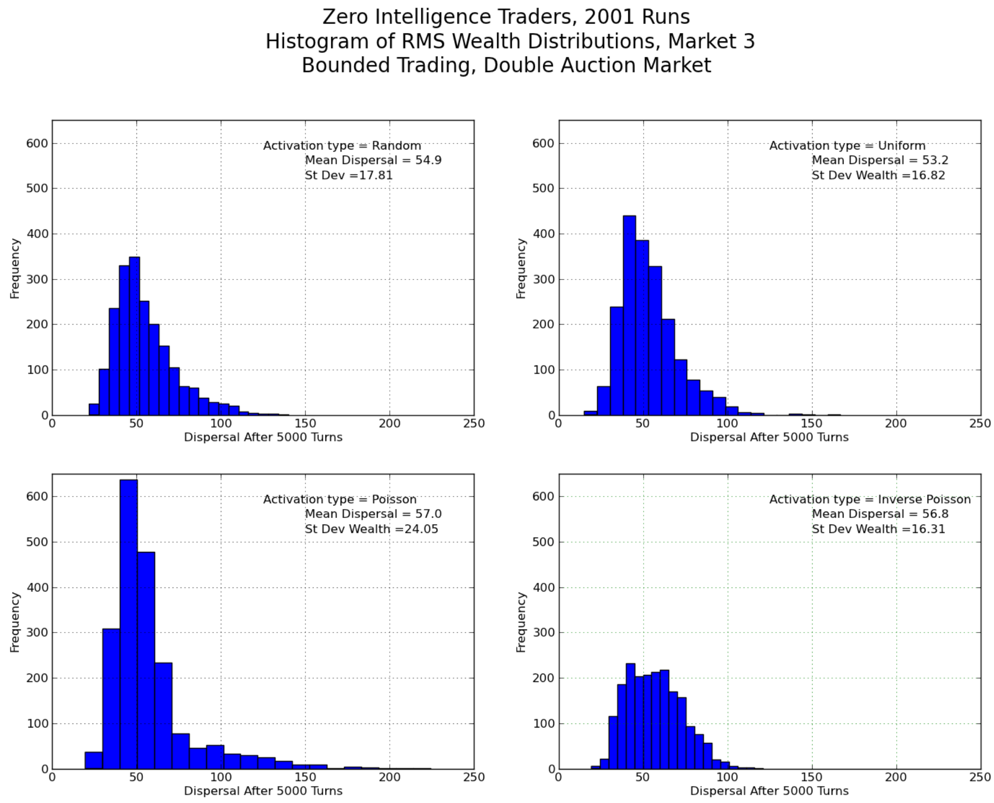

Figure 6. Wealth Dispersal, Market 3 (Constant Scale)

of 2000 runs of the market and activation, with each run extended to 5000 turns. At the end of each run, total wealth, wealth dispersion, and the turn of the last trade were recorded.

Market analysis shows that the exogenous activation schemes run to completion and the endogenous schemes (the Poisson activation types) still have some trading opportunities available at the end of 5000 turns. This is most apparent in the Last Turn measurements in Figure 7.

Figure 5 shows the four histograms of total wealth for all markets. The inverse Poisson activation exhibits extreme values of low wealth, but actually bunches much of the wealth closer to the maximum value for each market.

Table I. Mean Total Wealth at End of Run (2000 Runs)

Average Total Wealth			*Market*	
Activation	**1**	**2**	**3**	**4**
Random	899.0	1016.6	791.6	1497.7
Uniform	899.2	1017.2	791.7	1498.2
Poisson	892.2	1003.2	785.4	1480.5
Inverse Poisson	881.3	999.6	785.1	1488.8
Max Wealth	900	1020	792	1500

With 2000 runs, it is possible to test the hypothesis that these means are drawn from different populations against the null hypothesis that the variation is simply due to random errors (and that the random errors are normally distributed).

With four activation schemes there would be sixteen pairwise comparisons. It is not necessary to examine these exhaustively to see differences among the activation types. As Table II shows, most of these comparisons are highly significant. Even the random-uniform comparisons – the closest averages for all the markets – allow the rejection of the null hypothesis for markets 2 and 4. Note that values that are too small to calculate are reported as

Table II. *p*-values for Total Wealth Pairwise Comparisons

p-values		*Market*		
Comparison	**1**	**2**	**3**	**4**
Random - Uniform	0.021	**<u><0.001</u>**	0.035	**<u><0.001</u>**
Random - Poisson	**<u><0.001</u>**	**<u><0.001</u>**	**<u><0.001</u>**	**<u><0.001</u>**
Random – Inverse Pois-	**<u><0.001</u>**	**<u><0.001</u>**	**<u><0.001</u>**	**<u><0.001</u>**
Poisson - Inverse Pois-	**<u><0.001</u>**	**<u><0.001</u>**	0.525	**<u><0.001</u>**

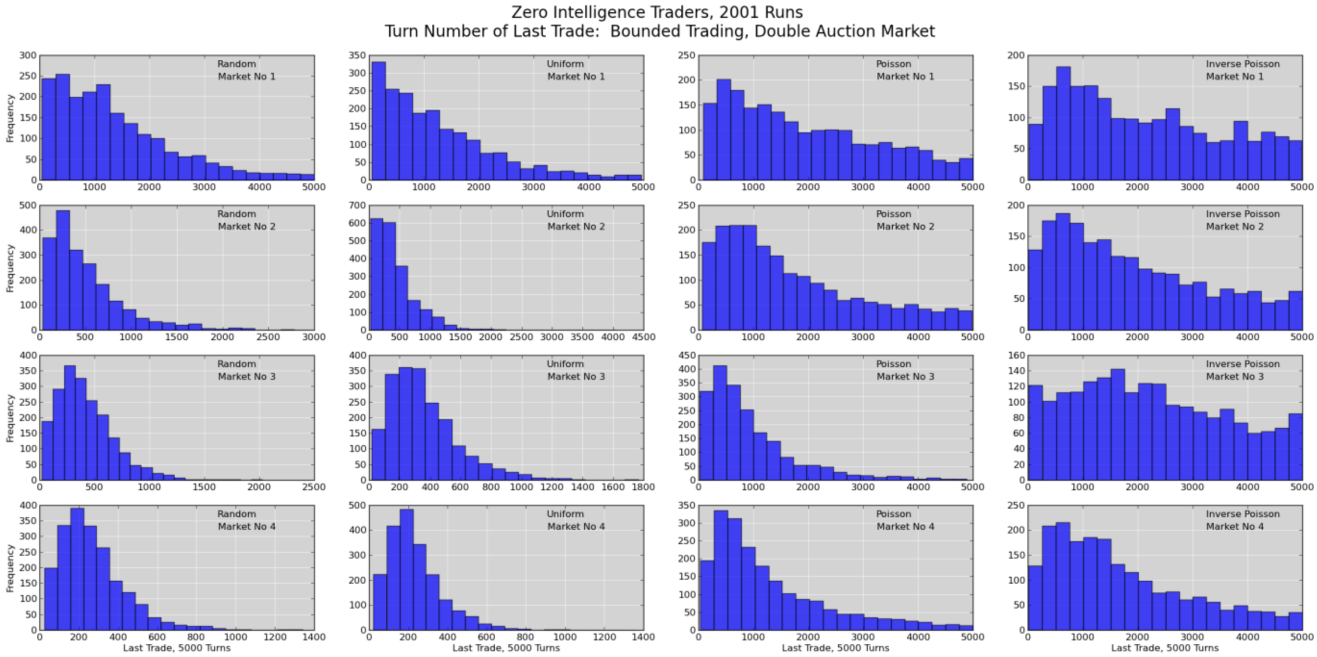

Figure 7. Last Trades in 5000 Turns (Variable Scale)

zero. (While the averages are close, the power of the test is derived from the n = 4000 combined data points for the pair.)

Gode and Sunder compared the total wealth in the simulated markets to the maximum total wealth possible. This maximum is shown on the final row of the wealth table for each of the four markets. Their objective was to compare how close the simulation came to maximum wealth with the proximity of the human markets. They deemed that their simulations across the four markets achieved essentially the same results as the human market, with efficiency percentages between 96 and 98%. These results were replicated in all markets by all activation types. The lowest percentage was 97.9% in the case of the inverse Poisson in Market 1.

Similar analysis can be conducted on the much more bell-shaped wealth dispersion. Wealth dispersion is depicted on the histograms on Figure 6. These have all been adjusted so that they appear on the same x- and y-axis scales, which we designate with a white background.

Table III. Mean Wealth Dispersion Over 2000 Runs

p-values	*Market*			
Comparison	**1**	**2**	**3**	**4**
Random - Uniform	0.23	0.20	**0.002**	0.36
Random - Poisson	**<.001**	0.278	**<.001**	**<.001**
Random – Inverse Poisson	0.14	0.28	**<.001**	0.457
Poisson - Inverse Poisson	**<.001**	0.59	0.67	**<.001**

Table IV. *p*-values for Mean Wealth Dispersion in Pairwise Comparisons

Average Wealth Dispersion	*Market*			
Activation	**1**	**2**	**3**	**4**
Random	29.2	51.2	54.9	110.3
Uniform	28.8	50.5	53.2	111.0
Poisson	31.6	51.9	57.0	102.9
Inverse Poisson	28.7	51.8	56.8	110.9

With the scales adjusted, it's clear that the histograms appear significantly different. The Poisson activation histogram shows a significantly larger tail than the others. This may not be apparent from the small size of the bars on the far right hand side of that plot, but the automatic adjustment of the graphing program clearly adjusts for larger bins for the Poisson case to accommodate the larger range of data.

While the wealth dispersion appeared to vary little across the runs, the large number of runs allowed us to determine that many of these differences were statistically significant. Using similar calculations to the averages of the wealth, we can develop another table of p-values. Table IV shows that somewhat fewer of the pairings show differences that are significant. Market 3 shows some interesting behavior in that even the random – uniform comparison results in a difference that is significant at the 99% confidence level. Still, we reject the null hypothesis that the differences between these sample means is a product of random fluctuations in seven of the 16 cases examined. Activation type makes a difference, at least statistically.

In addition to the odd shape of the Poisson activation histogram, it's also clear that the inverse Poisson activation type has a much tighter bunch of averages. The means between the two are quite similar (57 and 56.8), but the standard deviation is substantially larger for the Poisson activation scheme.

Finally, we analyzed the evolution these markets and activation schemes over the long term. Gode and Sunder did not consider the dynamics of their simulation during extended runs because they were comparing them with human traders in finite-time markets. We recorded the turn at which the last trade took place before the end of run and use this as a metric for market closure. In evaluating the results, it appears that 5000 turns was more than adequate for the random and uniform activation methods, but that Poisson and inverse Poisson were still exhibiting trading behavior late during a 5000-turn run (!).

Figure 7 shows the behavior of all four last trades for the four activation schemes. Clearly, for all markets, the extent of the trading varies substantially as the activation type is changed. Not only are the histograms of somewhat different shape, the Poisson and inverse Poisson clearly have censored trading activity.

This phenomenon would affect analysis of any ZIT models, especially if trading were cut off after a few hundred turns. It is uncertain where Gode and Sunder stopped trading. They set their cutoff at 30 seconds of computer time, which itself might be a different measure for endogenous than for exogenous activation. In executing our simulations, the random and uniform experiments take about half the time as the two Poisson activation experiments.

Table V shows a full factorial analysis of the actual values of the mean. The sizeable difference can be observed by inspection, but a complete analysis of the *p*-values confirms the statistical significance of the result. There is no pairing that has a *p*-value larger than 5×10^{-11}. Thus, it can be concluded that activation makes a potent difference in the later stages of the ZIT model.

Table V. Mean Last-Turn Over 2000 Runs

Mean Turn of Last Trade 5000- Turn Experiment	*Market*			
Activation	**1**	**2**	**3**	**4**
Random	1377.2	503.5	415.1	270.0
Uniform	1273.4	438.3	357.6	234.2
Poisson	1919.3	1718.9	947.4	1300.1
Inverse Poisson	2124.9	1927.7	2240.6	1695.1

VI. CONCLUSIONS

There are several motivations behind the question: Does activation change the outcome of agent-based models? Our simulation appears to answer different aspects of this question in different ways.

For the simple issue of statistical results, the analysis shows that for all three metrics (total wealth, wealth dispersion, and the last-trade parameter), there are statistically significant differences between at least some of the activation schemes, and for one metric there are significant differences among all of them.

We chose a 'real world' model – as opposed to a model of abstract agents engaged in mathematical game theory – to observe the impact of activation differences on policy recommendations. Gode and Sunder wanted to determine whether markets are made efficient by structural features (such as the requirement to make profitable trades) or by the rational decisions of human traders. They determined, using qualitative (but quite reasonable) analysis, that the constrained ZIT simulation essentially replicated the efficiency of the human traders in achieving the total theoretical wealth. They also concluded that simulated traders distributed the wealth close to -- but a little more than -- the human traders, at least in the early stages of trading. After a time, the human traders dispersed their profits more evenly, but this was undoubtedly due to the memory effect. Simulated traders forgot their supply and demand curves at the beginning of each experiment.

Would Gode and Sunder's conclusions have been different if they used different activation schemes? Probably not:

- All activation schemes and all markets ended with a total wealth that was between 97.92 and 99.96% of maximum wealth.
- Profit dispersion has a somewhat higher variance for the endogenous activation patterns, so it is possible that, given that they only did six runs, the authors might have generated outlier results. If they increased the number of runs, however, they would have returned to their original conclusion (simulated ZIT traders produce slightly larger dispersion, but far closer to human traders than unconstrained trading).

Gode and Sunder did not examine the question of model convergence or trade evolution. Thus, they would not have noticed the significant differences that appear in the last-trade statistics among the different activation schemes.

A third motivation for evaluating the importance of activation schemes is to establish a proper standard for research in which the agent-based models of one scientific team are replicated by subsequent researchers. The Gode and Sunder article was chosen because it appeared as a reference in 1171 subsequent articles. Clearly, many other researchers are at least working with the concept of simulating markets, and many are actually building agent-based models using the zero-intelligence trading paradigm. (None of those 1171 use the words "updating" or "activation" – or their derivatives – in the title, so activation is not a major research focus in this domain.) In the research reported above, the differential results from last trade analysis alone (if not all the results) show that if a replication of ZIT model is expanded beyond the work of Gode and Sunder, the results must be shown to be robust over different activation schemes. Thus, if agent-based researchers are to meet the standard of other sciences and work on replicating one another's experimental results, then reports of their results must include the activation scheme used in the model.

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Partner selection supports reputation-based cooperation in a Public Goods Game

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***Abstract*—In dyadic models of indirect reciprocity, the receivers' history of giving has a significant impact on the donor's decision. When the interaction involves more than two agents things become more complicated, and in large groups cooperation can hardly emerge. In this work we use a Public Goods Game to investigate whether publicly available reputation scores may support the evolution of cooperation and whether this is affected by the kind of network structure adopted. Moreover, if agents interact on a bipartite graph with partner selection cooperation can thrive in large groups and in a small amount of time.**

KEYWORDS: Evolution of cooperation; Public Goods Game; Network; Reputation.

I. Introduction

Two neighbors may agree to drain a meadow, which they possess in common: because it is easy for them to know each other's mind; and each must perceive that the immediate consequence of his failing in his part, is the abandoning of the whole project. But it is very difficult, and indeed impossible, that a thousand persons should agree in any such action; it being difficult for them to concert so complicated a design, and still more difficult for them to execute it; while each seeks a pretext to free himself of the trouble and expense, and would lay the whole burden on the others.

David Hume, A Treatise of Human Nature (London: J. M. Dent, 1952, II, p.239) - From reference [1].

Humans show levels of cooperation among non-kin that are unparalleled among other species. This difference becomes striking when facing social dilemmas, *i.e.*, situations in which cooperation is hard to achieve because the best move for an individual does not produce the best outcome for the group. Public goods games (PGG) represent a clear exemplification of this conflict between individual incentives and social welfare. If everybody contributes to the public good, cooperation is the social optimum, but free-riding on others' contributions represents the most rewarding option.

If norms, conventions and societal regulations have been proven effective in preventing the collapse of public goods (for a review, see [2], [3]), when individuals are faced with unknown strangers, with little or no opportunities for future re-encounters, cooperation easily collapses, unless punishment for non-cooperators is provided [4]. An alternative solution is represented by reputation, through which cheaters can be easily identified and avoided [5], [6]. Indirect reciprocity supported by reputation [7] can be one of the mechanisms explaining the evolution of cooperation in humans [8], especially in large groups of unrelated strangers who can, through language, actively communicate about their past experiences with cheaters [9].

As such, gossip may effectively bypass the "second-order free-rider problem", wherein the costs associated with solving one social dilemma produces a new one [10], [11]. This is the case of punishment: cooperators who do not sustain the costs of punishment are better off than cooperators who also punish. Therefore this solution to social dilemmas itself entails a social dilemma, whereas gossip, being essentially free should not imply such a second-order free-rider problem. In addition to costly punishment and reputation, ostracism of free-riders may represent a third solution. However, the direct effect of ostracizing a member is that the group size decreases, which automatically reduces maximal contribution levels to the public good for all remaining periods. Maier-Rigaud and colleagues show that in the lab PGG with ostracism opportunities increases contribution levels and contrary to monetary punishment, also has a significant positive effect on net earnings [12].

Models of indirect reciprocity usually take into account dyadic interactions [5], or group interactions in a mutual aid game [13], in which providing help has a cost for the helper but it also increases her image score, *i.e.*, a publicly visible record of her reputation. Image score increases or decreases according to individuals' past behaviors, thus providing a reliable way to discriminate between cheaters and cooperative players. Both in computer simulations [5], and in lab experiments with humans [14], cooperation can emerge and be maintained through image score.

When individuals facing a social dilemma can know other players' image score, cooperation can emerge in small groups, as showed by Suzuki and Akiyama [15]. In their work, cooperation can emerge and be maintained for groups of four individuals; though, when group size increases there is a concomitant decrease in the frequency of cooperation. The authors explain this decline as due to the difficulty of observing reputations of many individuals in large communities. This can be true in unstructured communities, but this rarely happens in human societies, characterized by interaction networks. To account for the role of societal structure, we designed a PGG in which players' interactions depend on the kind of network and on the possibility of actively choosing a subset of group members. More specifically, we compare cooperation levels among agents placed on a small-world network [16], defined by short average path lengths and high clustering, to the performance of agents on a bi-partite graph [17], [18]. The latter is generally used to model relations between two different classes of objects, like affiliation networks linking members and the groups they belong to. This structure is especially interesting for us because it is especially suited for partner selection, as it happens when a club refuses membership to a potential associate.

Here, we are interested in exploring the effect of network structure on the emergence of cooperation in a PGG. We compare two different network topologies and we show that reputation-based partner choice on a bi-partite graph can make cooperation thrive also in large groups of agents. We also show that this effect is robust to number of generations, group size and total number of agents in the system.

II. The Model

We consider a population of N individuals. In each round of the game, g agents are picked up at random to play a PGG among themselves. Players can cooperate contributing with a cost c to a common pot, or can defect withouth paying anything. Then, the total amount collected in the pot is multiplied for a benefit b and equally distributed among all the group members, without taking into account individual contributions. At the end of each interaction, cooperators' payoffs equals $(ib/g-1)c$, whereas defectors' payoffs is ibc/g. At the collective level, the best outcome is achieved when everyone cooperates, but cheaters are better off, because defection permits to avoid a loss when the number of cooperators is lower than gc/b.

Among the many solutions offered [4], Suzuki and Akiyama [15] designed a modified PGG in which agents can identify cheaters thanks to the so-called image score [5], [19]. The basic features of our model are the same of the one by Suzuki and Akiyama: in particular, each player i is characterized by two integer variables: the image score $s_i \in [-S_{max}, S_{max}]$ and the strategy $k_i \in [-S_{max}, S_{max}+1]$, being $S_{max} \geq 0$ a parameter of the model. When selected to play a round of the game, an individual cooperates if the average image score $\langle s \rangle_g$ of its opponent is equal to or higher than its own strategy k_i, otherwise it will not contribute. At the end of the round, the image score of the player is increased by 1 in case of cooperation, otherwise it is decreased by the same quantity. In any case, s_i remains in the allowed interval $[-S_{max}, S_{max}]$. At the initial stage, all the image scores and fitness levels are set to zero, whilst the strategies are randomly distributed among the individuals.

The image score is intended to give a quantitative evaluation of the public reputation of an individual in the scope of indirect reciprocity: if contributing once is rewarded by future contributions by others individuals, then any cooperative action must be recognized and considered positively by the entire population; on the other hand, the variability of the strategies describes the different attitudes and expectations of the single agents [5].

After m rounds, reproduction takes place. Again, we apply the same evolutionary algorithm used by Suzuki and Akiyama [15]. For N times we select at random a pair of individuals and with probability P we create a new individual inheriting the strategy of the parent with the highest fitness. Then parents are put again in the population, and offspring is stored in another pool. When this selection process has happened N times, the old population is deleted and replaced with the offspring. It is worth noticing that offspring inherit only the parents' strategy, while their image score and fitness is set equal to zero. Finally, we repeat all the procedure (m rounds followed by the reproduction stage), for an adequate number of generations. The simulation lasts until the system reaches a final (steady or frozen) configuration.

For sake of clarity, we observe that strategies defined as ($k \leq 0$) are the more "cooperation prone", with the limit case of $k = -S_{max}$ which is an unconditional cooperator, while the positive ones are the "cooperation averse" strategies, with the limit case of $k = S_{max}$ representing an inflexible defector.

Moving from the model described above, we are interested in testing whether two different network structures can promote cooperation for different group size and what effects partner selection can have in such an environment.

III. Results

A. Robustness of Suziki's and Akiyama's results

Suzuki and Akiyama tested their model for a given set of parameters with the following values: $N = 200,\ c = 1,\ b = 0.85g,\ S_{max} = 5,\ m = 800$. Their results show that a cooperative strategy can evolve and invade a population when group size g is small, but it does not survive when groups are large. For medium-sized communities, a coexistence between cooperators and defectors is possible.

The first step of our study is a check of the robustness of Suzuki and Akiyama results with respect to the values of the model parameters. A check of the role of m and N is reported already in [15]: it is claimed that the outcome is not relevantly influenced by the value of these two quantities, so we focus here on b, P and S_{max}.

The role of b in the PGG is quite clear in literature. Normally it is set to 3 independently from the group size. Using this value, we found that the final cooperation level decreases sharply as g increases, as shown in Fig. 1. The slower decrease in Suzuki's and Akiyama's model can be explained by the fact that being b proportional to the group size the number of contributors needed in order to make cooperation convenient remains constant in g instead of decreasing with it. On the other hand, even though less dramatic, the decrease is anyway observed, indicating that the negative effect of large groups on cooperation is stronger and it might depend on the PGG dynamics.

Concerning the behaviour of the model as a function of the parameter P, we tested three different values: $P = 0.9$ as in [15], $P = 0.75$ and $P = 1.0$. As it can be easily seen in Fig. 2, there is no fundamental difference due to the exact value of this parameter.

Finally, changing the value of S_{max}, we see that up to $S_{max} \simeq 15$, the behaviour of the system is rather homogeneous, as shown in Fig. 3.

Our results show that the behaviour of the model is actually robust for a large range of the paramenters at stake, thus replicating Suzuky and Akiyama's results.

B. Small-world networks

In order to enlarge the scope of the model, we inserted network structure in it, thus introducing some adaptations of the original model. The first change we made was in the mechanism of assortment. In the original model, every player had the same probability to interact with every other agent, therefore the population is placed on a totally connected graph (CG). This configuration is rather unrealistic, especially when we consider groups bigger than a given size. It is then interesting to test the model behaviour over more realistic, even though still abstract, networks. The first example we take under consideration is the so-called small-world network (SWN), as conceived by Watts and Strogatz in [16]. In short, a SWN, is a regular ring with few short-cuts linking originally far away nodes. It is constructed as shown in Fig. 4: we start from a ring where each node is connected with $2k$ nearest neighbours. Then, with probability p, each link is rewired (one of the node is left fixed, the other is changed), so that it finally leads to the creation of a network with pNk short-cuts. As shown in reference [16], for $1/Nk < p < 1/10$ the network shows the typical small-world effect: even though at local level the system behaves as a regular lattice, *i.e.*, an individual placed in a SWN cannot distinguish the network from a regular one just watching his/her neighbours, at a global level the average distance between two randomly selected individuals is very low (proportional to the logarithm of the system size), unlike the regular case.

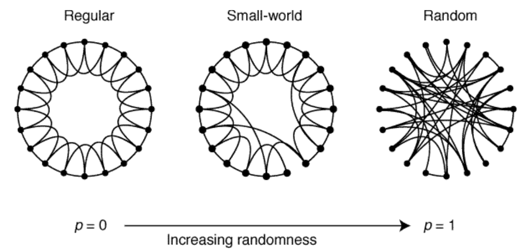

Fig. 4. Construction of SWN according Watts-Strogatz procedure. From reference [16].

In order to make the model work with this topology, we had to adapt the model dynamics to the specific situation. In particular, instead of extract g agents at each round, we picked up a single player at each round and $g-1$ of its neighbours. In order to be sure that each individual had at least $g-1$ neighbours, we set $k = g-1$. Moreover, at the end of each generation, the offspring was randomly placed on the preexistent network, which is defined at the beginning and does not change until the end of the simulation. Anyway, averaging over different realizations, each one has its own networks, so that the averages are also over the topology.

In Fig. 5, Fig. 6 and Fig. 7 we see cooperation levels for three different values of g, each one corresponding to a different size of the system. Actually, apart for the case $g = 2$, there is a not trivial dependence on the system size. In particular, the dynamics is always driving the system towards the achievement of complete cooperation, even if the timing is different: full cooperation is achieved fastly with small values of g and N, whereas it slowes down when both group and system sizes increase. Indeed, with $g = 10$ and $N = 800, 1600$ total cooperation cannot be achieved even with 10^5 generations, even if it is possible to anticipate the increase of the cooperation level towards the highest point. Moreover, it is remarkable how for $g \geq 4$ a plateau of high but not total cooperation appears. Our results show that the dynamic in itself makes full cooperation possible, but for bigger populations the time needed to reach it is so long that practically we see a coexistence between the two kinds of behaviour for a long time.

C. Bipartite graphs

Another topological configuration that accounts better for the complexity of real interactions among individuals is the so-called bipartite graph (BG) [17], [18]. A bipartite representation contains two types of nodes denoting agents and groups, respectively. It implies that connections can be established only between nodes of different types and no direct connection among individuals is allowed. Thus, such a bipartite representation preserves the information about the group structure: if two individuals belong to the same three groups, they are "more" connected than two other individuals who are members of the same group. These two pairs would be equally represented in the classical one-mode projected

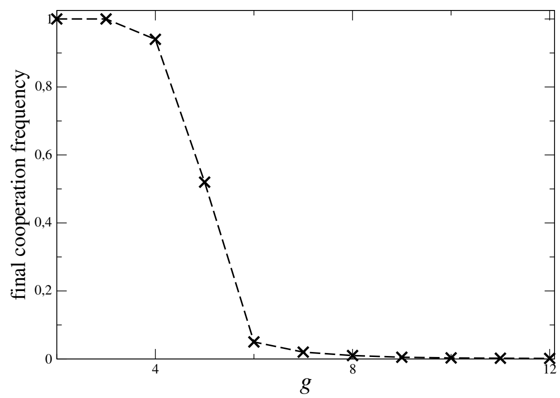

Fig. 1. Behaviour of the final frequency of cooperative actions as a function of the group size g. All the parameters are the same of reference [15], except $b = 3$. Each point averaged over 1000 realizations.

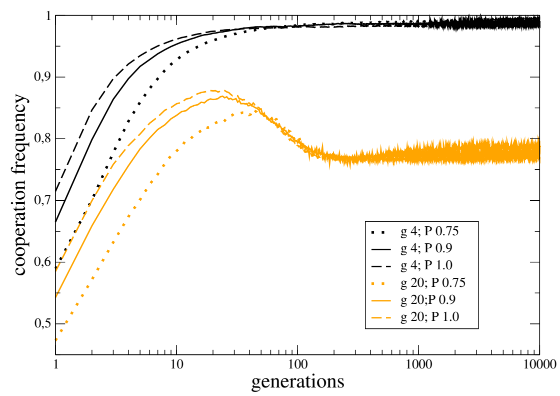

Fig. 2. Behaviour of the frequency of cooperative actions as a function of the number of generations for three different values of P: 0.75, 0.90 and 1.0. The remaining parameters are the same of reference [15]. Each curve averaged over 1000 realizations.

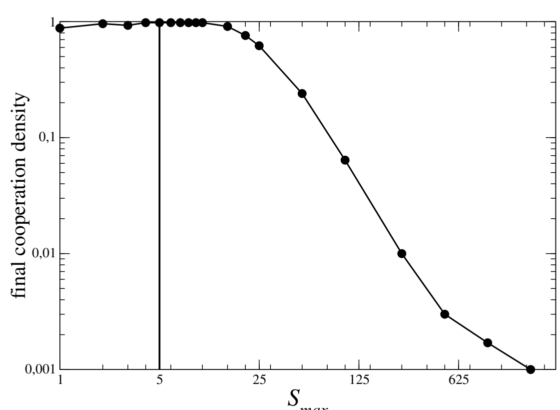

Fig. 3. Behaviour of the final frequency of cooperative actions as a function of S_{max}. The remaining parameters are the same of reference [15], the vertical line for $S_{max} = 5$ specifies the value utilized in reference [15]. Each point averaged over 1000 realizations.

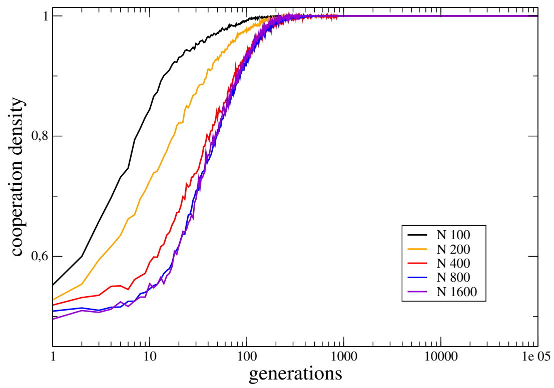

Fig. 5. Behaviour of the frequency of cooperative actions in a SWN with $p = 0.05$ as a function of the number of generations for $g = 2$ and different values of N (from top to bottom: 100, 200, 400, 800 and 1600). The remaining parameters are the same of reference [15]. Each curve averaged over more than 1000 realizations.

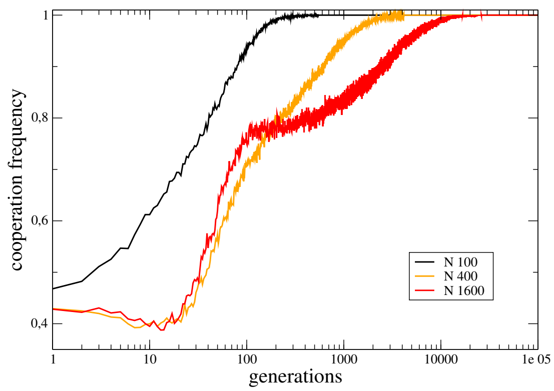

Fig. 6. Behaviour of the frequency of cooperative actions in a SWN with $p = 0.05$ as a function of the number of generations for $g = 4$ and different values of N (100, 400 and 1600). The remaining parameters are the same of reference [15]. Each curve averaged over more than 1000 realizations.

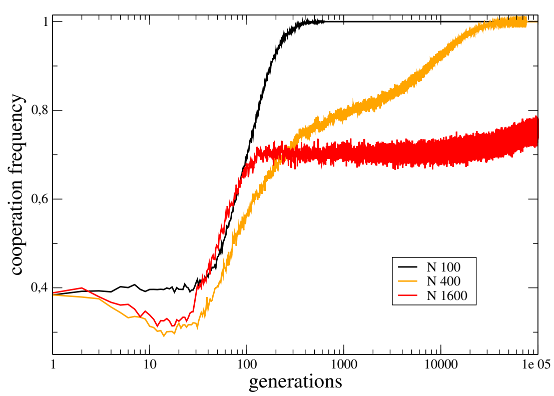

Fig. 7. Behaviour of the frequency of cooperative actions in a SWN with $p = 0.05$ as a function of the number of generations for $g = 10$ and different values of N (100, 400 and 1600). The remaining parameters are the same of reference [15]. Each curve averaged over more than 1000 realizations.

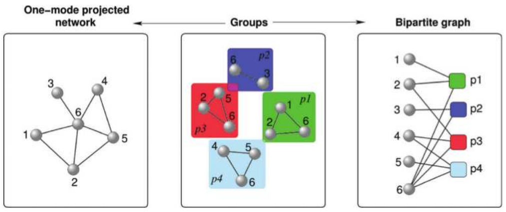

Fig. 8. Structure of a bipartite graph compared with a classical network. From reference [18].

network, while with the bipartite graph this mesoscopic level of interactions is better depicted, as illustrated in Fig. 8.

Also in this case we adapted the original dynamics of the model to make it work on this kind of network. In particular, the graph has N individuals distributed into M groups, each group composed of g members. At the beginning of each round, the network is built in this way: given $F \in (0, 1)$, we set gF initial members for each groups so that each individual belongs exclusively to one group. For instance, if $N = 150$, $g = 20$ and $F = 0.75$ (then $M = 10$), at this stage we would have 15 agents in the first group, other 15 in the second one and so on until the last 15 in the tenth group. Then, each group must be completed choosing $(1-F)g = 5$ individuals from the pool of those which do not belong to the group already. This can be accomplished in two different ways: first, by randomly picking $(1 - F)g$ agents among the rest of the population; second, by selecting them according to their reputation, *i.e.*, their image scores.

When partner selection is available, an external player is randomly selected by the group, but accepted only if its image score is positive. Only if there is no player in the whole population with good reputation, a candidate with negative image score is accepted in the group. Alternative ways of implementing partner selection were tested, like for example, accepting candidates with image score equal or larger than the average strategy of the initial member of the group, but this did not produce any appreciable effects on the outcome of the simulations. Once the network is completely defined, each group plays a round of the game, with the same rules working on CG and SWN. The procedure (network construction followed by a round of the game of each group) is repeated 10 times, then the evolution process takes place as previously described.

In Fig. 9 and Fig. 10 we show the behaviour of the model for $N = 200$ (or the closest integer compatible with the remaining parameters), $F = 0.75$, with the other parameters equal to the ones utilized by Suzuki and Akiyama [15].

Our results show that the final cooperation level is *lower* here then in the CG case if the added members of the groups are selected at random. However, when reputation-based partner selection is available in a population distributed on a bipartite graph, full cooperation is achieved in a very short amount of time (about ten generations), and this is true also for large groups ($g = 20$ in figure). This result does not depend on F: even when partner selection is restricted to a small percentage of agents, it can favour the invasion of the cooperative strategies throughout the system. This effect can be explained by the fact that, in general, in PGG it is better for individuals to get involved in as many groups as possible in order to maximize their income [20]. However, if this is not linked to a reputation-based partner selection mechanism, defection is still very profitable and cooperators are driven out of the system. On the contrary, if reputation is used to select group members, having a positive image score has a positive effect on fitness.

D. Final strategy distributions

In the model by Nowak and Sigmund [5], [19], based on the same image score mechanism, when the system ends up in a final configuration of complete cooperation, the only surviving strategy is usually $k = 0$, that is, the "winning" strategy is a rather moderately generous one. A similar behaviour appears with our model in CG and SW topologies.

On the other hand, when working on BG topology, the final system configuration, always totally cooperative, presents all the negative strategies, *i.e.* the more cooperative ones, as shown in Fig. 11. This means that taking into account more carefully the real properties of the social interactions among idividuals not only enhances cooperation rates throughout the whole population, but it allows allows the most generous and altruistic strategies to survive.

IV. Discussion

In a PGG in which the history of agents' past interactions is publicly available as an image score, cooperation can emerge and be maintained for small groups of agents. When we move from a mean-field situation to a small-world network, we observe that cooperation becomes stable after one hundred generations and for $g = 4$. The real improvement is achieved thanks to the introduction of a partner choice mechanism on a bi-partite graph, where if a small percentage of group members are chosen on the basis of their reputations, cooperation can thrive.

In a social dilemma the introduction of a reputation mechanism for partner selection on a bipartite graph makes deception unprofitable, thus cooperators can thrive. In such an environment, agents with a positive reputation are more socially desirable, thus they can enter several groups in which their contributions help to achieve the social optimum. On the other hand, defectors with negative reputations are actively avoided, thus driving them to complete extinction after ten generations. Even more striking is the fact that, unlike other models [15], [21], full cooperation is maintained even when group size increases.

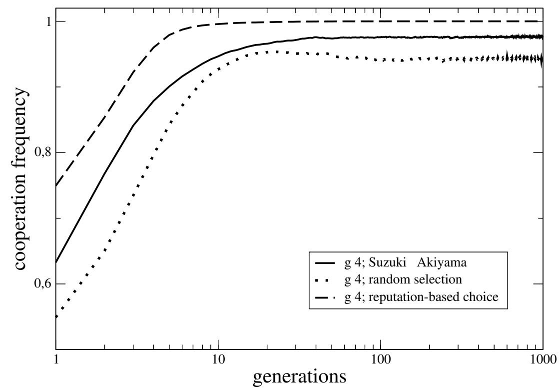

Fig. 9. Behaviour of the frequency of cooperative actions in a BG with as a function of the number of generations for $g = 4$, and $F = 0.75$. The remaining parameters are the same of reference [15]. Each curve averaged over 1000 realizations.

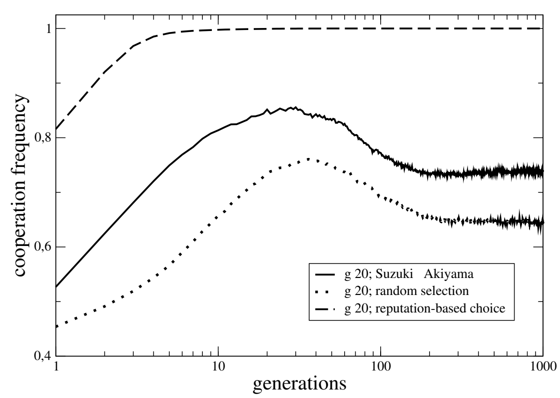

Fig. 10. Behaviour of the frequency of cooperative actions in a BG with as a function of the number of generations for $g = 20$ and $F = 0.75$. The remaining parameters are the same of reference [15]. Each curve averaged over 1000 realizations.

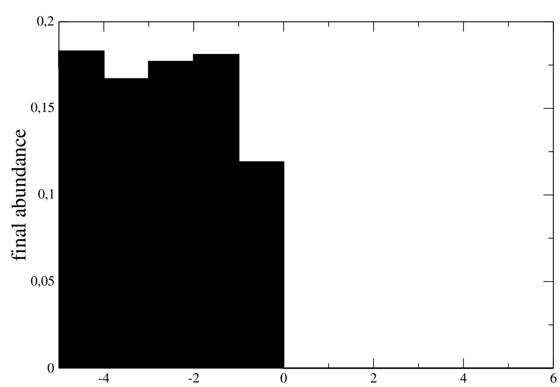

Fig. 11. Final (relative) strategy abundance for a system on BG, same system of Fig. 9 ($g = 4$) with reputation-based choice of the added members of each group. Values averaged over 1000 realizations.

V. Conclusions and perspectives

The puzzle of the evolution of cooperation in humans can be successfully addressed if we take into account features of human societies that could have paved the way for the emergence of cooperative behaviors, like social networks and reputation. Moving from a replication of Suzuky and Akiyama [15] we showed that cooperation can emerge and be maintained in groups of agents playing a PGG on a network. We used two network topologies with different groups and total population sizes, finding interesting differences especially in terms of the maximum level of cooperation achieved. Our results show that when partner selection is available in an affiliative network, cooperation can be easily reached even in large groups and for large system size.

The importance of social institutions [2] and informal social control [6], [22] is well known to social scientists who, like Ellickson [23], have stressed the importance of these features: *"A close-knit group has been defined as a social network whose members have credible and reciprocal prospects for the application of power against one another and a good supply of information on past and present internal events [. . .]. The hypothesis predicts that departures from conditions of reciprocal power, ready sanctioning opportunities, and adequate information are likely to impair the emergence of welfare-maximizing norms"* (p. 181).

Introducing a small world network does not alter the dynamics of cooperation in a PGG in a fundamental way, and this is also true for a bipartite graph with random partner selection. However, when we model the world as made of groups that can actively select at least one of their members, cooperators outperform free-riders in an easy and fast way. The evolutionary dynamics of our model can be linked to a proximate explanation of psychological mechanisms for ostracism and social exclusion, two dreadful outcomes for human beings [24], [25]. In large groups of unrelated individuals, direct observation is not possible, and usually records of an individual's past behaviors are not freely and publicly available. What is abundant and costless is gossip, *i.e.*, reported information about others' past actions, that can be used to avoid free-riders, either by refusing to interact with them, or joining another crew in which free-riders are supposedly absent. For this reasons we plan to run simulations in which agents will be able to report private information about their past experiences, thus overcoming the unrealistic limitations posed by image score. We posit that the combination of a bipartite graph social structure and gossip like exchanges will mimic human societies better and will provide useful insights about the evolution of cooperation in humans.

Acknowledgement

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An agent-based model of firm location with different regional policies

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***Abstract*—This paper presents an agent based model of firm location designed to explore the effect of regional policies on the spatial pattern of business activity. New firms are created each period taking into account the sector profitability and entry barriers. Firms choose their location and then they decide sequentially whether change their size or cease their activity accordingly to the profit maximization principle and the limited information they have. Their costs depend not only on the production level and the price of the productive factors but also on the land price. The characteristics of the territory where the firms are located are not static but rather evolve depending on the public policies, demographic variables and the firm localization patterns. The presented model shows endogenous rules of firm localization as well as the effects in the medium and long term of public policies.**

I. Introduction

Geography and spatial economics have studied in depth the rules of localization of the companies, but many of the complex behaviors that are observed in the reality are still, in great measure, unexplained [1] [2]. Cellular automata and multi agent simulation models constitute new approaches to the problem [3], allow integrating in the models relevant aspects that had not been included in the analysis in quantitative terms due its high complexity.

Multiagent models include agents that interact among each other and with the environment in an independent way. As Huhns and Singh [4] point out these agents consist on small self-contained programs that are able to control their own actions based on their perception of the environment and looking for, in most of the cases, the achievement of certain objectives [5].

Wooldridge and Jennings [6] pointed out some of the characteristics that the agents show and that coincide in great measure with those of the companies:

- Autonomy: Agents act in an independent way not being controlled from the exterior neither their actions neither their internal state while companies enjoy autonomy in their decisions, not being controlled by their competitors.
- Social ability: Agents interact using some kind of language. Companies exchange information by means of their decisions about prices and production.
- Reactivity: Agents as well as companies can perceive their environment and to respond to the stimuli received.
- Proactivity: Both are able not only to react respect the environment but rather they are able to carry out actions for own initiative to this way to reach their objectives.

These coincidences among the characteristics of the agents and those that have the firms make this type of simulations especially appropriate to characterize the behavior of the markets [7].

Cellular automata allow appropriately representing the evolution across the time the spatial variables such as land price and the population [8].

The two dimensions automata cellular models [9] consists on a number of identical cells in a grid provided with a set of variables and behavioral rules. Each cell has a value that can change during the simulation depending on some rules which specify how its next value depends on his actual value and the values of the cell's neighbors of k- dimension [10].

The aggregation of both types of approaches allows studying the behavior of the companies in its localization decisions as well as its effects on the environment. The objective of the paper is to show the main characteristics of this model. The work is structured in two parts: in the first one the structure of the main features of the model are presented and in the second one, an example of its application in a real case is shown, the effect on the localization of firms of the different of policies of two regions in Spain

II. Main features of the model

The agent-based model (ABM) starts with the creation of a number of layers that contain the data of all the firms that potentially can exist in the area. These layers are in many cases cellular automata that determine endogenously the environment variables. Usually the initial values of the exogenous variables proceed of vectorial Geographical Information System (GIS) [11] and they are transcribed into matrixes to be used efficiently in Matlab.

Among the main layers used in the model we can highlight the following ones:

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- Layer1 is a two dimensions matrix (x,y) that represents the territorial aspects that are considered that remain stable in the time such as land height.
- Layer2 is a three dimensions matrix (x,y,t) that shows the time evolution of the main characteristics of the territory. The values of the cells are codes that represent the uses of the land (urban, industrial, services, agriculture, forest, protected area, university technological area).
- Other layers denominated layer3 to layer7 contain the evolution of several spatial variables in the time such as infrastructures, highways, population, railroads, density of firms, etc.
- Other important layers collect the evolution of the land price and the political division of the territory, allowing the introduction of regional policies in the system. Land price is an endogenous variable and it depends among other factors on the localization of companies.

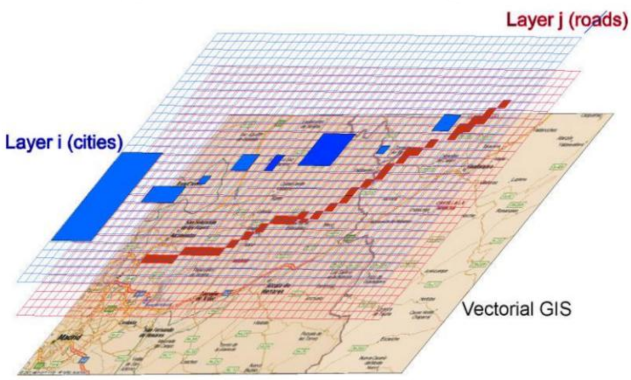

Fig 1. Generation of layers

There are two main approaches to implement the settlement of the agents in the cells: in the first one each cell is occupied by a single agent, in the other one the cells can be shared. Both approaches have advantages and drawbacks. The first option allows monitoring the general behavior of the model; however it seems not realistic when the size of the cells is not small. On the contrary, when the cells can be shared some important aspects of the model can be hidden when the agents cluster in few cells. It is more convenient to use models where agents don't share cells in theoretical studies while better empirical results are obtained when cells are shared. The spatial ABM we present allows both possibilities.

The search system used by firm to find the most convenient location is chosen among these three types: the first one, consist on looking for the place that offers the highest potential profit in the whole area; the second is looking for the place that has the best conditions between a reduced number of possible localizations chosen randomly. Lastly the third type consists on a limited searching in the neighborhood of a random emplacement. The first method is not realistic because the real estate information costs mainly in terms of time devotion [12].

Every company can leave a place when it closes down or if it decides to be relocated. In the first case, the firm is expelled of the market when their profitability is low while in the second one it changes the place although it is profitable if it considers that the derived benefits of the localization change overcome to the costs.

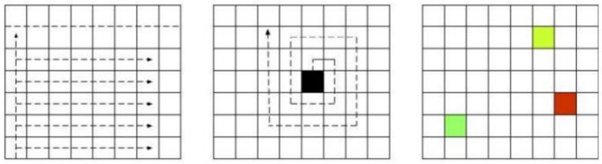

Fig 2. Search mechanisms

From the point of view of the firm mobility it is an evolutionary model that shows the dynamics of populations on the long term allowing the representation of different interrelated sectors. The behavior and the number of firms that exist in each sector are endogenously determined by the model.

Two types of firms are considered in the model: on the one hand the firms originally established in the area and, on the other one, the new ones. This division of the firms in two groups has been made to see as the population of firms evolves from the original situation.

The maximum production capacity of the originally established firms is distributed according to a lognormal function. This hypothesis on the distribution of the production is based on wide evidence that shows a marked asymmetry in the distribution of market shares of the firms [13]. The capacities of the new firms also follow lognormal distributions similar to that of the established companies.

The number of entries in each sector depends on two types of variables. On the one hand, those that have a high level of attraction for the new firms; on the other hand, those that suppose barriers to the entrance.

The barriers to the entrance included in the model are two: the average size of the existing firms in the previous period, as proxy of the existing economies of scale [14], and an exogenous vector of other entry barriers that include the land price. This vector allows the inclusion in the model of institutional changes or external interferences that affect the entrances, making them easier or preventing them.

Firms are able to change their size in each period, sometimes in a voluntary way to adapt to the characteristics of the market, and others because of their financial restrictions. The size is settled as a function of the size in the previous period in order to include the two main theories of firm growth: the stochastic one [15] and the deterministic one[16] (*alpha parameter)*

$$q_{it} = \alpha\left(q_{it-1}\left(1 + \frac{N(0,1)}{\tau}\right)\right) + (1-\alpha)\left(q_{it-1}\left(1 + \lambda\frac{q_{opt} - q_{it-1}}{q_{it-1}}\right)\right) \quad (1)$$

The available technologies are the same for all the companies of each group. So there is only one cost function for each firm that determines its average costs in function of its production level and its location. This decision has been adopted in order to highlight the central object of the analysis: the localization decision in response to regional policies and market factors.

Firms estimate rationally each period the global market supply in order to decide its own production level to maximize the profits. Firms observe the current price and supply levels to determine their production for the following period and they estimate the future supply of their competitors in function of their own experience, assuming that they will maintain their recent behavior [17].

Although the profitability does not necessarily assure the continuity of the firm, the probability of being expelled of the market is higher when the margin decreases [18]. This relationship is not linear since from certain level of profitability a significant increase in the survival possibility does not take place. However, the reduction of the margin below a critical level represents a significant increase in the probability of closing down [19]. A good location reduces the costs and improves the margins, promoting the firm success.

The coexistence of firms with different dimensions and, therefore, with different costs, means that, for a certain level of prices, firms with high probabilities of survival and others with practically none can exist at the same time. And as the margins of each firm depend on the price, the exits are affected indirectly by all the variables that affect this: demand, production levels, imports and entrances.

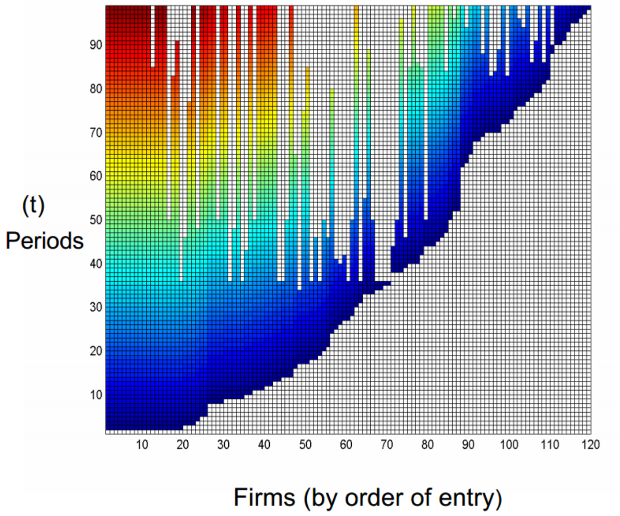

Fig 3. Firm demography

The non-linearity is observed in the Bernouilli function for the survival probability of the firm B(p). p is a logistic function that depends on the Lerner index for each sector:

$$p = \frac{1}{1+e^{-\frac{IL_i-\alpha}{\beta}}} \quad (2)$$

The demand functions are linear and are assumed to remain stable during the simulation to focus the study on firms' decisions without external demand shocks. Demand equation for firms created before t=0 is

$$P_{nt} = a_1 - a_2\ Q_{nt} - a_3\ Q_{et} \quad (3)$$

Demand equation for new firms:

$$P_{et} = b_1 - b_2\ Q_{nt} - b_3\ Q_{et} \quad (4)$$

Where P_{nt} is the price charged in time t, Q_n the aggregated production level, Q_e the production of the entrants. n and e make reference to initial firms and entrants respectively.

Demand functions conditioned by production factors are defined as:

$$k_t(w_t, r_t, q_{it}) = A^{-\frac{1}{a+b}}\left[\frac{a\ r}{b\ w}\right]^{\frac{b}{a+b}} q_{it}^{\frac{1}{a+b}} \quad (5)$$

$$l_t(w_t, r_t, q_{it}) = A^{-\frac{1}{a+b}}\left[\frac{a\ r}{b\ w}\right]^{-\frac{a}{a+b}} q_{it}^{\frac{1}{a+b}} \quad (6)$$

Then, the forecasted market supply is:

$$E(Q_{nt}) = \overline{Q}_{nt} + h_1(p_{n,t-1} - \overline{p}_{nt}) + h_2(Q_{n,t-1} - \overline{Q}_{nt}) \quad (7)$$

$$E(Q_{et}) = \overline{Q}_{et} + h_3(p_{e,t-1} - \overline{p}_{et}) + h_4(Q_{e,t-1} - \overline{Q}_{et}) \quad (8)$$

For initial firms and entrants respectively. Where mobile averages of the last k periods are computed; *h1* and *h3* are the response coefficients to price variations; *h2* and *h4* are the ones to quantity changes.

The estimated production for the established firm *i* and for its established competitors, *Q*ni*, is the market forecast for the group of firms:

$$E(Q^*_{nit}) = E(Q_{nit}) - E(q_{nit}) \quad (9)$$

The production that the market expects for each of the established companies is similar to that of market as a whole:

$$E(q_{nit}) = \overline{q}_{nit} + h_{i1}(p_{n,t-1} - \overline{p}_{nt}) + h_{i2}(q_{ni,t-1} - \overline{q}_{nit}) \quad (10)$$

It is computed each period after the total production computation. Thus, the profit function to optimize is:

$$\Pi_{nit} = p_{nt}(Q^*_{nit}, Q_{et}, q_{nit})\,q_{nit} - c_n(q_{nit}) \quad (11)$$

And the optimal production level for the established firms is expressed as:

$$q_{nit} = -\frac{\frac{\partial c_n(q_{nit})}{\partial q_{nit}} - p_{nt}(Q^*_{nit}, Q_{et}, q_{nit})}{\frac{\partial p_{nt}(Q^*_{nit}, Q_{et}, q_{nit})}{\partial q_{nit}}} \quad (12)$$

In the same way, the optimal production for entrants is:

$$q_{eit} = -\frac{\frac{\partial c_{et}(q_{ejt})}{\partial q_{ejt}} - p_{et}(Q^*_{ejt}, Q_{nt}, q_{ejt})}{\frac{\partial p_{et}(Q^*_{ejt}, Q_{nt}, q_{ejt})}{\partial q_{ejt}}} \quad (13)$$

The expected profits coincide with the margin that each group of companies has earned in the previous period, defining these ones as the difference between the sales price and the average of the marginal cost of the companies in the group.

$$E\pi_{nit} = IL_{nt-1} = \frac{P_{nt-1} - \left(\sum CMg_{nt-1} \big/ N_{t-1} \right)}{P_{nt-1}} \quad (14)$$

$$E\pi_{eit} = IL_{et-1} = \frac{P_{et-1} - \left(\sum CMg_{et-1} \big/ E_{t-1} \right)}{P_{et-1}} \quad (15)$$

where N_t and E_t are the number of established firms and entrants in each period and CMg_t are the marginal cost of each company.

III. Model Application

The model is applied an industrial area called *Corredor del Henares* (CdH) that has more than 600,000 inhabitants and is one of the biggest industrial area in the south of Europe. It is divided into two regions where different policies are applied. The area can be seen as a continuum of urban and industrial areas in the proximity of the European route E90, one of the nine west-east references routes of the continent.

Before starting the description of CdH, it is convenient to make a brief reference the Madrid Region that, located in the geographical center of the Iberian Peninsula, constitutes the central node of terrestrial and air communications of the country and the most important administrative and economic center. The industrial and demographic growth in Madrid environment has been articulated around a radial net of roads that communicate the capital of Spain with the rest of the national territory.

Madrid Madrid (with near 850 inhabitants/Km^2) presents the highest population density of Spain, comparable to other developed European regions. The mean population's density is higher by the main municipalities of CdH and it arrives until near 8,000 inhabitants/Km^2 in the case of the municipality of Coslada. It is denominated *Corredor del Henares* to the land fringe of approximately 60 Km of longitude that extends from the oriental border of Madrid city until the city of Guadalajara, settling on the whole on the valley of the Henares river and a traverse tract of the Jarama valley.

Fig 4. Region under study (CdH)

The fertile and flat land favored the consolidation of the towns and the development of the road network that have been historically a main piece in the economic and social articulation of the area.

The most important municipality in the area under study is Alcalá de Henares, so much for its size and recent development, like for its history. It is located in the center of CdH between Madrid and Guadalajara.

The cities of this area have developed around the highway and the railroad that connect Madrid with Barcelona and the rest of Europe.

In CdH there can be distinguished two well differentiated areas:

A. - The one that we could denominate as “recovered industrial area in decline” that includes the area to the east of the city of Madrid until Alcalá of Henares. It is the area that has experienced a bigger economic and demographic development. This area is in Madrid region, traditionally it has a high level of economic activity and occupation; due to the scarcity of industrial land in the region.

Regional public support to firms is limited by the regional policies of the EU, although the high unemployement is reverting the scarcity of public funding in this area.

B. - The one that we could denominate as “recently industrialized area” embraces the territory to the east of Alcalá of Henares until the city of Guadalajara. It includes the municipalities of Azuqueca de Henares, Alovera, Cabanillas del Campo, Marchamalo and Guadalajara, all of them belonging to the region of Guadalajara that is part of Castille-La Mancha and on the contrary that in the Madrid side of the Corridor it has a lot of cheap industrial land. The industrialization in this area has happened later and it seems to have been due at least partially to the different subsidies to the industrial investment in comparison to the ones offered by the neighboring Madrid region.

The industrial growth of CdH began during the decade of the sixties and it affected mainly the municipality of Coslada (the nearest to Madrid), also extending along the E90 highway to the municipalities of San Fernando, Torrejón and Alcalá. During the last five years the industrial and demographic growth has extended in a double way:

On the one hand, a diffusion of the industrialization process toward other municipalities of Madrid region adjacent to the central axis of the Corridor (among other we can highlight Mejorada del Campo, Paracuellos del Jarama, Ajalvir, Torres de la Alameda and Daganzo de Arriba). In this case, normally they are companies of small size that are attracted by the lower prices of the land in these municipalities. The improvements in the infrastructures and the new roads that communicate this location with E90 and other main highways also play an important role in the development of these towns.

On the other hand, it has been a development toward the East following the E90 and the railroad until the city of Guadalajara [20]. A remarkable process of industrial localization of firms has taken place. In many cases these companies were previously located in other places of Madrid region or, even, in other distant regions.

The firms have been attracted to this area mainly by the availability of industrial land next to the E90 highway, well communicated and not too far from Madrid. The lower prices of the land and the higher public funding to the industrial investment have constituted twp crucial variables in the localization process in this area.

In this work the questions related with the land offer and the managerial mobility are also approached, contemplating the land supply, as a factor that conditions the entrance of new companies, and as a determinant of the disappearance of industrial establishments expelled by the possibility of obtaining high profits due to considerable real state appreciations.

As complete information for the environment variables were not available they were approaches by means of mathematical functions.

The figure 5 shows the distribution of the localization advantages for the firms where is possible to observe the influence of the transportation costs and the proximity to the markets.

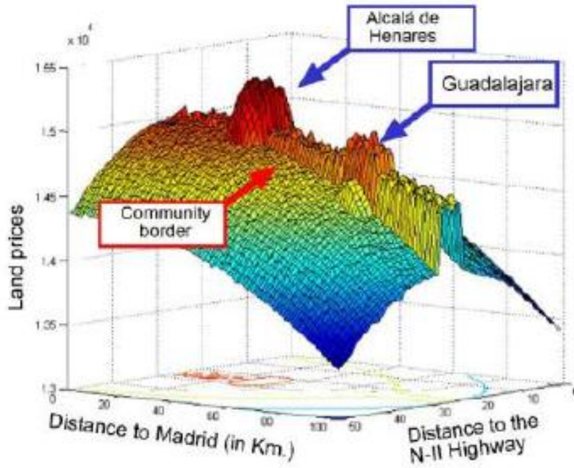

Fig 5. Location utility without policy impact

It can be appreciated that the land price is considerably higher around the E90 highway, and around the main urban areas, Alcalá and Guadalajara. The figures also reveals the localization advantages and the land price are not distributed in a uniform way. There are places where the advantages and the price of the land are considerably different from their nearer environment.

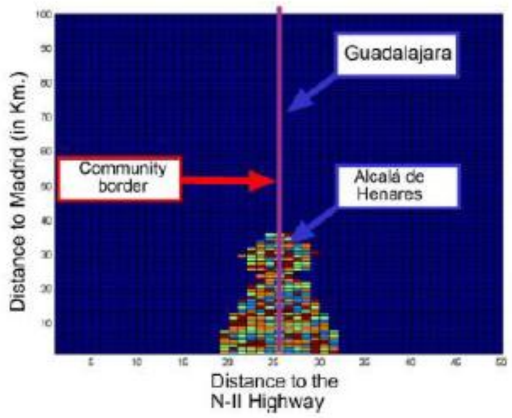

Fig 6. Business location without policy impact

This aspect has considerable importance since it allows the random emergence of groups of companies around points that have some advantages in comparison with neat places. These points can be the seed for the emergence of clusters.

The result of the simulation with this data (figure 6) shows how the companies are located around the E90 highway marked in purple in the nearest area to Madrid until Alcalá. The nearer to Madrid the bigger the industrial area is. No one firm is located in the less populated region although the land price is lower. This result opposes the actual business location pattern observed in Figure 7, with the majority of firms near Madrid and also in Alcalá de Henares, but some of them in Castille-la Mancha near the border between the two region and other ones in Guadlajara.

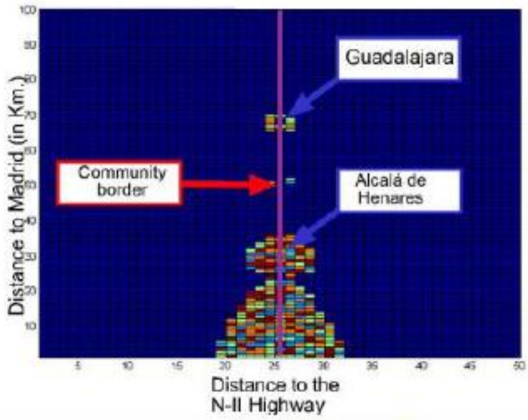

Fig 7. Actual business location

The difference between the result of the simulation and the actual pattern can have two origins. The first possibility is historic reasons, but in that case we would observe a declining industry in Castille-la Mancha and the opposite dynamics is observed in the last two decades. Then the difference between the simulation result and the actual behavior must be the different policy of the regional governments of these two regions. In fact Madrid is more concerned about environment and Castille-la Mancha tries to attract new companies with low tax policies and less regulation [20]. Our objective is to show how these policies affect the costs of companies and we can represent the policy impact as a grant to new plants.

To check if the lack of accuracy of the model was due to the existence of public helps to the localization of companies in Castilla – La Mancha a variable step it was introduced in the price of the land lowering the level of the price in all the cells corresponding to this community (figure 8). The following simulations showed a similar results to the reality.

In this case, a significant part of the companies is located to the other side of the border between the two regions, being created two clusters of firms, one just in the border near to Azuqueca and other bigger in Guadalajara.

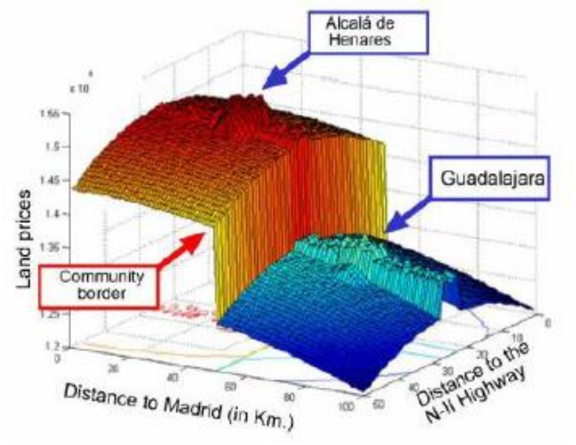

Fig 8. Location utility with the policy impact

One of the most outstanding results is that the politicians of incentives, when they don't suppose improvements in the efficiency of the company, they give changes as a result in the space distribution motivated by the competitive distortions that can generate (deviation effect) more than the number of companies located in the group of the considered geographical area to increase (creation effect).

IV. Conclusions

In this paper we present an ABM that allows measuring and visualizing the spatial patterns of business activity and forecast its dynamics under the current or different public policy scenarios. We check the validity of the model with an industrial area divided into two regions with different policies.

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More for Less: on Consumer Rationality and Bargaining Power on Telecommunication Markets

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***Abstract*—We analyse the large scale agent-based model of a prepaid telecommunication market with oligopolistic competition, heterogeneous calling patterns and different levels of agent rationality. We apply innovative implementation approach of utilizing high performance CUDA computing devices which allows us to consider population of up to 1 million consumers.**

We measure influence of a call graph structure, intra-family network choice coordination and agent rationality level on the market equilibrium. We discover that boundedly rational subscribers, who exploit simple decision heuristics to coordinate network choice within closed user groups, exert much stronger pressure on suppliers than fully rational ones. This leads to lower average calling costs, increased welfare and decreased monopolistic power of operators. We also observe asymmetry in operator margins and volume of on-net and off-net calls in accordance with empirical facts.

I. Introduction

The breakup of national monopolies and liberalization of telecommunication markets in recent decades revived interest in economics of the sector. The seminal publications of Armstrong [1998] and Laffont et al. [1998a,b] became a cornerstone of the ongoing debate on nature of competition in the industry. The original model, subsequently known as the A-LRT framework, analysed a duopoly market with Bertrand style price competition and Hotelling-like network differentiation. In order to preserve its analytical tractability the authors made many simplifying assumptions, in particular they assumed a fully connected and uniform call graph between subscribers. Consequently consumers used operator's market share as a proxy for proportion of their peers using the network when considering which network to join.

It was soon noticed that the model failed to explain numerous stylized facts such as large on-net/off-net price differentials, high interconnection rates and asymmetry between on-net and off-net call volumes in equilibrium.[1] This motivated many researchers to extend it. One of the research threads focused on incorporating network heterogeneity into the framework. Some simple models of heterogeneity were proposed. Cherdron [2001] developed a model with two user groups and a subscriber calling pattern biased towards one of the groups. Dessein [2003, 2004] analysed models with call volume heterogeneity by dividing subscriber population into light and heavy users. In a similar manner Gabrielsen and Vagstad [2003] proposed a model with high and low demand user groups. These ideas were extended into a more general framework by Hahn [2004]. Gabrielsen and Vagstad [2008] introduced an idea of "calling clubs" the members of which call each other more often than the general population. More recently Hoernig et al. [2011] proposed a model of "calling circles" with non-uniform, concentrated calling patterns correlated with subscriber's network preferences. In contrast to the earlier model of "calling clubs" they allowed the circles to overlap. Finally to bridge a gap between theory and reality Harrison et al. [2009a,b] introduced a multiagent approach by explicitly simulating a call graph as a regular random graph.

All these papers however share the common simplifying assumption – a "representative" consumer owns a single telecommunication service and consumers do not coordinate their network choices. Clearly, this assumption is not met in practice. Families and companies can own more than one service and if they do they coordinate operator choices for their services as shown by Birke and Swann [2006, 2010]. Likewise Armstrong and Wright [2009] hypothesize that existence of "closed user groups" coordinating network membership choice may explain observed bias towards on-net calls and encourages on-net/off-net price discrimination by operators.

Modelling this kind of coordinated behaviour combined with network heterogeneity is a methodological challenge for purely mathematical approach. To overcome this limitation Kamiński and Łatek [2010] proposed a multiagent model implementing a concept of a *customer* – a network choice decision maker comprising multiple services. Alas, their results were not directly comparable to work of Laffont et al. [1998b]. Then Kamiński [2012a,b] proposed a multiagent model generalizing the model of Laffont et al. [1998b] beyond the duopoly case and replicating it as a special case. His work took into account call graph heterogeneity and coordination of subscriber choices within family-like groups. He operated on a relatively small population of 4096 fully-rational subscribers.

In this paper we extend the approach of Kamiński [2012a] to consider 2 classes of customers – fully and boundedly rational. Additionally we subdivide the latter class by using 2 different heuristics for network choice coordination among cooperating subscribers. Furthermore we introduce high performance CUDA computing technology to operate on a much larger

[1] see Harbord and Pagnozzi [2010, section 3.2] for recent empirical evidence from selected European markets

agent population (up to 1 million). This innovative approach allows us to: *(i)* take precise measurements for oligopoly markets with 3 and 4 operators which proven to be problematic with small agent population proposed by Kamiński [2012b]; (*ii)* compare the outcomes for fully rational subscribers with outcomes for subscribers characterized by bounded rationality; (*iii)* contribute to the research on bounded rationality by providing another example of *"less-is-more"* effect when simple heuristic decision rules prove to be superior to fully rational decision making.

The rest of the paper is organized as follows. In section II we describe the model used for the simulation and discuss the rationale for introducing the novel element of bounded rationality. In section III we describe simulation setup and present the results. We discuss the results in section IV. Section V concludes.

II. Model Description

In this section we describe the behaviour of agents (customers, subscribers and operators), method of generation of a call graph and subscriber families in the model. The specification strictly replicates model of Laffont et al. [1998b] for linear discriminatory pricing with extensions proposed by Kamiński [2012b] allowing for customer heterogeneity and oligopolistic competition. In the presentation of the base framework we follow description presented in Kamiński [2012a] with necessary additions and modifications.

Consider a telecommunication market on which there are K operators and N subscribers. A *subscriber* is a single calling contract with the operator. Each subscriber is owned and managed by a *customer* and a customer comprises one or more subscribers. Depending on context we may also call a subscriber – a *service*, and a customer – a *family*.[2] Subscribers call each other with non-uniform intensity – every subscriber maintains her list of "contacts" which is a subset of the subscriber population. The ensemble of subscribers' contacts constitutes the social communication network or a *call graph*.

The market is assumed to follow calling party pays regime and operators can discriminate between on-net and off-net calls. The pricing is linear i.e. there is no fixed fee for network membership and no "free minutes" allowance. There is also no switching costs for changing the operator. The market is mature – thus we take that the set of operators, customers, subscribers and a call graph remain constant.

Every operator $k \in \{1, ..., K\}$ sets a price for a unit of call time inside his network on_k and outside his network off_k. Let $s(i) \in \{1, ..., K\}$ be the operator chosen for subscriber i by a customer who owns it.

A. Subscriber and Customer behaviour

Subscriber call intensity depends on a call price. Let w_{ij} be the call intensity from subscriber i to subscriber j given the calling price equals 1 and q_{ij} be proportional change of this volume given actual market price. To determine the price paid by subscriber i calling subscriber j we have to check if they use the same operator. The price formula is defined as

$$p_{ij} = on_{s(i)}[s(i) = s(j)] + \mathit{off}_{s(i)}[s(i) = s(j)],$$

where expression $[\ell]$ evaluates to 1 if ℓ is true and to 0 if it is false. The rule states that if subscribers i and j belong to the same operator then on-net price is charged and otherwise off-net price is used.

Extending Laffont et al. [1998b] we define a subscriber's net surplus as

$$V_i\big(s(i)\big) = \sum_{j=1}^{N} w_{ij}\left(\frac{q_{ij}^{1-1/\eta}}{1-1/\eta} - q_{ij}p_{ij}\right) - \frac{X^i_{s(i)}\sum_{j=1}^{N} w_{ij}}{2\sigma},$$

where $\eta > 1$ is price demand elasticity, $X^i_{s(i)} \in [0, 1]$ is measure of subscriber i preference towards operator $s(i)$ and $\sigma > 0$ is a measure of strength of this preference. We assume that subscriber preferences are independently uniformly distributed $\mathbf{X}^i = (X^i_1, \ldots, X^i_K) \in [0, 1]^K$. In comparison to formula given by Laffont et al. [1998b] we need to add a normalizing factor $\sum_{j=1}^{N} w_{ij}$ to reflect the fact that a call graph need not be fully connected and uniformly weighted.

The above equation can be solved for optimal call volume by a subscriber given operator prices. A utility maximizing subscriber will set $q_{ij} = p_{ij}^{-\eta}$ and will obtain surplus

$$V_i\big(s(i)\big) = \sum_{j=1}^{N} w_{ij}\frac{p_{ij}^{1-\eta}}{\eta - 1} - \frac{X^i_{s(i)}\sum_{j=1}^{N} w_{ij}}{2\sigma}.$$

Using this formula a subscriber can choose operator $s(i)$ so as to maximize the surplus. This is the standard analytical approach of Laffont et al. [1998b].

1) Fully rational customer: We extend the A-LRT approach and assume that a customer selects the *globally* optimal allocation of a family of subscribers to operators. Let $F \subset \{1, \ldots, N\}$ be a list of subscribers belonging to a single customer. Then a customer chooses the subscriber allocation $\vec{a} = \big(\forall i \in F : s(i)\big)$ that maximizes the aggregated family surplus

$$V_F(\vec{a}) = \sum_{i \in F} V_i\big(s(i)\big)$$

The optimal solution to the above allocation problem can be different from individual subscriber optimization because it allows a customer to *coordinate* operator choice among subscribers.[3] For example (as found in empirical data and later results of the model) one can expect that $on_k < \mathit{off}_k$. In such a case a customer may be better off by allocating all the subscribers to one operator to benefit from cheaper on-net

[2] to reflect that it corresponds to a "*friends & family*" circle in telecommunication jargon

[3] The fact of coordination within closed user groups is supported by empirical data – for example Birke and Swann [2006] find out in the examined sample that 68% of households with 2 mobile subscriptions use the same network operator

Algorithm 1 Find best subscriber allocation $\vec{a} \in \{1,..,K\}^{|F|}$

$bestUtility \leftarrow (-\infty)$
for all $\vec{x} \in \{1,..,K\}^{|F|}$ **do**
  if $V_F(\vec{x}) > bestUtility$ **then**
    $bestUtility \leftarrow V_F(\vec{x})$
    $\vec{a} \leftarrow \vec{x}$
    $tieCounter \leftarrow 1$
  else if $V_F(\vec{x}) = bestUtility$ **then**
    $tieCounter$++
    if $1/tieCounter > runif(0,1)$ **then**
      $\vec{a} \leftarrow \vec{x}$
    end if
  end if
end for
return $\vec{a}$

calls within a family circle.[4]

Please note that in the model customers choose operators non-strategically and take operator prices as given. Algorithm 1 describes details of the implementation.

2) Boundedly rational customer: One may argue that allocating services in a globally optimal way is too strong an assumption. Indeed, the number of possible allocations a fully-rational customer has to consider grows exponentially with family size as $K^{|F|}$. With 4 operators and 5 family members a total of 1024 allocations has to be considered. Computational burden with even larger families could be unbearable for a flesh & blood agent. Therefore we consider alternative scenarios with nearly-rational customers who optimize within a bounded set of possibilities and resort to a simple "*take-the-best*" heuristics in allocating their subscribers. These are:

1) *single operator optimization*: allocate the entire pool of subscribers to one of the operators or keep the current allocation – whichever best, where the initial allocation is randomly selected (see Algorithm 2);
2) *initial individual optimization*: maximize subscriber utilities individually taking other family member choices as given; repeat the procedure 3 times to allow for adjustment for other family members choices; then proceed as in Algorithm 2.

The constraints of human mind in processing large amounts of information laid foundations under the theory of bounded rationality [Simon, 1955]. Today there is abundance of evidence that individuals retreat to simplified reasoning and heuristic decision making when confronted with an overwhelmingly complex decision problem [Gigerenzer and Selten, 2002]. In context of telecommunications this is traditionally being related to plethora of available tariffs and their

[4]Obviously this type of uniform allocation needs not be globally optimal in every case as it depends on proportion of intra-family to extra-family call volume. In general finding the globally optimal subscriber allocation in case of a heterogeneous call graph is a non-trivial task and its completion as such can be guaranteed by the "brute-force" evaluation of *every* possible allocation. This is the approach taken in this work for fully rational customers – despite the obvious disadvantage of computational complexity of $O(K^{|F|})$.

Algorithm 2 Find best subscriber allocation $\vec{a}$: single operator optimization (heuristics 1)

$\vec{a} \leftarrow \vec{x} \leftarrow \{\forall i \in F : s(i)\}$ (initial subscriber allocation)
for $k = 1$ to K **do**
  for all $i \in F$ **do**
    $x_i \leftarrow k$
  end for
  if $V_F(\vec{x}) > V_F(\vec{a})$ **then**
    $\vec{a} \leftarrow \vec{x}$
    $tieCounter \leftarrow 1$
  else if $V_F(\vec{x}) = V_F(\vec{a})$ **then**
    $tieCounter$++
    if $1/tieCounter > runif(0,1)$ **then**
      $\vec{a} \leftarrow \vec{x}$
    end if
  end if
end for
return $\vec{a}$

structural complexity. Bolle and Heimel [2005] observed that even intellectually sophisticated mobile phone users (university students) base their network membership decision on simple comparison of absolute levels of on-net/off-net price vectors failing to weigh properly proportion of on-net to off-net calls. This "fallacy of dominant price vectors" as they call it obviously leads to sub-optimal choice and higher average calling costs. The result was confirmed on an independent sample of students and faculty staff by Haucap and Heimeshoff [2011], who call the phenomenon a "price differentiation bias". Barth and Graf [2012] came to a similar conclusion in a discrete choice experiment. In a recent empirical study based on a large dataset from China Telecom Miao and Jayakar [2014] reported a vast majority of consumers to make non-optimal selection from the menu of available tariffs. They also found out probability of non-optimal selection to increase with complexity of a tariff plan. Likewise Lambrecht and Skiera [2006], Mitomo et al. [2009] and Gerpott [2009] observed a "flat rate bias" – propensity of consumers to overestimate savings provided by "unlimited" tariffs even if measured usage-based rates would result in lower average cost.

More generic evidence comes from extensive literature on bounded rationality. We consider studies of chess players to be particularity relevant to the subscriber coordination problem. The task of allocating services of a large family, say with 10 subscribers, to numerous available networks resembles the problem of a chess player in terms of immense quantity of available strategies. Chess player reasoning was studied by De Groot [1965] and later by Simon [1972] and Chase and Simon [1973a,b]. De Groot discovered that both beginners and master players apply similar simplified decision procedures (heuristics). At each move they analyse only a small subset of available strategies – no more than a dozen or so. The secret of course is to pick the right subset for analysis and this is where masters "master" as they know, through experience and learning, how to select the most promising ones.

Although the decision heuristics designed for our experiment may seem simplistic at first they follow the rules outlined by master chess players. It is easily seen that some allocation strategies, namely uniform allocation of services to one of the operators, bear higher potential for substantial gain in utility than any seemingly "random" strategy. When time or computational capacity is scarce it is best to focus on the most promising alternatives – as master chess players do. Such simplified optimization approach is also justified by anecdotal evidence – many if not most large organizations equip their staff with mobile phones from a single operator, although corporate contracts are somewhat more complex than a simple prepaid market model analysed here.

The second heuristics extends the first one by allowing subscribers to individually optimize their network choices prior attempting to assign all the family services to one operator. The rationale behind such approach is that a single operator optimization (heuristic rule 1) is beneficial mainly for large families. Firstly, the effort of fully rational allocation is huge for such families due to combinatorial explosion of the search space so heuristic decision making provides dramatic savings in this respect. Secondly, the larger a family gets the more likely volume of intra-family calls outweighs volume of extra-family calls. Small families on the other hand may be better off by *not* coordinating their choices and optimizing individually instead. They are also more likely to encounter a Pareto-optimal allocation within the 3-iteration adjustment schema we allowed for as size of their decision set is much smaller. Simply speaking the heuristic rule 2 allows small families to benefit from individual optimization and large families from a single-operator optimization at almost no computational overhead.

In the end it is worth noting that we model both rational and nearly-rational customers as having passive expectations i.e. they assume their neighbourhood to remain static when making network allocation decision for their subscribers. In fact the environment is not static as all the other customers make their subscriber allocation decisions at the same time and based on the same information set. Therefore we repeat allocation procedures for the entire customer population until the stable subscriber allocation is reached or changes are of simple cyclical nature i.e. no subscriber changes network allocation or some subscribers switch back and forth between networks in stable patterns.

B. Operator behaviour

Take that a_c is cost of initiating the call, b_c is cost of terminating the call and i_c is interconnection fee (paid by a call initiating operator to a terminating operator). By f_c we denote fixed cost of maintaining a subscriber by a chosen network operator. Under such notation operator k calculates profit π_k using formula (again it is a direct extension of Laffont et al. [1998b]):

$$\begin{aligned}\pi_k(on_k, \mathit{off}_k) = (on_k - a_c - b_c)on_k^{-\eta} \sum_{s(i)=k=s(j)} w_{ij} + \\ +(\mathit{off}_k - a_c - i_c)\mathit{off}_k{}^{-\eta} \sum_{s(i)=k\neq s(j)} w_{ij} + \\ + \sum_{s(i)\neq k=s(j)} (i_c - b_c)\mathit{off}_k{}^{-\eta} w_{ij} + \\ -\{i : s(i) = k\} f_c \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{w_{ij}}{N}.\end{aligned}$$

The formula comprises four terms taking into account optimal call intensity given prices ($q = p^{-\eta}$). In the first term we calculate operator profit from on-net calls. The second and third terms represent profits from outgoing and incoming off-net calls respectively. The last term counts fixed costs of customer maintenance, for example customer service and billing cost. Similarly to parameter σ in order to assure its consistency with the reference model it has to be normalized.

C. Equilibrium Prices

We compute equilibrium prices for both the reference A-LRT model and for its multiagent counterpart. Note that Laffont et al. [1998b] provide only implicit formula for equilibrium, so it is not possible to calculate the reference prices directly. Therefore following Kamiński [2012b] we applied an adaptation of numerical procedure proposed by Krawczyk and Zuccollo [2006]. We start from prices equal to marginal cost. In each step of the simulation operators find the best response prices in the neighbourhood of current prices and next they update their prices by moving halfway from current prices towards the best prices. In each iteration we narrow the neighbourhood radius. The procedure is repeated 2^{13} times – we confirmed experimentally that it is sufficient for obtaining accuracy of results in order of 10^{-3}.

Similar approach is taken for obtaining the multiagent model equilibrium prices. We start from prices in proximity of the reference A-LRT prices and with a random allocation of subscribers to networks. In each simulation step the elected operator finds the best response prices by testing if it is profitable to change its on-net and off-net prices by ± 0.01 or leave them unchanged. Then the new pricing is announced, other operators adjust their prices and consumer adjust their network membership choices. The procedure is repeated until the stationary state is reached i.e. the current prices being the best prices and stable allocation of subscribers to networks.

We assume operators to "anticipate" how customers will react to changed prices. This is achieved by an operator recursively sub-simulating the market response for new pricing as proposed by Łatek et al. [2009]. Because the multiagent simulation is non-deterministic there is a natural tendency towards instability of the optimal decisions. In order to pinpoint approximate equilibrium in each step prices are rounded to precision of 0.01. If optimal responses do not deviate more than this value from current prices then current prices are taken as the equilibrium approximation.

D. Call Graph Generation

We assume a call graph to have small-world property for consistency with structure of empirical telecommunication networks [Onnela et al., 2007a,b]. We generate it using Watts and Strogatz [1998] algorithm adapted to handle directed graphs. Graph generation is started from ring lattice with neighbourhood radius given as a parameter, next edges are rewired with defined probability. Because we assume the graph is directed, rewiring is done separately for each direction of initial connection between services.

A complementary part of a call graph generation is assignment of services to customers (families). We define parameter $family$ denoting maximal family size. Each family has random size that is drawn from Zipf distribution truncated at the parameter value level. In this way smaller families are more probable than large ones. Additionally we make services belonging to the same family a clique in a call graph which accounts for the fact that services belonging to the same family tend to call each other.

III. Simulation Results

In this section we first we describe the setup of the simulation experiment and then we present the results obtained.

A. Experiment Setup

The parameter range for the simulation is given in Table I. We follow recommendations of Kamiński [2012a] with minute modifications. We take a call termination cost $b_c = 1.0$ as the numéraire so that all the remaining parameters are expressed relative to it. It is natural to assume parameters a_c and i_c to be slightly larger than b_c and therefore we set their range to $[1.00; 1.50]$ and $[1.00; 1.75]$ respectively. The choice of the network substitutability parameter σ follows recommendations of Laffont et al. [1998b] where it is required not to be too large in order to ensure existence of a stable shared-market equilibrium. On the other hand if it was too small then the non-pricing component would dominate subscriber's utility which would be unrealistic. In order to balance these two effects and following Harrison et al. [2009a] and De Bijl and Peitz [2002] the range of σ was set to $[1.00; 2.00]$. In a similar manner following Laffont et al. [1998b] the value of elasticity parameter η should be greater than 1. On the other hand Ingraham and Sidak [2004] report that price elasticity of demand on telecommunication markets is not high, hence the choice of parameter range is $[1.25; 1.75]$. Next it is natural to assume that f_c should not be large. It is normalized not to exceed 10% of average customer calling costs when $on_k = off_k = 1$. Network radius parameter range was chosen following data from Wojewnik et al. [2011] and a graph rewire probability parameter spans full range of admissible values. The maximum family size parameter spans from 1 to 5 and the number of operators from 2 to 4.

We extend the span of parameter $family$ for boundedly rational customers to measure impact of family size more precisely. We put the cap of 5 on the parameter for fully rational customers due to computational complexity constraints (see section II-A2 for the discussion). Consequently we extend the span of parameter $radius$ to measure potential influence of interactions between the two.

TABLE I
Simulation Parameter Value Range

parameter	value (range)	parameter	value (range)
σ	$[1.0, 2.0]$	f_c	$[0.0, 0.1]$
η	$[1.25, 1.75]$	$rewire$	$[0.0, 1.0]$
b_c	1.0	N_{LRT2}	102400
a_c	$[1.0, 1.5]$	N_{EXT34}	531441
i_c	$[1.0, 1.75]$		
Fully rational		Boundedly rational	
$radius$	$\{3, 4, 5\}$	$radius$	$\{3, \ldots, 10\}$
$family$	$\{1, \ldots, 5\}$	$family$	$\{1, \ldots, 10\}$

B. Simulation Docking

We performed simulation docking to verify if it replicated the A-LRT model when the equivalent parametrization was used. For this purpose we used a fully connected subscriber graph with equal connection weights and single member families i.e. subscribers calling each other with uniform intensity and no intra-family coordination. We examined 4 different subscriber population sizes (15k, 100k, 500k and 1mln) and 3 different methods of probing subscriber preference space – equidistant grid, pseudo- and quasi-random. Mersenne-Twister and randomized Sobol were used as pseudo- and quasi-randomness sources respectively. We randomly selected 100 simulation parameter sets and for each set performed 32 simulation runs per model, per population size, per preference space probing method. The results of the docking exercise are summarized in Table II. Models are coded using 5 alphanumeric characters schema as follows:

- prefix LRT2 marks the standard duopoly model of Laffont et al. [1998b] with unit interval uniform preferences;
- models prefixed EXTn where n is number of operators are extended oligopoly models as proposed by Kamiński [2012b] with subscriber preferences independently uniformly distributed on hypercube $[0, 1]^K$;
- suffixes {S,R,Q} stand for equidistant grid, pseudo-random and quasi-random preference space probing respectively.

Columns *don* and *doff* are mean deviations from the numerically computed theoretical A-LRT equilibrium prices (on-net and off-net respectively). Columns *sdon* and *sdoff* are mean standard deviations of these values. Column *onshare* is mean share of on-net calls, the standard deviation of this value is 0 in all cases therefore it is not shown in the table.

The reader may notice that equidistant grid preferences (type S) delivered the most accurate results for the A-LRT equivalent setup (LRT2). The accuracy however drastically deteriorated for an extended Kamiński [2012b] model specification. The reason was that equidistant probing of multidimensional preference space caused heavy discretization of the model response surface.[5] This resulted in large bias. For the extended specification pseudo-random (R) and quasi-random (Q) probing worked much better and with comparable accuracy. One may also see that accuracy of models with 500k

[5] the problem known as "*curse of dimensionality*" in numerical analysis

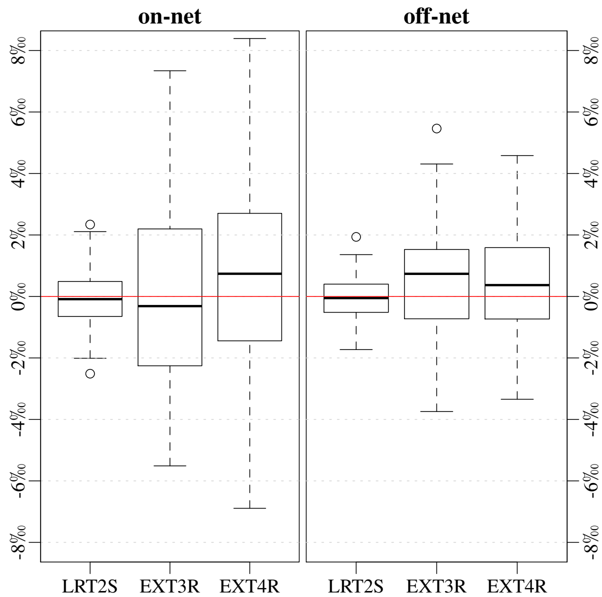

Fig. 1. Simulated to theoretical price deviations for the A-LRT equivalent configuration

and 1mln subscribers is very close. It was natural therefore to choose the smaller population for further analysis as having lower computational capacity requirements.

We used accuracy of docking results to select models for further analysis and the actual simulation run. We have arbitrarily chosen the subscriber population sizes to be $N_{LRT2} = 320^2 = 102400$ for the duopoly A-LRT equivalent setup and $N_{EXT34} = 81^3 = 729^3 = 531441$ for the extended triopoly and 4-network oligopoly as providing the best accuracy to performance ratios. For the preference space probing we have chosen uniform grid (S) and pseudo-random preferences (R) for the duopoly and oligopoly models respectively. The quasi-random approach (Q) delivered slightly lower variance of the results but we opted for pseudo-randomness as more reliable for standard error estimates.

Fig. 1 shows simulated to theoretical price deviations of the selected models for the A-LRT equivalent configuration (averaged observations per point). One may see the multiagent models reproducing theoretical prices with high accuracy – deviating by no more than 0.9% and 0.5% for on-net and off-net prices respectively in case of model EXT4R. The small discrepancies came from two sources: (*a*) rounding errors (we used 4 and 2 decimal places for computing the theoretical A-LRT and multiagent equilibrium prices respectively) and (*b*) stochastic nature of discrete subscriber preferences in the multiagent setup for the oligopoly models (EXT3R, EXT4R).

C. Results

The results of the multiagent simulation were obtained using 10131 random parametrizations for the duopoly (LRT2) model and 7745 random parametrizations for the triopoly (EXT3) and 4-network oligopoly (EXT4) models. For each parametrization there were in average 32 simulation runs for the duopoly model and 19 simulation runs for the oligopoly models. For each run of EXT3 and EXT4 models a new set of random preferences was drawn. Additionally a new random call and family graphs were generated every eight run. In total 712041 simulation runs were performed.

We applied linear regression metamodeling approach to ensure simple interpretation of the results. Even though the relationship between parameters and equilibrium prices is in fact non-linear, within the chosen paremeter range such approximation is acceptable as suggested by R^2 values of the regression model close to 1. The regression results for the average calling cost are presented in tables III and IV. Network choice coordination classes are coded as "FamilyCN" where C denotes fully rational (F), heuristic type 1 (H) and type 2 (G) coordination procedures respectively, and $N \in \{1, \ldots, 10\}$ denotes a maximum family size.

Fig. 2 shows, *ceteris paribus*, average on-net and off-net margin differentials between the reference A-LRT model and the simulated multiagent models with network heterogeneity and different levels of agent rationality for the duopoly market. The theoretical prediction of Laffont et al. [1998b] is that in equilibrium on-net and off-net profit margins are equal. As can be seen simulated operator margins deviate significantly from the theoretical results. When no customer coordination is taken into account $(family = 1)$ the simulated on-net and off-net margins are in average *higher* by 5 and 1 percentage points respectively. This represents the pure effect of the network heterogeneity and confirms that for non-uniform call graphs tariff mediated network effects are internalized by operators in form of higher profits. This experimental result is in accordance with recent theoretical predictions of Hoernig et al. [2011] and is independent of the number of competing operators as seen on Fig. 2, 5 and 6.

Customer *coordination effect* counteracts the network heterogeneity effect and quickly outweighs it as the family size grows. In the duopoly setup with large families the fall in on-net margins is stronger than rise in off-net margins. Overall the average calling costs are decreased as seen on Fig. 3. The coordination effect is strongest for the duopoly market and fades as the number of networks grows (Fig. 5 and 6). This is intuitively understandable – with more operators, peer services are more dispersed among them and coordination becomes more intricate. Also operator margins go down due to intensified competition so there is less room for price adjustment anyhow. For oligopoly markets with 3 and 4 operators and fully rational customers the fall in on-net margins is just about enough to offset the rise in off-net margins. This causes costs to remain constant regardless of a family size.

Quite unexpectedly the fall in margins and average calling costs is dramatically larger in case of boundedly rational customers as compared to fully rational ones. Moreover in this case both on-net and off-net margins go down *simultaneously*. One may see for example that in case of a duopoly market with up to 5 member families fall in on-net margin is more than 2 and 3 times deeper for heuristic rule 1 and 2 respectively as compared to fully rational case (Fig. 2). Again the magnitude

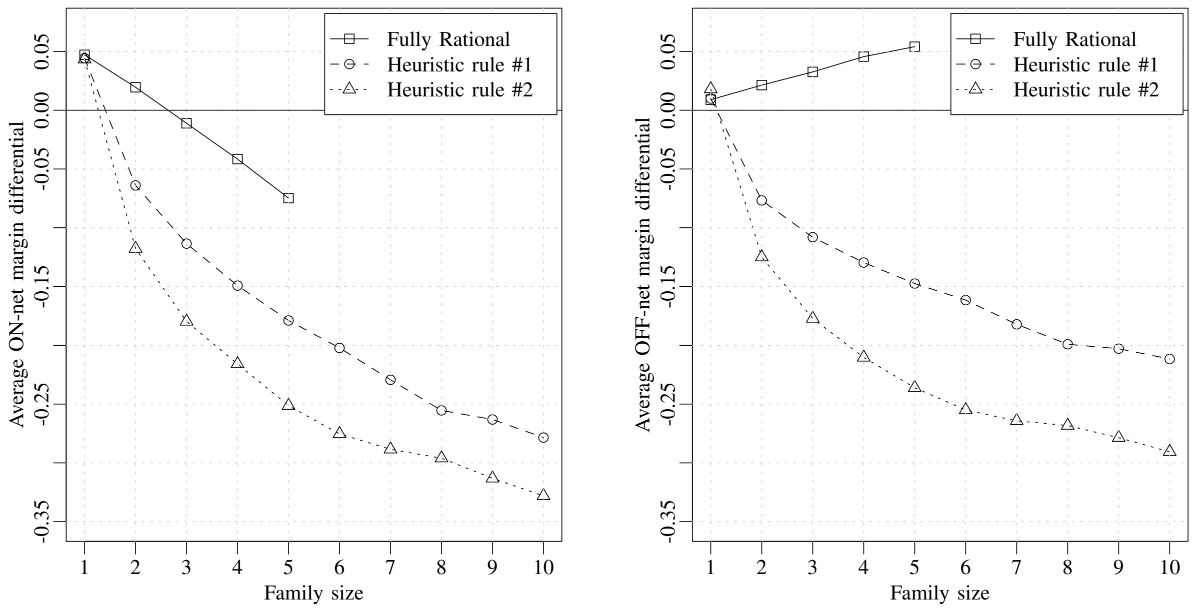

Fig. 2. Simulated to theoretical margin differentials for the duopoly model (LRT2S)

of the effect fades as number of operators grows for the same reason as above, but its direction remains the same for both on-net and off-net prices.

Another interesting simulation outcome is bias towards on-net calls. In the A-LRT framework in equilibrium the share of on-net calls equals the market share of the operator. This is at odds with empirical data as on-net volume share observed on real markets is much higher [Harbord and Pagnozzi, 2010]. As seen on Fig. 4 this effect emerges from the multiagent model. Again we see impact of the heterogeneity effect (when $family = 1$) and the coordination effect – on-net volume share grows as the family size grows. Interestingly the differential to the A-LRT model gets larger as number of operators grows as seen on Fig. 5 and 6. As previously the effect is much stronger for boundedly rational customers as compared to fully rational ones.

Finally it is worth pointing out that the effect of the interconnection charge (i_c) on the average consumer cost is systematically larger in the multiagent setup than in the A-LRT equivalent setup, despite monopolistic power of operators in the former being weakened by the coordination effect. This shows that models ignoring network graph heterogeneity underestimate influence of this parameter on market prices.

IV. Discussion

Both the magnitude and the direction of influence of agent rationality level on the market equilibrium came as a surprise. Conventional wisdom perceives boundedly rational behaviour as inferior substitute to fully rational one and expects it to deliver results that are second-order worse at minimum. Moreover one would expect that in a large population small individual level deviations from Pareto-optimal choices (i.e. nearly-rational behaviour) cancel each other out and do not cause significant distortion of the aggregated outcome.

At least two lines of research questioned such reasoning. Gigerenzer [2004] provides examples of heuristic decision making leading to results superior to fully rational one – the "*less-is-more*" effect. Akerlof and Yellen [1985] show how seemingly insignificant second-order deviations from perfect rationality cause unexpected first-order systemic effects. Contributing to this line of thinking the results of our model provide an example of less mental effort leading to the more desirable outcome – increased welfare of agents. They also show how nearly-optimal behaviour may lead to substantial deflection from the theoretical results.

One should however be careful in drawing generalized conclusions. In an attempt to explain the phenomenon we need to consider whether it is an artifact of the model, the emergent property of the system being modelled or maybe both. We argue that the latter is the case. Part of the explanation lies in the way we model subscriber preferences. We inherit the A-LRT approach with preferences uniformly distributed on a generalized unit interval $[0, 1]^K$. Notice that when we bundle i.i.d. subscribers into customers and as the family size grows the aggregated customer preferences approach the normal distribution and concentrate around the marginal subscriber. Hence the population of customers (who are decision makers in our model) is more indifferent between operators than population of subscribers. As a result the competition between operators intensifies and prices go down. This effect is equivalent to increasing value of σ – the substitutability parameter. The above is not the complete rationale however. If it were there would not be visible discrepancies between fully-rational and boundedly rational outcomes as the σ-effect occurs for *any* type of subscriber coordination.

Strong network effects seem to be the hidden driving force.

A single subscriber switching operators may trigger a cascade of followers who find it beneficial to do the same in the modified network constellation. This ignites a chain-like reaction in the entire population. This induced churn effect is at work for both fully and boundedly rational setups however it is orders of magnitude stronger in the latter case. To see why consider that in the fully rational setup families will most likely *not* choose uniform network membership while in the boundedly rational setup they will most likely choose it. Than in the latter case entire subscriber families (customers) switch operators as opposed to mostly subscriber level switches in the former case. Let us remind here that customers in the model choose networks non-strategically i.e. they take the environment as given and do not anticipate far-reaching consequences of their decision on the systemic level. Paradoxically this causes fully rational customers to overlook potential gains in utility reaped by boundedly rational agents as a cumulative side effect of their simplified reasoning.

Another considerable fact is divergence between outcomes of the two apparently similar heuristic rules. It was already explained in section II-A2 but we may repeat for clarity that the heuristic rule 1 is beneficial mostly for large families. Small families do better by *not* coordinating on a single network as volume of their intra-family calls is unlikely to outweigh volume of extra-family calls. Such families are better off when subscribers make network choices individually. Heuristic rule 2 allows for such diversity of choice and hence fits the environment better. Consequently it leads to implicit market segmentation as small and large families act differently. Overall customers are able to extract more surplus for themselves. Since in our model operators are not allowed to discriminate pricing on customer classes they respond by decreasing prices yet again to give up more of the surplus for "smarter" customers. This affects off-net prices more than on-net prices as seen on Fig. 5 and 6.

To what extent the subscriber coordination effect is at work on real markets is an open question that requires further research, especially if you consider some unrealistic assumptions of the model. For example subscriber mobility is assumed to be frictionless as there is no cost associated with network switching. So you may have a lot of network "jumpers". Nevertheless consistency of the results with theoretical predictions on the one hand and the stylized facts on the other indicate the effect as a plausible explanation to many enigmatic market phenomena, one complementary to hypothesis of "call externalities" prevailing in the theoretical literature. Furthermore diversity of the results and sensitivity of the model suggest that scrutinizing actual network choice coordination procedures among consumers is crucial for understanding the mechanics of telecommunication markets, particularly in context of the long-lasting regulatory discussion on the extent of monopolistic power of network operators. Our research demonstrates that it depends heavily on micro-foundations as apparently insignificant differences in agent behaviour lead to substantially different market outcomes.

IMPLEMENTATION NOTE

The simulation was implemented as a standalone Java application with the compute intensive parts ported to C with NVidia CUDA extensions. We used Java CUDA bindings to glue the pieces together. CUDA converts mass-market graphical processing units (GPUs) into massively parallel high performance computing devices. It has been used for scientific computing in many domains [Owens et al., 2008, Nickolls and

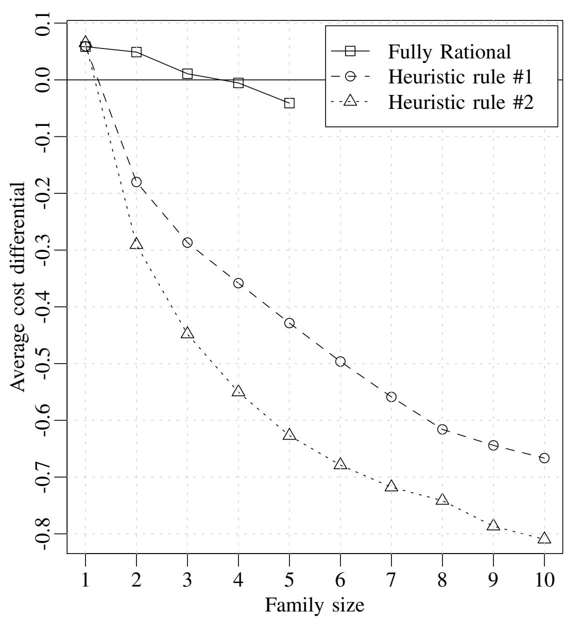

Fig. 3. Simulated to theoretical average cost differential for the duopoly model (LRT2S)

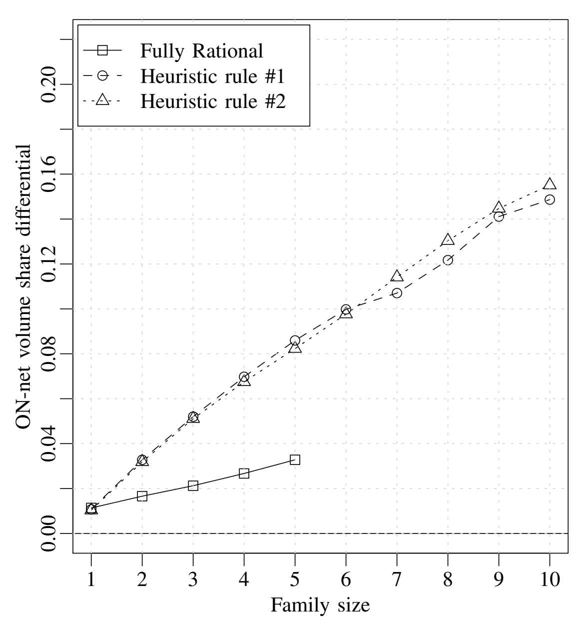

Fig. 4. Simulated to theoretical on-net volume share differential for the duopoly model (LRT2S)

Dally, 2010].

The application have run on mixture of commodity Intel and NVidia hardware under control of Linux operating system. Access to hardware has been provided courtesy NVidia Test Drive program by Boston Limited and Megware Computer Vertrieb und Service GmbH. Access to the source code will be provided by authors upon an e-mail request.

V. Concluding Remarks

We have built the large scale multi-agent model of a mobile telecommunication market. It extends the standard model of Laffont et al. [1998b] by introducing customer heterogeneity, intra-family network choice coordination and different levels of customer rationality.

We confirmed that network heterogeneity plays an important role in shaping equilibrium prices on telecommunication markets. We observed the heterogeneity surplus being internalized by operators in form of higher profits as predicted by Hoernig et al. [2011]. We have shown the subscriber *coordination effect* to counteract the heterogeneity effect and offset or outweigh it leading to significant fall in operator margins and lower average calling costs.

Most importantly we discovered that the level of customer rationality has very strong influence on the market equilibrium. We have shown that, due to unanticipated network effects, boundedly rational customers extract significantly more of the surplus than fully rational ones. Surprisingly, tariff mediated network effects caused by termination based price discrimination turned against operators confronted with nearly rational, network choice coordinating subscribers.

We also proposed an innovative approach to implementation by utilizing high performance CUDA computing devices. This allowed us to operate on large scale with population of up to 1 million agents. We demonstrated how mass-market, commodity GPU devices can be used by social scientists as an inexpensive alternative for traditional data centres. We conclude that massive parallelism of CUDA devices makes it a perfect fit for multigent simulations characterized by high level of inherent parallelism.

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APPENDIX

TABLE II
MODEL DOCKING RESULTS

Model	Population	don	sdon	doff	sdoff	onshare
EXT2Q	15625	0.0091	0.0551	0.0028	0.0582	0.5000
EXT2R	15625	0.0178	0.1291	0.0198	0.1342	0.5000
EXT2S	15625	-0.1973	0.1236	-0.2891	0.1297	0.5000
EXT3Q	15625	0.0032	0.0747	0.0114	0.0701	0.3333
EXT3R	15625	0.0098	0.0971	0.0165	0.1072	0.3333
EXT3S	15625	2.3996	0.1624	2.8022	0.1763	0.3339
EXT4Q	14641	0.0166	0.1008	0.0093	0.0741	0.2500
EXT4R	14641	0.0143	0.0942	0.0116	0.0877	0.2500
EXT4S	14641	3.0507	0.3256	3.5281	0.3550	0.2545
LRT2Q	15625	-0.0012	0.0226	0.0004	0.0212	0.5000
LRT2R	15625	0.0200	0.1275	0.0213	0.1320	0.5000
LRT2S	15625	-0.0014	0.0064	-0.0012	0.0063	0.5000
EXT2Q	117649	-0.0007	0.0264	0.0010	0.0235	0.5000
EXT2R	117649	0.0000	0.0486	0.0017	0.0481	0.5000
EXT2S	117649	0.1061	0.0290	-0.0689	0.0315	0.5000
EXT3Q	117649	-0.0014	0.0291	0.0024	0.0193	0.3333
EXT3R	117649	-0.0000	0.0411	0.0038	0.0390	0.3333
EXT3S	117649	0.2762	0.1364	0.3696	0.1499	0.3335
EXT4Q	104976	0.0043	0.0409	0.0017	0.0215	0.2500
EXT4R	104976	0.0056	0.0469	0.0032	0.0326	0.2500
EXT4S	104976	2.3398	0.2231	2.7599	0.2514	0.2517
LRT2Q	117649	-0.0004	0.0073	-0.0004	0.0061	0.5000
LRT2R	117649	0.0010	0.0489	0.0028	0.0477	0.5000
LRT2S	117649	-0.0003	0.0022	-0.0002	0.0029	0.5000
EXT2Q	531441	0.0003	0.0110	0.0008	0.0088	0.5000
EXT2R	531441	0.0002	0.0252	0.0010	0.0233	0.5000
EXT2S	531441	0.0089	0.0291	0.1784	0.0772	0.5000
EXT3Q	531441	-0.0005	0.0149	0.0013	0.0084	0.3333
EXT3R	531441	-0.0004	0.0220	0.0018	0.0195	0.3333
EXT3S	531441	-0.4257	0.0359	-0.4090	0.0398	0.3334
EXT4Q	531441	0.0016	0.0167	0.0011	0.0079	0.2500
EXT4R	531441	0.0016	0.0229	0.0015	0.0157	0.2500
EXT4S	531441	0.8856	0.5223	1.0829	0.6278	0.2508
LRT2Q	531441	-0.0006	0.0028	-0.0005	0.0020	0.5000
LRT2R	531441	-0.0015	0.0253	-0.0009	0.0236	0.5000
LRT2S	531441	-0.0006	0.0003	-0.0003	0.0006	0.5000
EXT2Q	1000000	0.0004	0.0085	0.0007	0.0070	0.5000
EXT2R	1000000	0.0004	0.0189	0.0005	0.0178	0.5000
EXT2S	1000000	0.0052	0.0215	0.1359	0.0492	0.5000
EXT3Q	1000000	-0.0007	0.0116	0.0010	0.0067	0.3333
EXT3R	1000000	0.0000	0.0169	0.0019	0.0147	0.3333
EXT3S	1000000	-0.3708	0.0369	-0.3536	0.0383	0.3334
EXT4Q	1048576	0.0011	0.0125	0.0010	0.0057	0.2500
EXT4R	1048576	0.0016	0.0182	0.0006	0.0118	0.2500
EXT4S	1048576	0.1410	0.2017	0.2083	0.2511	0.2505
LRT2Q	1000000	-0.0006	0.0018	-0.0006	0.0011	0.5000
LRT2R	1000000	-0.0013	0.0193	-0.0005	0.0179	0.5000
LRT2S	1000000	-0.0005	0.0000	-0.0006	0.0000	0.5000

TABLE III
REGRESSION OF THE AVERAGE CALLING COST – THE A-LRT EQUIVALENT SETUP

	LRT2S				EXT3R				EXT4R			
	Estimate	Std.Err	t value	Pr(>$\|t\|$)	Estimate	Std.Err	t value	Pr(>$\|t\|$)	Estimate	Std.Err	t value	Pr(>$\|t\|$)
(Intercept)	0.1602	0.0020	78.2743	0.0000	-0.3248	0.0027	-121.6703	0.0000	-0.3694	0.0026	-142.6373	0.0000
sigma	-0.7627	0.0004	-1755.5613	0.0000	-0.6095	0.0006	-1065.1016	0.0000	-0.4984	0.0006	-897.0317	0.0000
eta	1.1506	0.0009	1302.9708	0.0000	1.1148	0.0012	952.3294	0.0000	1.0114	0.0011	889.8822	0.0000
ic	0.1041	0.0007	144.1288	0.0000	0.3243	0.0009	366.7979	0.0000	0.3353	0.0009	390.5088	0.0000
ac	1.9433	0.0009	2231.9662	0.0000	1.7474	0.0012	1518.8540	0.0000	1.6243	0.0011	1452.6669	0.0000
f	7.0465	0.0044	1601.4341	0.0000	6.8455	0.0058	1172.4098	0.0000	6.5418	0.0057	1153.1944	0.0000
	RSE: 0.0736 on 336598 DF, Adj.R^2: 0.9739				RSE: 0.0747 on 198339 DF, Adj.R^2: 0.9678				RSE: 0.0725 on 197958 DF, Adj.R^2: 0.9640			

TABLE IV
REGRESSION OF THE AVERAGE CALLING COST – THE MULTIAGENT SETUP

	LRT2S				EXT3R				EXT4R			
	Estimate	Std.Err	t value	Pr(>$\|t\|$)	Estimate	Std.Err	t value	Pr(>$\|t\|$)	Estimate	Std.Err	t value	Pr(>$\|t\|$)
(Intercept)	0.2803	0.0032	87.1028	0.0000	-0.1486	0.0033	-45.5957	0.0000	-0.2323	0.0030	-76.9718	0.0000
sigma	-0.6718	0.0006	-1054.9123	0.0000	-0.5333	0.0007	-812.9612	0.0000	-0.4406	0.0006	-725.1634	0.0000
eta	1.0671	0.0013	829.2190	0.0000	0.9994	0.0013	745.3509	0.0000	0.9145	0.0012	736.1419	0.0000
ic	0.1772	0.0011	164.5358	0.0000	0.3630	0.0010	347.3133	0.0000	0.3704	0.0010	382.5382	0.0000
ac	1.8330	0.0013	1443.8558	0.0000	1.6700	0.0013	1264.9617	0.0000	1.5677	0.0012	1280.5955	0.0000
f	6.7904	0.0064	1059.2387	0.0000	6.5881	0.0067	984.8478	0.0000	6.3448	0.0062	1023.1532	0.0000
rewire	-0.1735	0.0006	-270.4930	0.0000	-0.1208	0.0007	-181.5881	0.0000	-0.0879	0.0006	-142.5061	0.0000
radiusr=4	0.0122	0.0005	24.7803	0.0000	0.0055	0.0006	9.7988	0.0000	0.0031	0.0005	6.0398	0.0000
radiusr=5	0.0195	0.0005	39.0220	0.0000	0.0063	0.0006	11.0646	0.0000	0.0026	0.0005	5.0346	0.0000
radiusr=6	0.0182	0.0011	17.1324	0.0000	0.0074	0.0009	8.3679	0.0000	0.0039	0.0008	4.7156	0.0000
radiusr=7	0.0123	0.0011	11.5272	0.0000	0.0115	0.0009	12.9661	0.0000	0.0084	0.0008	10.2043	0.0000
radiusr=8	0.0225	0.0010	21.6842	0.0000	0.0157	0.0009	18.0055	0.0000	0.0094	0.0008	11.6464	0.0000
radiusr=9	0.0135	0.0013	10.7262	0.0000	0.0050	0.0010	4.7174	0.0000	0.0016	0.0010	1.6472	0.0995
radiusr=10	0.0125	0.0012	10.1877	0.0000	0.0041	0.0010	3.9528	0.0001	0.0018	0.0010	1.8935	0.0583
FamilyF1	0.0585	0.0012	48.5098	0.0000	0.0461	0.0012	39.2199	0.0000	0.0364	0.0011	33.3879	0.0000
FamilyF2	0.0489	0.0012	39.2481	0.0000	0.0535	0.0012	43.4216	0.0000	0.0456	0.0011	39.9165	0.0000
FamilyF3	0.0108	0.0012	9.1054	0.0000	0.0384	0.0011	33.6400	0.0000	0.0360	0.0011	34.0611	0.0000
FamilyF4	-0.0054	0.0012	-4.5254	0.0000	0.0457	0.0012	39.2590	0.0000	0.0462	0.0011	42.8909	0.0000
FamilyF5	-0.0410	0.0012	-33.9068	0.0000	0.0370	0.0012	31.3832	0.0000	0.0431	0.0011	39.5773	0.0000
FamilyH1	0.0592	0.0014	41.3713	0.0000	0.0597	0.0015	39.8899	0.0000	0.0480	0.0014	34.6196	0.0000
FamilyH2	-0.1800	0.0015	-122.6138	0.0000	0.0022	0.0015	1.5027	0.1329	0.0216	0.0014	15.9309	0.0000
FamilyH3	-0.2868	0.0014	-206.1914	0.0000	-0.0540	0.0015	-35.9890	0.0000	-0.0202	0.0014	-14.5722	0.0000
FamilyH4	-0.3583	0.0014	-253.9186	0.0000	-0.1258	0.0015	-84.8218	0.0000	-0.0802	0.0014	-58.3866	0.0000
FamilyH5	-0.4286	0.0014	-301.5214	0.0000	-0.1935	0.0015	-130.8469	0.0000	-0.1359	0.0014	-99.2570	0.0000
FamilyH6	-0.4963	0.0018	-276.1554	0.0000	-0.2456	0.0015	-166.1425	0.0000	-0.1771	0.0014	-129.3945	0.0000
FamilyH7	-0.5588	0.0018	-302.8385	0.0000	-0.3003	0.0015	-198.9627	0.0000	-0.2220	0.0014	-158.8458	0.0000
FamilyH8	-0.6159	0.0018	-341.0998	0.0000	-0.3453	0.0015	-232.6603	0.0000	-0.2571	0.0014	-187.1531	0.0000
FamilyH9	-0.6442	0.0017	-368.2016	0.0000	-0.3774	0.0014	-261.0040	0.0000	-0.2825	0.0013	-211.0761	0.0000
FamilyH10	-0.6666	0.0018	-367.2946	0.0000	-0.4012	0.0015	-268.7229	0.0000	-0.3000	0.0014	-217.0025	0.0000
FamilyG1	0.0650	0.0019	33.3858	0.0000	0.0524	0.0016	31.8987	0.0000	0.0424	0.0015	27.8968	0.0000
FamilyG2	-0.2907	0.0020	-147.9344	0.0000	-0.0688	0.0016	-42.3793	0.0000	-0.0253	0.0015	-16.7978	0.0000
FamilyG3	-0.4481	0.0021	-213.2274	0.0000	-0.1828	0.0017	-104.7305	0.0000	-0.1109	0.0016	-68.6169	0.0000
FamilyG4	-0.5503	0.0021	-267.0427	0.0000	-0.2655	0.0017	-152.7928	0.0000	-0.1763	0.0016	-109.8182	0.0000
FamilyG5	-0.6271	0.0020	-318.2227	0.0000	-0.3259	0.0016	-199.0975	0.0000	-0.2232	0.0015	-147.2806	0.0000
FamilyG6	-0.6789	0.0020	-340.4438	0.0000	-0.3771	0.0017	-224.4127	0.0000	-0.2643	0.0016	-169.6662	0.0000
FamilyG7	-0.7178	0.0019	-374.4083	0.0000	-0.4181	0.0016	-261.1374	0.0000	-0.2977	0.0015	-200.7579	0.0000
FamilyG8	-0.7415	0.0020	-365.6167	0.0000	-0.4421	0.0017	-263.4054	0.0000	-0.3162	0.0016	-203.3334	0.0000
FamilyG9	-0.7866	0.0020	-400.7365	0.0000	-0.4847	0.0017	-290.5156	0.0000	-0.3538	0.0015	-229.1157	0.0000
FamilyG10	-0.8096	0.0019	-425.6128	0.0000	-0.5034	0.0016	-311.9743	0.0000	-0.3676	0.0015	-245.9765	0.0000
	RSE: 0.1072 on 336565 DF, Adj.R^2: 0.9559				RSE: 0.0854 on 198306 DF, Adj.R^2: 0.9613				RSE: 0.0791 on 197925 DF, Adj.R^2: 0.9588			

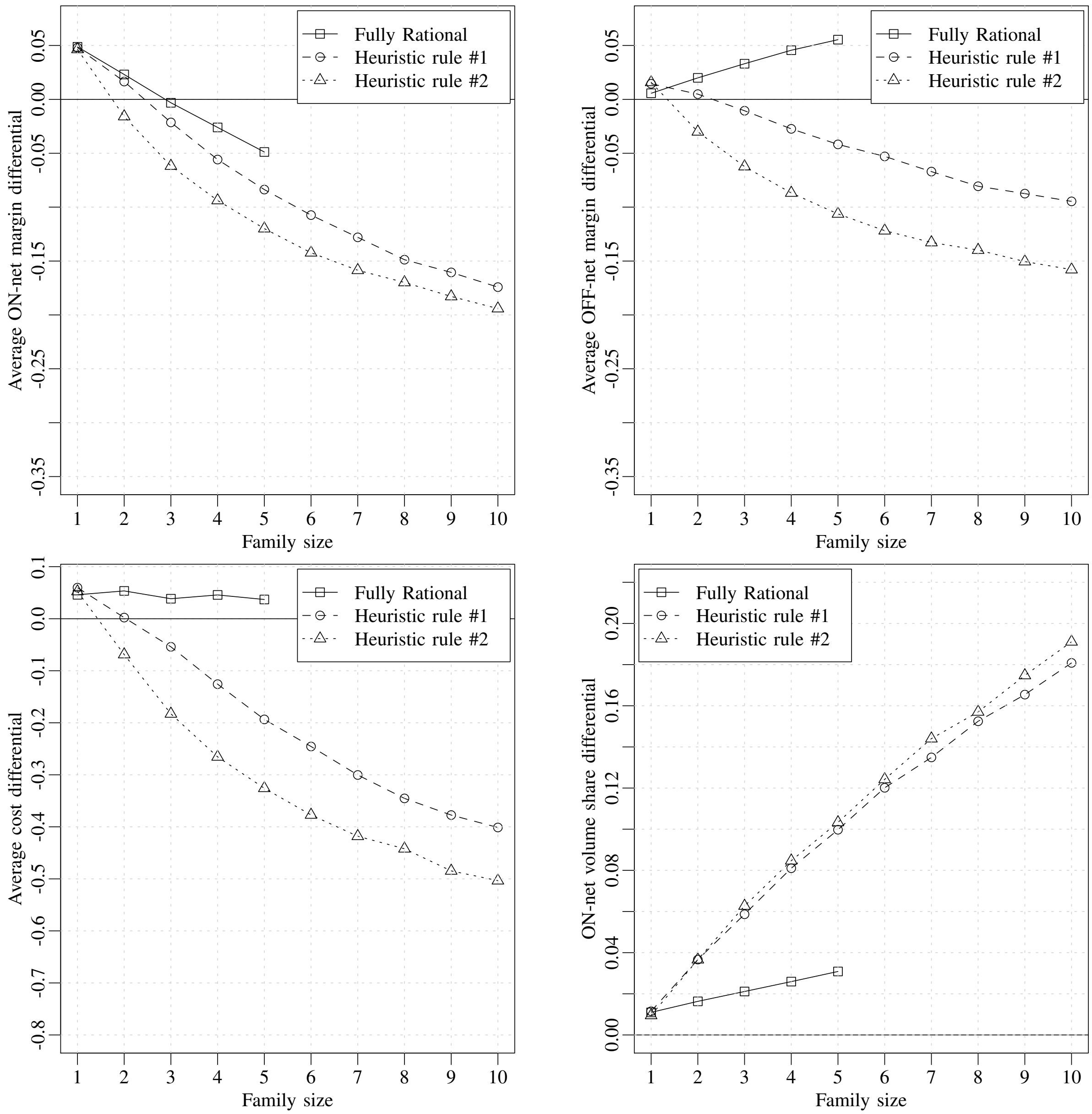

Fig. 5. Results for the triopoly model (EXT3)

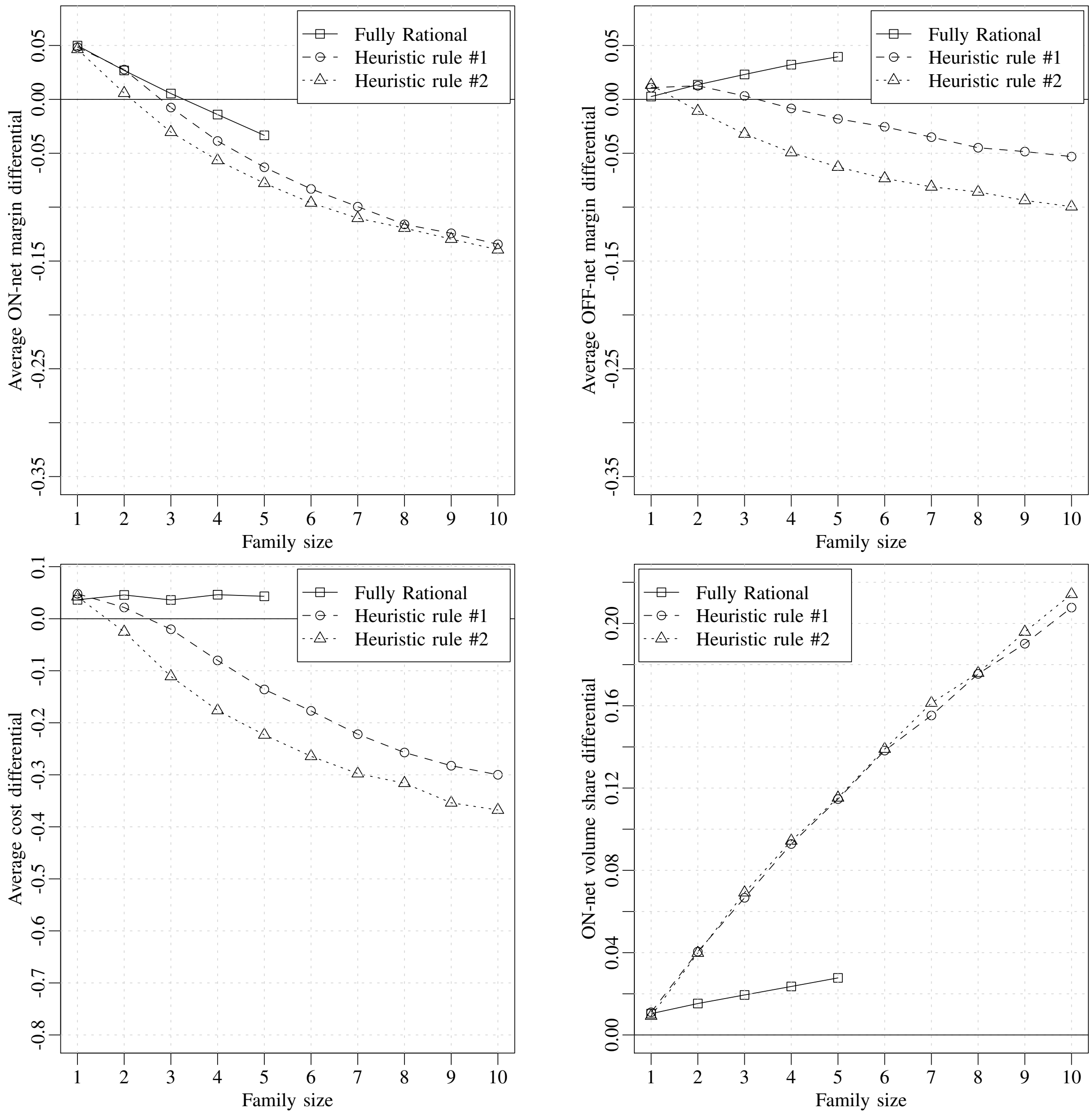

Fig. 6. Results for the 4 network oligopoly model (EXT4)

Demographic agent-based simulation of Gambians immigrants in Spain

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Abstract— **Changes in our society have created a challenge for policymakers, who confront a need of tools to evaluate the possible effects of their policies. Agent-based modelling and simulation is a promising methodology which can be used in the study of population dynamics. In this paper we introduce an agent-based simulation approach to project the population of Gambian migrants in Spain during 10 years. Our approach not only enables to simulate the life course of individuals, but also allows deeping on the movements, interactions, and behaviours of the target population. The model is able to capture individual characteristics and to overcome some data-related limitations with assumptions on behavioural rules. With this methodology, we want to show the potential of the tool with the study of a real case scenario.**

I. Introduction

Today, our society is inexorably shifting in form and nature lead by challenging transitions driven by social, economic, environmental and technological changes. Population dynamics influences every aspect of human, social and economic development. The research area that studies human population in relation to changes brought about by the interplay of births, deaths and migration is demography [1]. Demography is a field in geography that is often used as the basis for government policies in areas such as labour market, education, healthcare, social welfare and taxation. Among social research, it has greatly contributed to project people to guide societal planning [2]. Although population projections are simplified, uncertain representations of people, they are usually used as input to policy making and planning models in areas such as labour market, education, healthcare, social welfare and taxation.

In recent years simulation has gain popularity as a tool to understand the insights of social complexity. However, it has been little used in demographic research to help explaining dynamics [3]. Simulation methodologies provide the opportunity to develop a virtual laboratory for exploring and validating current and new approaches. The purpose is to avoid conducting real social experiments, which may be expensive, unethical or even infeasible.

In the past few years, the use of micro-level simulation models in population projection has become more widespread, especially in the field of migratory movements or human reproduction [3]. Taking profit of the increasing availability of data at micro level, microsimulation allows including individual-specific explanatory variables in the model. In microsimulation paradigm, modellers have to specify a random sampling process for each individual at each simulation time point, to determine the state of each individual at the next simulation time point. Many microsimulation tools have been built for certain public policies [4]–[7].

Despite microsimulation extensive use, this technique has two main limitations [8]. On one hand, it models individuals' behaviour in terms of probabilities which are supposed to match with preferences, plans and decisions. On the other hand, it simulates people at the individual level, not taking into account their interactions. Moreover, microsimulation requires realistic micro-data so it can be difficult to apply when appropriate data are not available [9].

Agent-Based Modelling (ABM) represents an alternative to cope with those limitations. Many demographic processes take place based on individual choice behaviour and interactions among people [10]. Therefore, ABM is interesting for demography for their capacity of generating personal event histories and producing estimates of the full distribution outcome. Moreover, ABM is particularly useful for projecting a population answering "what if" questions such as the effect of a certain policy on a specific demographic characteristic. It allows modelling the impact of personal decision making processes in strategic planning or government policies.

In this paper, we present an application of ABM in demographics. Section II revises the use of ABM in population dynamics studies and the latest tools available for agent-based simulation. The framework used for this study is introduced in Section III. Section IV presents the context of Gambian migration in Spain and explains the simulation case study we have conducted of Gambian immigrants in Spain.

II. AGENT-BASED DEMOGRAPHIC SIMULATON

Despite agent-based modelling useful features, there has been a limited use in the area of demography. [11] used this approach to explore the interplay between the demographic system and the cultural system in an artificial society of hunter-gatherers. Other researchers used it to project past migrations in Germany [12] or to understand residential dynamics in Israel [13]. Among most recent works, ABM has been applied to study student migrations in the UK [9], to examine patterns of infection and immunity [14], to understand environmental migration in Burkina Fasso [15], and to see how changing family structures in the UK population may influence the provision of health care [16].

As a result of the growing popularity of ABM in many fields, several tools have been developed in the last years to explore the complexity of social systems, enabling the execution of generic ABMs [17]–[20]. In most of them, ABM is commonly used for small scenarios because the number of agents and interactions between them can be extremely large in some case studies. However, in the case of policy models, both the amount of compute power required and detailed micro-level data are significant.

III. YADES: A PARALLEL SIMULATION TOOL FOR DEMOGRAPHICS

There is general interest in using individual-based simulation (such as micro-simulation and agent-based simulation) with larger sample sizes in demographic simulation models. This raises a performance issue because individual-based simulation is relatively slow if the model includes a large number of individuals and the simulation time unit is very small. The execution time will be even worse when the sampling process in each individual requires a complex regression model. It should be noted that the simulation execution time depends not only on the processor speed but also the memory capacity. If the model includes a large number of individuals, it might require more memory than the memory capacity of a single-processor computer which will cause memory swapping. Hence, it is possible that sequential simulation might be too slow. Parallel simulation may offer an alternative.

In this work we used Yades, a agent-based simulation tool for demographics which can profit high performance computing capabilities [21], [22]. It provides the placeholders for different demographic processes such as fertility, mortality, change in economic status, change in marital status, and migration. The main advantage of this approach is the ability to run large agent-based scenarios, when other tools present limitations. Moreover, Yades particularly focus on demographic simulation might facilitate modellers the development of demographic related models.

To help on specifying ABMs, Yades incorporates an interface and it features automatic code generation. In that way modellers can define the set of variables and components that will define the simulation model. They should be able to reap the performance offered by parallel computers transparently. Thus, Yades has three components: a web user interface, a demographic simulation library and the simulation code generator. The web user interface allows demographic modellers to specify demographic model components in a number of representations familiar to demographers such as regression and statistical distribution function. The simulation code generator can produce the corresponding C++ code that is linked to the demographic simulation library which uses a scalable parallel discrete-event simulation engine. The generated code is ready for compilation using a target C++ compiler. The demographic simulation library supports both sequential and parallel execution of the simulation model. The resulting framework is shown in Figure 1.

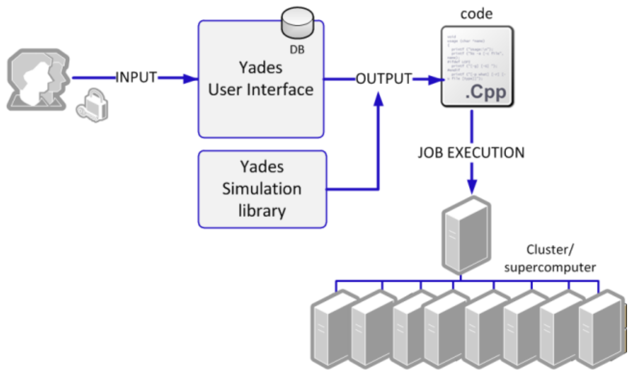

Figure 1. Yades simulation framework

Yades was implemented using μsik parallel discrete-event simulation library [23]. It supports both sequential and parallel execution of the simulation model and has shown good scalability in previous studies [24]. Yades adopts the process interaction world-view in which a simulation model is formed by a set of interacting *agents*. Agents communicate through events. Multiple agents can be mapped onto a *PopulationSimulator* that is run on top of a processor. A machine can have more than one processor (e.g., in multi-core architecture).

There are two types of agents in Yades: *family unit* and *region*. A family unit is defined as a single independent individual or two independent individuals living together (as married, in civil-partnership, or in cohabitation) and any dependent individuals (children). A family unit may receive events which are related to five demographic components that may change the system states. Modellers can specify models for five demographic components: fertility, a change in economic status, a change in marital status, migration and mortality. The fertility component determines whether a female individual will give birth, based on the characteristic of the female individual and the current calendar time. The model returns the time when the baby is due. Similarly, modellers can use the characteristic of an individual and the current calendar time to determine a new economic status of that individual.

A new marital status can be modelled based on the characteristics of the individual (or individuals for a couple) and the current calendar time. If the new status is either married or cohabitating, modellers need to define the criteria that will be used to match the individual to another individual from the list of prospective partners (i.e. we use a closed marriage model). If a suitable partner is found, then a 'family formation' event will be scheduled for both individuals. Otherwise, the individual will be added to the list for a fixed duration. If a partner still cannot be found at the end of the duration, an event will be sent to remove the individual from the list.

Modellers also need to specify a model that is used to determine whether a family unit is going to migrate. If the destination is in another country (emigration), the family unit will simply be removed from the simulation. Finally, in the mortality component, modellers need to model the time when an individual will die based on the characteristics of the individual. Commonly used methods, such as life table and survival function can be used for the mortality component.

The second type of agent in Yades represents a region where a number of families live. This agent will handle domestic migrations, immigration, changes in simulation parameters and periodic reports. Yades allows users to have regions with different population characteristics. Figure 2 shows how the demographic scenario is mapped on a distributed architecture as already described.

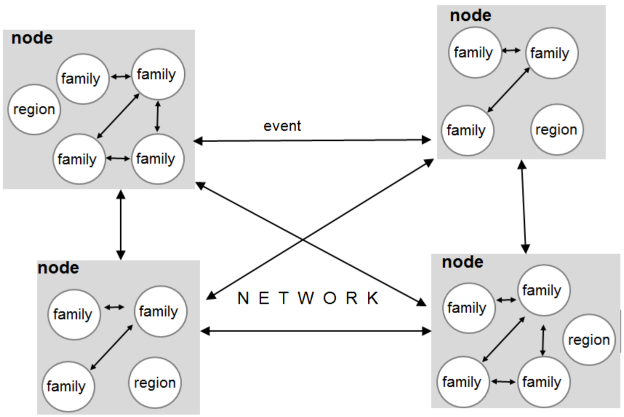

Figure 2. Mapping of agents in the physical architecture

IV. SIMULATION OF GAMBIAN MIGRANTS IN CATALONIA

In our paper, we propose to use Yades to understand the demographic evolution of Gambian community in Spain. The Gambia is a small country in the Sub-Saharan Africa. Despite its small size, its migration rate has been quite high last 30 years. According to the World Bank, in 2010 Spain received the 34.15% of emigrants from the Gambia, being the leading destination country. In the region of Gambia movements outside the country are perceived as a familiar strategy and follow two differentiate patterns: surviving and mobility [25]. Mobility movements generally answer to a familiar project, where the household does a significant financial investment. That is the reason why migrations are due to a process of selection in the origin, to maximize the success of the project.

The case under study carries out an analysis of the evolution of the population of The Gambia between 2000 and 2010. The period is interesting for research because migration flows from Sub-Saharan Africa (including The Gambia) to Spain increased significantly. Spanish economy prospered in that decade probably increasing the expectancies of Gambian migrants and increasing migration movements.

The Gambian is the four largest Sub-Saharan African group of emigrants in Spain, with a total of 20,639 people, according to the 2011 census of Spanish National Institute of Statistics (INE). It is the group of emigrants in Spain with the highest fertility, the higher proportion of children under 16 years old and the lowest proportion of people older than 65 [26]. Thus, we are facing a young population, with very high fertility rate (Total Fertility Rate in 2001 was approximately 8 children per woman). Moreover, Gambian emigrant group shows an unequal sex and age distribution as we can see in Figure 3.

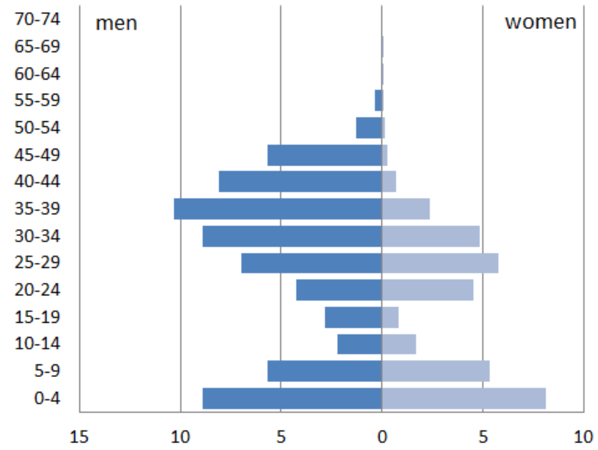

Figure 3. Gambian population pyramid in 2001. Source: INE 2001 census

The gender disequilibrium shows two different migratory strategies [27]. From one hand, the high masculine proportion, especially when compared to other African migrants in Spain, might respond to economic reasons in the origin. On the other hand, low women proportion might be a consequence of family reunification processes. Moreover, most of Gambian emigrants have mainly a rural origin.

These factors of Gambian population make an impact on local population structures in Spain. Gambian emigrants exhibit a distinctive pattern from the rest of migrants, i.e. they tend to reside only in certain areas, dispersed across the various regions, with the largest concentrations in Catalonia (76.16% in 2011), and work in agricultural sectors, domestic services, construction, or the service industry.

Our model considers the aspects which best characterize the Gambian emigrant population in Spain: high fertility, partnership trends, deaths, labour market, and mobility. Data was obtained from census and country surveys on migration patterns. Behavioural rules were built from ethnographic records of anthropological studies [25], [26], [28]. The simulation results have been compared to the observed distribution of the Gambian population in 2010. Through the implementation of behavioural simple rules at the individual level, the heterogeneity of the group and its residential mobility is captured in the model. Despite some simplifications made to study this phenomenon, the projected population presents similarities with statistical records and encourages us to further enhance the tool.

The proposed case study suits well the high-degree complexity of general ABMs because the development of the population is affected by a large number of interrelated and dynamics factors: gender, age, economic level, family, matchmaking and reproduction patterns, life cycles and so on. Moreover, the proposed ABM is interesting for studying these particular phenomena since it provides a way to gain insight of the population at an individual-level. Thus, with our work we show the potential of agent-based simulation on group dynamics with a real case study. Furthermore, this work will increase Yades credibility for the community of modellers, showing the possibilities ABM tools can provide to assist them in the understanding of demographic processes to guide decision making or exploration of "what if" situations.

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Analysing a Complex Agent-Based Model Using Data-Mining Techniques

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***Abstract*—** A complex "Data Integration Model" of voter behaviour is described. However it is very complex and hard to analyse. For such a model "thin" samples of the outcomes using classic parameter sweeps are inadequate. In order to get a more holistic picture of its behaviour data-mining techniques are applied to the data generated by many runs of the model, each with randomised parameter values.

I. Introduction

The model that is discussed here is intended as a "data integration model" (Edmonds 2010b). That is a consistent, detailed and dynamic description, in the form of an agent-based simulation, of the available evidence concerning the question of why people bother to vote. This integrates a variety of kinds and qualities of evidence, from source data and statistics to more qualitative evidence in the form of interviews. The model was developed following a "KIDS" rather than a "KISS" methodology, that is, it aims to be more guided by the available evidence rather than simplicity (Edmonds & Moss 2005). A consequence of this is that the model is complicated, including many different, competing and interleaving mechanisms.

It is in the process of being validated. This validation will multi-dimensional, so that both the micro-evidence will be compared against available micro-level evidence as well as outputs compared against macro-level evidence in appropriate ways (Moss & Edmonds 2005). However this validation will necessarily be partial, that is, some aspects of the simulation will be compared against available evidence and some only against opinion. However by documenting as many of the assumptions as possible, these aspects will be amenable to criticism and correction in future versions of the model and hence play a part in the bootstrapping of knowledge (Edmonds 2010a).

In particular this model aims to enable the exploration of some social processes behind voter turnout, including demographic trends in household size and composition, social influence via the social networks the individuals are embedded within, wider social norms such as civic duty, personal habit and identity, as well as individual rationality. This structure was designed to allow the relative priority and interaction of many different context-dependent social processes to be explored.

However a consequence of this approach is that the model itself is too complex to fully understand.

This model is in the process of being abstracted in the form of simpler models. The aim of the more abstract models is that they will be analytically tractable, whilst also giving approximately the same outputs in terms of key outputs, such as the level and trends in voter turnout. In this way it is hoped that the set of models might obtain to both relevance and rigour, albeit in different parts of the 'model chain'.

However the model is very complex which poses a challenge when one tries to check, analyse and validate it. Here, we need to complement low-dimensional parameter sweeps and hypothesis driven experimentation to get a more holistic picture of simulation behaviour. One way of doing this this is described in this paper, that of using data-mining techniques to get insights into model dynamics and outcomes and then use this to direct more specific investigations.

The first section simply describes the model, roughly following the ODD format (Grimm et al. 2006, Polhill 2010). This is followed by the analysis of the model output, using data-mining techniques.

II. the Model

A. Model Layers

The model turned out to have a number of, "layers". Each of which (mostly) only depends on the "lower" layers.

1. *The demographics of households and individuals*. Individuals exist within households at locations within a 2D grid. Individuals are born, age, leave home, partner/split, have children and die based on statistics about these processes derived from the UK population.
2. *Membership of activities*. Individuals change their membership of households, neighbourhoods, schools, work, and activities over time, depending on their age as well as joining rates. Depending on the type of activity, the particular instance chosen to join (which workplace,

school, activity etc.) might be influenced by a number of factors.

3. *Dynamic social networks*. Individuals make friends through membership in these activities. A friend of a friend link creation mechanism also exists but only within each type of link. Links are dropped randomly at a certain rate.
4. *Social Influence over the network*. Messages representing political discussions/messages are sent over the (current) social networks, which are remembered by agents, leading (possibly) to changes in their characteristics.
5. *Voting behaviour*. An individual's characteristics, situation, household situation etc. results in a decision whether to vote, and then vote.

For the purposes of this paper we will only consider states 1, 2, 3, and 4. Thus, for reasons of space we will ignore other aspects of this complex model.

B. Entities, state variables, scales

The model is based around a 2D grid of locations, each of which may be a: household, place of work, school, activity (two kinds) or empty. Households consist of a number of agents which each represent a single person. Agents are born, age, partner, have children and die as the simulation progresses. Agents have a large number of characteristics, but these include: a memory of past events, a party affiliation (or none), a set of family relationships (children, partner, and/or parents) and social connections with other agents. It is over the network of social relationships that influence occurs in the form of events that represent communication about political or civic matters. The agents are influenced over time via these communications. When an election occurs agents decide whether to vote.

Places of work, schools and activities are placeholders. They do not change or move (unlike the households). Their only characteristic is their membership (who works there, which children go to school there, which are members of an activity). A household is simply a container for the agents who form that household.

Agents are the primary elements in the simulation and have the many characteristics, including: age, ethnicity, partner, children, parents, whether employed, immigrant-generation, class, memberships (those schools, places of work or activities that an agent belongs to), social links, and a memory of events (such as recent political conversations they have had).

C. Process overview, scheduling

The simulation is initialised at the start. Then the simulation proceeds in discrete time steps, one step usually representing each month in a year. Each time step the following stages are done.

1. External immigration – households moving into area from outside of the UK sampled from immigrants in BHPS sample, unless grid is full
2. Internal immigration – households moving into area from inside of the UK sampled from all BHPS sample, unless grid is full (remixed in terms of given majority/minority mix)
3. Emigration – households moving out of the area
4. Birth and death – births and deaths probabilistically using statistics
5. Forgetting – stuff being lost from the endorsements of agents at different rates, e.g. remembrance of conversations
6. Network-changes – social links to other agents and activities made and broken
7. Partnerships are formed, move to live together if possible
8. Partnerships dissolved, one partner moves out
9. Household might move within the simulation area
10. Have conversations – hold conversations over the social network, influencing others in the process, the frequency of this is adjusted using the influence-rate parameter
11. Updating agents' attributes in terms of: noticing politics, interest level, and civic duty
12. [Once a year] update: the party preference, party habit and generalised habit
13. Drift-process – shift of voters into and from each political party by a drift process: voters for ruling party (not very interested in politics) drift away to grey, some grey drift to a party
14. During an election tick agents decide whether to vote in a multi-stage process.
15. Updating various plots and statistics for output about what is happening in the simulation

For each of these stages agents are fired in a random order (newly random each time and process). In most of these processes the update for each agent has no immediate effect on any other agent, so these agent processes are effectively in parallel. Similarly most of these stages could be done in any order with very little impact on the outcome, the exception being the sub-stages of voting (14).

III. Design

Basic principles. The starting point for the model design was a collection of "causal stories" about behaviour that might be relevant. Each such story traces a single causal thread through the complexity of social and cognitive processes whilst letting the context of these be implicit and whilst ignoring their possible myriad interactions. This "menu" of behaviours drove the architecture of the model as it was designed to allow most of these stories to be expressed by agents. When the simulation is run the local conditions of each agent separately define the context of that agent whilst also allowing the complex mixing of many different social and cognitive processes.

To fill in some of the cognitive and contextual "glue" evidence from many different sources has been included to motivate the assumptions and mechanisms of the model. Thus it is difficult to identify discrete "submodels" in this.

However, a post-hoc analysis of the structure that emerged suggests the following could be considered as submodels:

1. The main social unit is the household, a collection of individuals living within the same house. People who partner may form a new household, or people moving from outside the area may also do so. Many social processes occur within the household and others occur preferentially between members of the same household. Households occupy a place within the 2D grid.
2. Basic demographic processes specify how people enter the model (though moving into it from the UK or abroad), are born to partners, age, leave home, partner, separate, and die. These are based on some available statistics as to the probability of these events, depending upon whether the immediate situation of the agent makes these plausible. This demographic model includes a 5-category social class model using statistics to determine class mobility.
3. To this basic demographic is added a number of activities. These are schools, places of work, activity type1 and activity type2 (corresponding to things like: places of worship, sports clubs etc.). Agents between the age of 4 and 18 attend school; those 18-65 can go to a place of work, and join (or leave) activities. The activities take up a location but they have no characteristics except their current membership. All children are member of the nearest school; if in work adults are members of a random place of work; with a certain probability adults join an activity and, if so join the one whose other members are (on average) most similar to themselves.
4. A dynamic social network develops between agents. Each link represents a relationship that would allow for a conversation about politics and civic duty. The links are typed – the types are: partner, household, neighbourhood, work, school, activity1 and activity2. There are several ways that a new link can form: all people in the same household are linked with a household link, there is a chance that people in neighbouring households might link, people who go to the same school or parents of children who go to the same school might link; people who are members of the same activity might form a link. Further for each of these link types there is a chance of making a link with a "friend of a friend". Links can be dropped under certain circumstances and with certain situations.
5. Agents can have different levels of political interest, a party political leaning, a sense of civic duty to vote, a generalised habit to vote, a party identification, and a memory of whether past voting/not brought about their desired outcome.
6. A process of social influence occurs over this social network in the form of discrete (as opposed to continuous) political discussions. A political discussion occurs if: (a) there is a link between the two (b) the talker is at least interested in politics has at least a view on politics and (c) the receiver at least notices political discussions.
7. These political discussions have several effects on agents that are not described here.
8. When an election occurs, each individual decides whether to vote.
9. Voting statistics are then recorded.

The above are not the full details but a summary of their main features. Generally micro-causation in the model happens down the order above (from first to later), but there are some weaker and slower feedbacks that occur back upwards, for example the outcome of an election effects agents' perceptions of the experience of voting.

Emergence. Clearly in such a complicated model it is not possible to make an easy and clean distinction between results that emerge and those that are programmed into the model. Indeed, the model was designed with a view to integrate available evidence rather than produce or demonstrate emergent effects (or to be predictable). However it is not the case that all outcomes from the model are straightforwardly forced by the settings and programmed micro-processes.

The initialisation of the model (see below) has a complicated but predictable effect on the model, in that the kinds of household the model is seeded with will affect the tendencies that follow. Thus in the data set that these are selected (at random) from those from "invisible minorities" (Irish etc.) tend to be more politically involved and have a higher sense of civic duty.

The impact of many of the parameters is straightforward, for example: increasing the probability of holding a conversation increases the general level of political interest and hence the turnout; increasing the forgetting rate (the "forget-mult" parameter) means that people do not recall so many positive political messages and hence the level of interest in politics falls quicker. The immediate effect of mobilisation is fairly straightforward – the more people are mobilised the more vote – but how this effects the longer term is less obvious in that it seems to have greatest impact upon the levels of civic duty and general habit, than (for example) in terms of a cascade effect in brining yet others out to vote.

Adaptation. Agents generally do not seek to increase or optimise any measure of success nor do they reproduce behaviours that they perceive as successful. The exceptions are: (a) when agents weigh up their past experiences of voting as one factor in the decision of whether to vote again, (b) when moving to a new location within the model, the choice might be influenced in the sense of seeking a location with neighbours similar to themselves and (c) if choosing to join a type of activity agents will choose the instance of the activity whose membership is, on average, the most similar to themselves.

Learning. Agents do learn, adapting their traits depending on circumstances and history, including adapting their *social network*. Agents develop their social network in a number of ways over time: (a) they are automatically linked to other members of the same household, (b) they connect with a probability to those at the same school (or other parents with children at the same school), activity, workplace or immediate neighbours (but preferentially to those more similar to themselves) and (c) for each kind of link (neighbourhood, school, activity1, activity2, workplace) they can make a link to some of those linked to those they are linked to (so called "friend of a friend". There is a fixed probability of dropping links at each time click, also if an agent moves they are almost certain to lose existing school, neighbourhood and household links (there is a small probability of retaining them).

Prediction. Agents do not do any prediction in this model. In particular, there is no tactical voting, nor expectations about whether it is worth voting based on predicted outcome.

Sensing. This is a social model, so that agents primarily sense other agents in three ways: (a) through their current links to other agents, (b) through indirect links to other agents, e.g. by being members of the same activity, having kids at the same school or being in neighbouring cells (c) through political discussions over the direct links. Thus all sensing is local in the sense of their links, memberships or neighbourhood (except that agents are aware of the result of elections).

Interaction. Agents interact with each other by having political "conversations", which may influence the recipient. Each "conversation" carries messages of political leaning and civic duty (depending on the characteristics of the converser). These are not strictly conversations since each one is one way, but over time these may go both ways between agents, reinforcing existing characteristics of leaning, political interest and sense of civic duty. If an agent moves location, it will bring its partner and children with it (as well as possibly orphaned children in the household). Agents form sexual partnerships, selecting from those in their social network, and can only have children when within such a partnership. Partnerships dissolve with a low random probability in which case one partner will move out leaving any children behind.

Stochasticity. Many processes in the model have a stochastic element in them once the conditions for their occurrence are locally met in an agent. This includes the processes of: moving location, emigrating, immigrating, getting a job, losing a job, making new social links or losing them, joining an activity or leaving one, having a political conversation, acquiring civic duty as a result of a conversation, dragging others to go and vote if they are, and mobilising voters. Other process have a probability of occurring but with the probability varying on the basis of some statistics, including: birth, death, moving out of the parental home, becoming ill, and children changing class later in life form that they were born with (which also depends on having a post-18 education).

The processes that determine the probability of someone voting are deterministic but somewhat complicated (see 8 in the section on design principles and 14 under the section on scheduling) . Many circumstances, such as having a sense of civic duty or being politically involved force a probability of voting at 1 (unless a confounding factor intervenes).

Processes that are entirely deterministic include: going to school or leaving it, retiring from work, the election result, changes in the habit of voting, or political identification.

A major stochastic impact on the model is in the initialisation of the households at the start of the simulation and the choice of new households that enter during the simulation due to immigration. In these processes entire households are selected at random from re-mixed sample of households form the 1992 wave of the BHPS. The "re-mixing" is done to achieve the user defined proportion of majority population as well as to ensure that out-of-UK immigration is selected form those recorded as immigrants in the BHPS sample. Thus the mix of initial households in each run of the simulation will be somewhat different, but on the whole, the balance of household characteristics will be representative for simulations with larger populations albeit with some stochastic variation.

Collectives. Some of the agent characteristics do influence how the agents make links and move. Which locations a household moves to is influenced by a bias towards moving next to households with similar characteristics; which instance of a kind of activity 1/2 are joined will be those whose existing members have (on average) the most similar characteristics as themselves; which person they make links with via an activity will be biased by a similar homophily formula. Thus over time agents will tend to have more links with those similar to themselves. However due to the presence of much stochasticity in the model this does not produce pronounced segregation, but rather a "softer" bias in terms of social links. The characteristics that are involved are: age, ethnicity, class and political leaning. At the moment there is a single dissimilarity measure used between two agents regardless of the context (in future versions this will be changed so that there are different measure for different circumstances, so (for example) a weaker one at work than for choosing which instance of an activity to join).

Political parties are not currently represented, except implicitly in terms of the mobilisation process. Individuals influence each other individually and not collectively in this model.

Observation. Many different statistics are collected from the simulation. Broadly the more complex a simulation, the more different aspects need to be validated in order to have any confidence that the model represents what one intends it to. Following the process of cross-validation (Moss & Edmonds 2005) broad evidence and statistics are used to inform the specification micro-level agent rules but then the results coming out of the model also checked, both statistically and in broader qualitative terms. Thus many graphs and histograms are provided, giving different "views" into what is happening in the complex simulation.

The simulation also monitors many statistics, including: the year, month, size of electorate, population size, number of first generation immigrants, number of second generation immigrants, number of visible minority and invisible minorities, number of patches that are empty, average proportion of household links in which agents voted for the same party, average proportion of friendship links in which agents voted for the same party, average proportion of household links in which agents either voted or did not the same, average proportion of friendship links in which agents either voted or did not the same, the link density (proportion of all possible links that exist), and the average local clustering (proportion of linked to agents that are linked to each other).

In addition there is a trace, where the events that occur to a randomly chosen agent are logged. When this agent dies a new born agent is chosen and logged. This is to give a feel for the sort of life trajectories agents are going through.

Many statistics are (optionally) recorded in a ".csv" file for subsequent analysis, including:

- run-id: a unique integer assigned to the run of the simulations
- year: the year the simulation tick is in
- month: the month the simulation tick represents
- pop-size: the number of agents in the simulation
- electorate: the number of potential voters, i.e. those 18 and over
- av-age: average age of population
- num-voting: number who actually voted in last election
- turnout: proportion of electorate voting, i.e. num-voting / electorate
- av-adfriends: mean number of friends (adults only)
- sd-adfriends: standard-deviation of number of friends (adults)
- prop-maj: proportion of the population who are of the majority ethnicity
- prop-adult: proportion of the population who are of age 18 years and over
- prop-1stgen: proportion of the population who are 1st generation immigrants
- av-clust: average local clustering (the proportion of friends that are friends with each other) of adults
- link-dens: proportion of links from all possible links
- av-fr-samevote: average number of friendship links whose agents had voted for the same colour (grey if not)
- av-fr-whvoted: average number of friendship links whose agents had voted/not
- av-hh-samevote: average number of household links whose agents (at each end of link) had voted for same colour (grey if not)
- av-hh-whvoted: : average number of household links whose agents (at each end of link) had voted or not in the same way
- av-sim-hh: average similarity of individuals in a household
- av-sim-fr: average similarity of those linked
- ncvs-ac: number of conversations within 'activity' related links per month (rate-ncvs-ac is scaled by av population size)
- ncvs-sc: number of conversations within 'school' related links,per month (rate-ncvs-ac is this scaled by av population size)
- num-adult-involved: number of agents with "involved" level of political interest (prop-adults-involved is this scaled by av population size)

IV. Details

Initialization. The grid is initialised in the following manner:

1. The grid dimensions are set by the programmer
2. Set proportions of the grid are occupied with schools, work places, activity1 and activity2
3. A given proportion of patches that are left are populated with new households. These are selected as a complete household from a large sample of taken at random from the 1992 wave of the BHPS, but "remixed" to a set degree of majority population (by splitting the original file into majority/non-majority households and then probabilistically choosing at random from each part according to parameter settings). Some details about households have to be inferred from the data as this is not always unambiguous. Some initial agent characteristics are set using proxies from the data, e.g. civic duty is set for agents who are recorded as being a member of certain kinds of organisation
4. Links to household members and some random neighbours are made
5. To give the households an initial network the procedure to develop other network links is done 10 times for each household.
6. Appropriate activities are joined depending on those in the BHPS data.

Thus the exact composition of the grid varies in each run but are drawn from the same sample, so in a sufficiently large initial set of households (determined by the size of the grid and how much is left empty) one gets a similar mixture each time. Various other things are initialised including: shapes and colours for main display, election dates, and party labels.

Input Data. There are two sets of data that are used in the model:

1. A sample of the 1992 wave of the BHPS data as described above.
2. Various statistics concerning the underlying demographics, such as birth rate (depending on the age of parent), death probability (each age), probability of males and females leaving home. At the moment these are statistics from only roughly the appropriate time.

A. Submodels

The model has the following "foreground" parameters, including notably:

- birth-mult: a scaling parameter that changes the birth rates uniformly
- death-mult: a scaling parameter that changes the death rates uniformly
- move-prob-mult: a scaling parameter that changes the probability of moving
- drop-friend-prob: the probability a link is dropped in a year
- drop-activity-prob: the probability an activity membership is dropped each year
- influence-rate: a scaling parameter determining the maximum number of chances to influence others each agent has each year
- prob-partner: the probability of forming a sexual partnership if single per year
- density: the initial density of households in the 2D grid
- majority-prop: the proportion of the initial population from the majority group
- immigration-rate: percentage of population that immigrates from outside the UK into the model (and hence is randomly selected from the immigrants section of the BHPS file)
- int-immigration-rate: percentage of population that immigrates from inside the UK into the model (and hence is randomly selected from the re-mixed version of the BHPS file)
- emigration-rate: the rate (per year) that households leave the model.

V. Model Analysis

The approach adopted here is to do many runs of the model (in this case 3862 independent runs) with some of the parameters for each run set randomly. Thus, many different combinations of possible parameter values were tried. The idea is to sample a sufficient 'block' of possible parameter values in several dimensions (in this case 9 dimensions). Clearly the more parameters one varies (and hence the higher the dimension is the space of possibilities sampled) the broader a 'view' of the data one obtains. However one needs a sufficient 'density' of points, so the more dimensions the more runs need to be done.

The parameters and the uniform distributions used to select their values were:

- density: [0.65, 0.95]
- drop-activity-prob: [0.05, 0.15]
- drop-friend-prob: [0, 0.01]
- emmigration-rate: [0 ,0.03]
- immigration-rate: [0, 0.02]
- int-immigration-rate: [0, 0.02]
- majority-prop: [0.55, 1]
- prob-move-near: [0, 1]
- prob-partner: [0.01, 0.03]

The outputs of the model were a set of values measured at the end of the run (at end of year 100), including: pop-size, electorate, av-age, sd-age, av-hsize, sd-hsize, av-adfriends, sd-adfriends, prop-maj, prop-inv-min, prop-vis-min, prop-adult, prop-1stgen, prop-2ndgen, prop-nonempty-n, prop-sim-n, prop-sim-fr, link-dens, av-clust, av-sim-hh, av-sim-fr, ncvs-pt, ncvs-hh, ncvs-wm, ncvs-ac, ncvs-ne, ncvs-sc, num-adult-involved, num-adult-interested, num-adult-view-taking, num-adult-noticing, num-adult-not-noticing, num-with-0-friends, num-with-1-5-friends, num-with-6-10-friends, num-with-11+friends, num-short-campaign-messages, num-long-campaign-messages.

A. Clustering in lower dimensions

Many of the attributes are highly correlated, so here we concentrate on only 13 attributes:

pop.size, av.age, av.adfriends, prop.maj, prop.adult, prop.1stgen, link.dens, av.clust, av.sim.hh, av.sim.fr, ncvs.ac, ncvs.sc, num.adult.involved

For an initial exploration of the data, agglomerative hierarchical clustering was performed – this is a method whereby each record/simulation starts in its own cluster, and the algorithm iteratively joins the two nearest clusters until we reach the point where only one cluster remains. Euclidean distance was used to measure distance between pairs of simulations, and Ward's linkage criterion was used to calculate the dissimilarity between clusters.

Figure 1 displays a dendrogram of the clustering, which shows how the data was merged. In order to choose the number of clusters, the dendrogram is generally cut at the smallest height that has a large increase in within cluster variance – here three clusters are formed (as shown) by cutting at a height of around 1000.

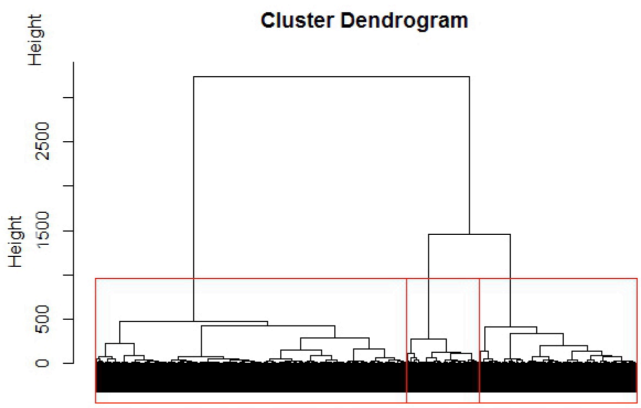

Figure 1. dendrogram of hierarchical clustering of simulations

Hierarchical clustering may be used to cluster the columns (attributes) as well as the rows (simulations) of data, and can be depicted using a heatmap as shown in Figure 2. A heatmap represents numbers as colours. We can see the three clusters from Figure 1 representing the rows (but sideways this time), together with a clustering of the columns (the thirteen output attributes). The output attributes themselves appear to fit neatly into two clusters. This type of visualization can provide a good initial view of any patterns within the dataset.

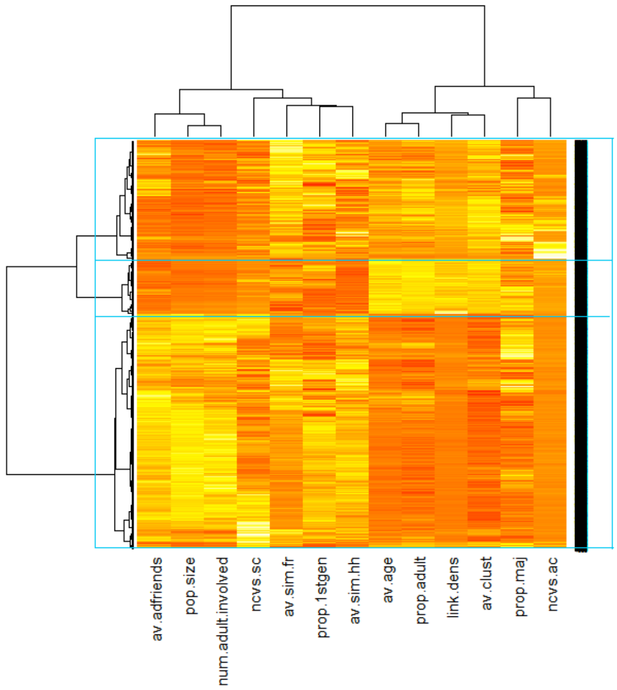

Figure 2. A heatmap of the hierarchical clustering

K-means clustering (Macqueen 1967) is a method of partitioning a data set into a number (k) of different clusters – it is a form of unsupervised machine learning, in that there are no pre-defined class labels for the data. The aim is simply to group together data items in such a way that items within a cluster are more similar to each other than to those in other clusters.

The k-means algorithm requires the number of clusters to be known beforehand – this may be determined either through expert knowledge and/or analysis of the data. K records are randomly chosen to represent the cluster centres, and every record within the data set is assigned to its nearest cluster centre (using a Euclidean distance measure for numerical data). Once all records are assigned to a cluster, the centre of the cluster is recalculated by taking the mean of all records contained in it. Any record that is now nearer to another cluster is reassigned, and the cluster centres are recalculated again. This process continues until no records change clusters (or we reach some pre-defined stopping criterion).

K-means has its drawbacks – it can be difficult to choose the optimal value for k, and the random nature of the initialisation (simply choosing k random records) means that we may not always find an optimal solution. However, it can provide a quick and efficient method for clustering numerical data.

The data was normalised and various experiments were performed to identify the optimal number of clusters**.** Figure 3 plots the within group sum of squares against the number of clusters for 10 randomly initialised runs of the k-means algorithm. The optimal number of clusters is generally thought to be the point at which there is an “elbow” or bend in the plot – this would seem to indicate that 3 clusters is optimal.

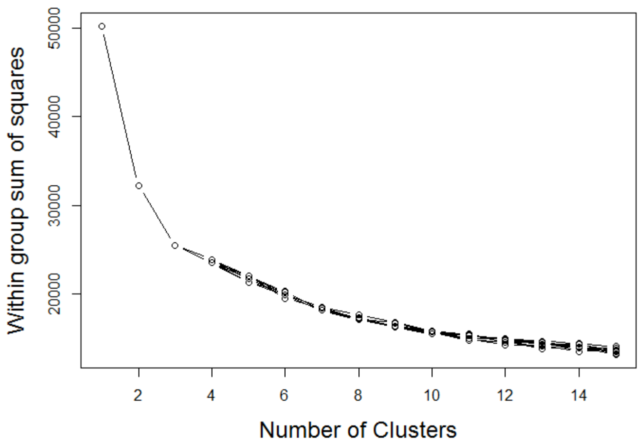

Figure 3. The within group sum of squares against the number of clusters for 10 randomly initialised runs using k-means

A clustergram (Schonlau 2004) is used to visualise cluster assignments as the number of clusters increases, using the k-means algorithm. The cluster mean is plotted for each k cluster, with the width of the lines on the graph representing how large the clusters are – therefore it is possible to visualise roughly how many records are in each cluster, and how the clusters split/join. The clusters are plotted proportional to size, by weighting the means against the first principal component of the data. The clustergram can be used as a visual aid in determining the optimal number of clusters (k) for a given data set.

Here (Figure 4) we can also see that 3 cluster centres would appear to be optimal. The data falls into three strands - even with the addition of further cluster centres those three strands still remain fairly stable. Further clustergrams were produced to check against random initialisations of the clustering (not shown for reasons of space), but from these it was concluded that three cluster centres would be optimal.

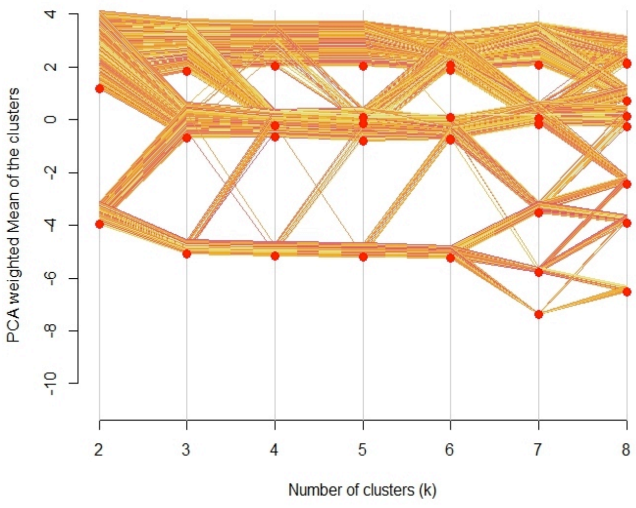

Figure 4. Clustergram of PCA-weighted mean of k-mean clusters vs. number of clusters

B. K-means clustering using 3 cluster centres

Clustering was performed on the 13 normalised attributes using 3 cluster centres. The R implementation of the k-means algorithm, which utilises the algorithm as defined by (Hartigan & Wong 1979) was used. Twenty randomly initialised runs were performed, with the best chosen. The table below (Table 1) contains the cluster means for each of the attributes in the three clusters in this clustering.

The goodness of the clustering, at 49.3% is not very high, indicating they are not very distinct. Of the three clusters, cluster 1 is fairly small (comprising 14% of the records), and the other two much larger (cluster 2 containing 35% of the records, and cluster 2 having 51%).

These clusters can be characterised as follows. **Cluster 1** is a sparsely populated outcome, with an older population, fewer friends on average, higher majority proportion, but more clustered. Relatively few adults are politically involved. **Cluster 2** and **Cluster 3** both have younger populations with a lower level of the majority ethnicity, and more immigrants, more similar friends and households, but higher levels of political involvement than **Cluster 1**. **Cluster 3** differs from **Cluster 2** in having a bigger population, lower clustering and a much lower rate of political conversation via school-related networks.

TABLE 1.
DETAILS OF THE CENTROIDS OF THE 3 K-MEANS CLUSTERS

Attribute	Cluster 1 (543 records)	Cluster 2 (1333 records)	Cluster 3 (1986 records)
Pop.size	100	557	1750
Av.age	76	58	55
Av.adfriends	0.73	1.36	1.82
Prop.maj	74%	67%	65%
Prop.adult	99%	94%	93.5%
Prop.1stgen	8%	13%	14%
av.clust	0.97	0.84	0.70
av.sim.hh	2.45	3.53	3.74
av.sim.fr	2.82	3.70	3.33
Rate ncvs.ac	1.3%	1.3%	0.0%
Rate ncvs.sc	0.45%	0.20%	0.13%
Prop. Adults involved	0.97%	1.6%	1.7%
Within cluster sum of squares	6748.243	11288.460	7407.591
Total sum of squares	50193		
Between SS/ Total SS	**49.3%**		

Figure 5 plots the clusters against the first two discriminants. In all, whilst the dividing line between different clusters is quite clean, it may be somewhat arbitrary just where to draw the line, as there are no clear gaps between clusters.

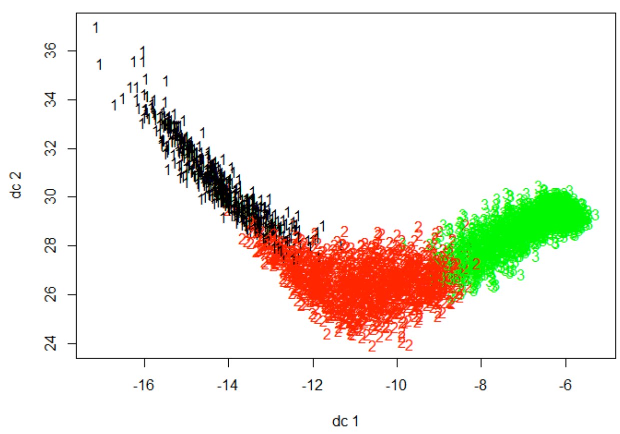

Figure 5. centroid plot against the first two discriminant functions showing the 3 clusters

If we go back to the previous hierarchical clustering and compare these three clusters with the three found using hierarchical clustering, 92% of the simulations fall into exactly the same clusters.

Figure 10 (at the end of the paper) is a pairs plot of the thirteen attributes coloured by their cluster assignments. It is difficult to read, but gives an idea of how the clusters are distributed. Despite the fact that there are no neat lines separating the clusters in some of the dimensions, the plots do show that this categorisation spreads in meaningful patterns in each dimension. Here one can see that, for example the number of adult conversations across activity-related links is proportional to the extent of adult involvement, but only for **Cluster 2**, and that link-density only significantly varies for **Cluster 1**.

In an effort to understand how the varying input parameters might relate to the clustering of the simulation outputs, Figure 6 contains a pairs plot of the three of the varying input parameters coloured by their cluster assignments. This presents a noisier picture of how the inputs might lead to those cluster assignments (we have only shown the three relatively clear pair plots in Figure 6). Here we can see that **Cluster 1** does indeed tend to result from low immigration, high emigration parameter settings; **Cluster 3** from high immigration (either internal or international), low emigration parameter settings; and **Cluster 2** somewhere in between.

However, a method such as decision tree learning can provide a clearer view of how these inputs, in combination, produced the clusters. It may also provide a better understanding of how the model works, and allow a user to predict in advance which cluster a simulation will fall into. Figure 9 shows the pruned decision tree that defines the clusters.

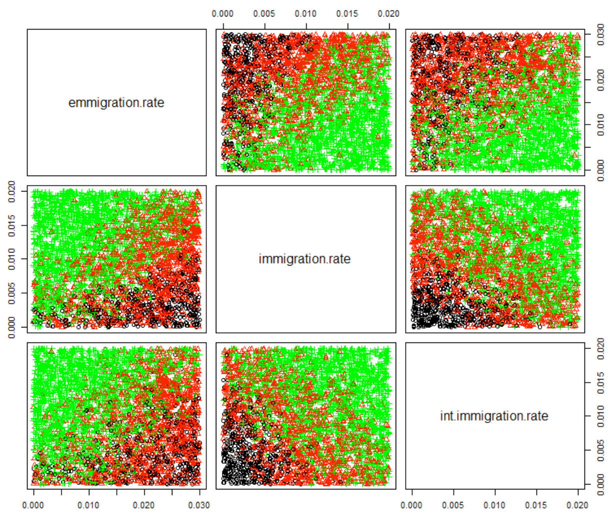

Figure 6. Shows the three clusters against the 3 parameters: emigration rate, immigration rate and internal immigration rate

C. Using varying input parameters to predict clusters

Decision tree learning is a method of predicting a target attribute (or classification), based on given input attributes. It is a form of supervised machine learning, in that the algorithm learns from labelled training data to produce a model which can then predict the value (or classification) of a target variable for new (unlabelled) data.

Decision trees are particularly popular since, in comparison to many other machine learning algorithms, their rules can be easier to understand and visualise in the form of a tree. Decision trees recursively partition data, using either the Gini coefficient or Information Gain at each step to determine the optimal input attribute to partition on. Given many input attributes, a decision tree will therefore select just those attributes that are important to predicting the target.

A tree model may over-fit data – i.e. learn the training data so well that it cannot generalise well on testing/unseen data – to avoid this, a tree is often grown overly large and then pruned back to an optimal level (using a complexity parameter).

The data was split into a training and testing data set (70:30 split) and a classification tree was built to predict the cluster assignment (derived previously from the outputs), using only the 9 varying input parameters as predictors. The rpart R package (Therneau & Atkinson 1997), which is an implementation of the Classification and Regression Tree (CART) algorithm (Breiman et al. 1983), was used to build the decision tree.

The resulting pruned tree (complexity parameter=0.0044) had **85.59% accuracy** on the testing data, and used only the attributes **emmigration.rate, immigration.rate and int.immigration.rate,** as predictors. This may therefore indicate that these particular attributes are more "important" to the data, at least in terms of predicting the previously found clustering of simulations. The tree is shown in Figure 9 in the appendix.

D. Comparison with Sensitivity Analysis

This is born out when a single parameter sweep varying just one of these dimensions is examined. So, for example, when runs of the model are done with only the immigration rate varied, and one plots the average similarity of friends for different rates one gets the graph show in Figure 7.

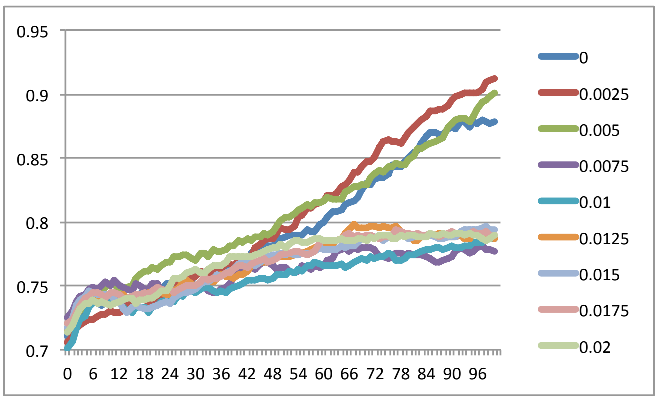

Figure 7. Average proportion of similar friends against time for different immigration rates

Here one sees a sharp division between runs with immigration rates of 0.5% and below and those above. The point of this paper is not to talk about why this happens (we hypothesise that for low rates households are able to segregate, whilst at higher rates the proportions of immigrants makes this impractical), but rather to get a broader picture of the overall behaviour of the simulation model and put particular selected results in that context.

In contrast, whilst the proportion of the original population that belonged to the majority population did impact upon the results, its influence diminishes over simulation time. Figure 8 shows how link density changes over the simulation for different initial proportions of the majority population.

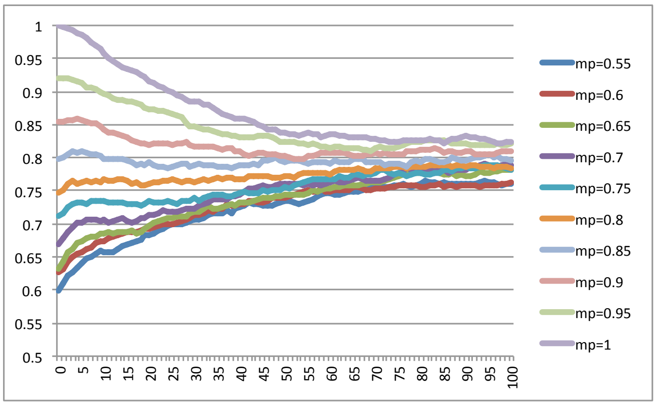

Figure 8. Average link density against time for different initial majority proportions

VI. Concluding Discussion

If complex models are inevitable, as has been argued elsewhere (Edmonds Edmonds and Moss 2005), then we will be faced with the problem of understanding them. Simple parameter sweeps and associated graphs may not be enough to characterise a complex simulation model, since they only give "thin" cross-sections of the overall behaviour. Applying Data-mining techniques to many runs of a model with randomised parameters may help to broaden the "view" of such a model, leading to a more holistic understanding. This broader view may allow a more complex understanding of the model behaviour, as well as help the researcher to focus in on which factors might influence the results more.

In general data-mining and knowledge discovery techniques have not been used much in conjunction with agent-based modelling, but this is a shame, since they both aim to understand complex data, in non-linear ways. They differ in the extent to which they are data-focussed or theory-driven – data mining being the former and ABM the latter. However both go beyond the simplistic assumptions and techniques of linear regressions models and their variants in showing some of the complexity that lies behind the data and in not hiding this within a linear fitted model.

Acknowledgment

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APPENDIX (FULL PAGE DIAGRAMS)

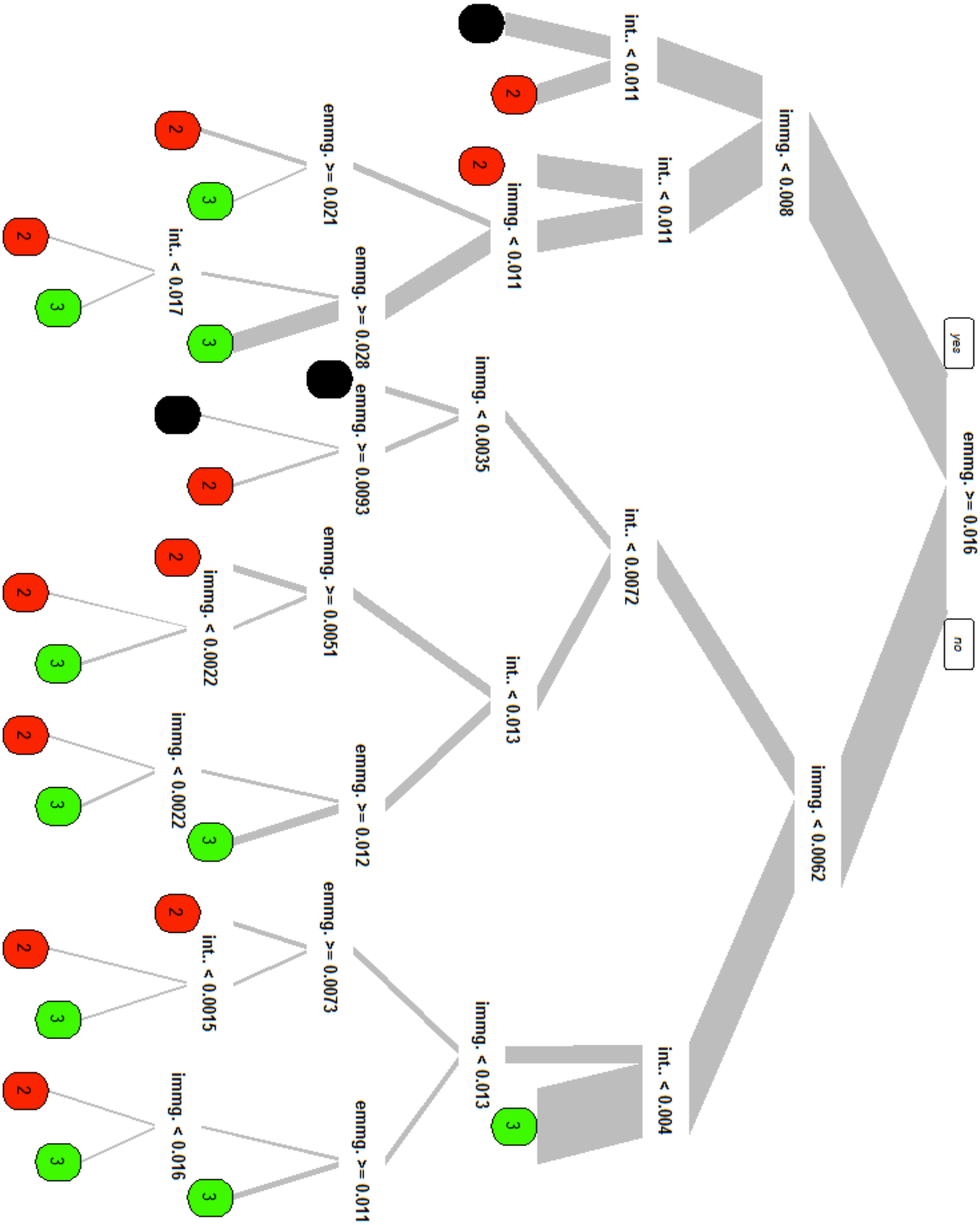

Figure 9. The induced decision tree that specifics the three clusters

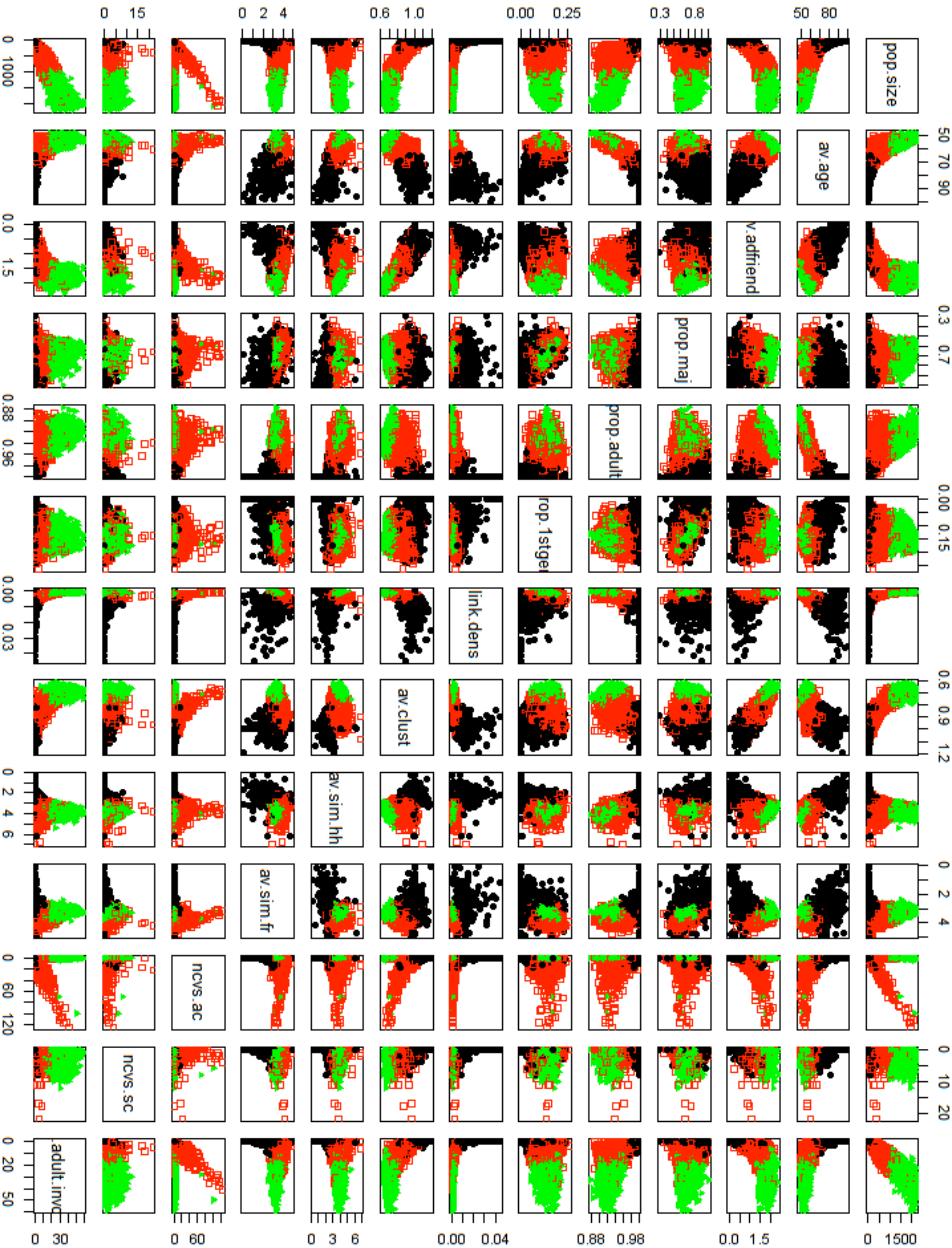

Figure 10. Scatter Plots of the Different Output Measures Against each other, with the three clusters coloured as above

Job Satisfaction as a Unified Mechanism for Agent Behaviour on a Labour Market with Referral Hiring

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***Abstract*—Existing agent-based labour-market models include a very simplistic mechanism of choosing vacancies. This paper proposes to use job satisfaction as a unified mechanism for deciding on both starting to work on a particular job and quitting the current job. An enhanced job satisfaction mechanism consisting of monetary, social, content, and career components is proposed. As an illustrative context, a labour-market model with referral hiring and informal job search through own social networks is presented.**

I. Introduction

The importance of social networks on the labour market was repeatedly shown both empirically and theoretically. Social networks affect the actions of both firms and individuals at different stages of the employment process.

Firms frequently use the social networks of their employees in the process of referral hiring. Research shows that in different countries, 30 to 50 per cent of companies hire by employee referral [1], [2], but it is far more common in small and medium firms, while large firms tend to rely on formal hiring practices [2], [3]. Different theoretical explanations of the rationale behind using referral hiring were proposed, and all of them are connected to reducing the costs of hiring [4]. Firstly, the referrals of existing employees, which are a trusted source of information for their employer, help reduce the problem of bilateral asymmetric information and the associated costs. Secondly, asking employees for job candidates they would recommend is a much less costly way of finding workforce than going through formal channels.

For individuals, social networks are even more important. Studies show that between 30 and 50 per cent of individuals found their new jobs through friends and relatives [5], [6], and individuals with access to larger social networks use informal job search channels more often [7]. Moreover, social support from co-workers and managers, along with other factors, is an important component of job satisfaction [8]–[12]. The Job Demands-Resources model [13] notes that social support acts as a buffer against high job demands, thus, preventing job strain; it also improves employees' motivation and productivity. Low job satisfaction is a strong indicator of a decision to quit [14].

Job satisfaction (JS) is a multi-faceted construct. A significant body of research exists studying the factors important for JS. There is general agreement that, besides social support, an important role is played by intrinsic job attributes, financial rewards, career growth, job security, and working conditions [15]–[18].

Referral hiring and job search through social networks were modelled both mathematically [19]–[21] and through simulations [22]–[25]. A common deficiency of these models is simplistic modelling of the choice among available vacancies, where the unemployed either take any vacancy or choose the best vacancy only based on the proposed wage.

In [26], a mechanism for including JS in agent-based simulations was proposed for more comprehensive modelling of individual dynamics on the labour market. There, JS was used both to choose the most appealing vacancy and to decide about on-the-job search. JS depended on relative wage and social network component.

In this paper, I take the idea of [26] further and propose to include other important facets of job satisfaction: job content and career opportunities. This mechanism is then integrated into a labour-market model with referral hiring and job search through social networks. I then study how introducing the JS mechanism changes the dynamics on the labour market.

The paper is structured as follows. The following section describes the job satisfaction mechanism in detail. Section III sets up the labour-market model. Then Sect. IV discusses how parameters should be set up, taking into account existing empirical data. Results are discussed in Sect. V. The last section concludes.

II. Job Satisfaction Mechanism

As in [26], I divide JS in two components: expected JS, s^e_{ijf}, and actual (or current, as called in [26]) JS, s^a_{ijf}. Both are defined for agent i relative to job j at firm f. In other words, I introduce the dependence of JS on the firm, whereby there is certain correlation in JS for jobs inside a firm. This reflects the perception that some companies are *in general* better employers than others.

As in real life, JS is modelled as a multi-faceted concept. It consisted of wages and social support (mainly from co-workers) in [26]. This does cover compensation and support facets, but does not take into account job content and career opportunities. Including these latter facets introduces substantial difficulties. The former two facets can be modelled objectively (with their relative importance depending on some agent-specific weight), in the sense that the agent can be absolutely sure about the wage it will receive and the number of friends (approximating social support) it will have on a concrete job. In contrast, job content and career opportunities are vague concepts, more related to perceptions rather than to hard data. Nowadays, nearly every job advertisement speaks about an "interesting" job with "ample" career opportunities, which individuals have to interpret in the context of their existing knowledge about the firm and the job under consideration.

To make the matters simple, I assume that there are two types of jobs. The first type has ample career opportunities and high variety (which approximates content), while the second has limited career opportunities and low variety. The former jobs can be represented (and will be calibrated) by non-manual jobs (International Standard Classification of Occupations (ISCO) major groups 1 (managers) through 5 (service workers)), while the latter by manual jobs (ISCO major groups 6 (skilled agricultural and fishery workers) through 9 (elementary occupations)).

While agents perceive, e.g., manual jobs as having limited career opportunities, the perception of career opportunities for a given vacancy for such job depends also on the firm that posted it. Again, I assume that the only characteristic of the firm important for the perception of both career opportunities and variety at a given vacancy is the size of the firm.[1]

Thus, the perception of job content and career opportunities depend on the type of job (manual vs. non-manual) and firm size.

Hence, expected JS is a function of:[2]

- Monetary compensation defined as the ratio of the expected wage of agent i on job j in firm f to its reservation wage, w_{ijf}/w_i^r
- Social support defined as the ratio of the number of friends of agent i in firm f (which I will refer to as "local friends") to the total number of its friends (i.e., the share of its friends working in firm f), n_i^f/n_i
- Job variety defined as a function of the type of job and firm size, $v\{T(j), S(f)\}$
- Career opportunities defined as a function of the type of job and firm size, $c\{T(j), S(f)\}$

The functional form of expected JS is as follows:

$$s_{ijf}^e = \Lambda\left\{6\left[\frac{w_{ijf}}{w_i^r}-1\right]\right\} + \left[2\Lambda\left\{\frac{6n_i^f}{n_i}\right\}-1\right] + v\{T(j), S(f)\} + c\{T(j), S(f)\}\,, \quad (1)$$

where $\Lambda\{\cdot\}$ is the logistic function, whose range is $[0, 1]$. The logistic function makes JS increase with monetary compensation and social support, but the return to these factors in terms of JS is decreasing (any next dollar or local friend increases JS less). Importantly, it also bounds the range of JS. The factor of 6 appears because $\Lambda(6) \approx 1$ and $\Lambda(-6) \approx 0$. Thus, the first summand approaches zero when $w_{ijf} \ll w_i^r$ and one when $w_{ijf} = 2w_i^r$. The second summand is zero when the agent has no local friends ($n_i^f = 0$) and approaches one when it has all friends working with firm f. Functions $v[\cdot]$ and $c[\cdot]$ also have the range of $[0, 1]$; they will be defined in Sec. IV. Thus, s_{ijf}^e can take values in $[0, 4]$.

[1]Industry might be an additional important factor, but in the current paper it is ignored.

[2]In this paper, I use parentheses and braces in the definition of functions and square brackets to group expressions. E.g., $f(x+y)$ and $f\{x+y\}$ should be read as "function f of $x+y$," while $f[x+y]$ should be read as "f multiplied by $x+y$."

Algorithm 1 Monthly Actions on the Labour Market

```
if start of year then
    New population added
    Persons aged over ā retire
end if
Non-start-up firms with zero workforce die
if start of year then
    Firms select annual workforce change
    Firms select wage change factor
end if
Update labour-market experience of persons
Create new firms
Firms update wages for expiring contracts
Firms change workforce and/or publish vacancies
Persons update current job satisfaction and consider starting
on-the-job search
Persons update reservation wage and apply to vacancies
Firms send acknowledgements to selected persons
Persons reply to the best acknowledgement, quit current job
if needed, and start working
Firms update failed vacancies
```

Actual JS represents the dynamics in the facets of expected JS (mainly, wage and social support) and all other factors gauged by a normally distributed random disturbance ξ:[3]

$$\Delta s_{ijf}^a(t) = \Delta s_{ijf}^e(t) + \xi\,. \quad (2)$$

By construction, the expected JS is always in $[0, 4]$. The value of the actual JS is reset at the closest boundary of this interval if Eq. (2) gives out-of-boundary values.

III. Model Specification

There are two types of agents: persons and firms. The model includes only the labour market; in particular, the education market is ignored. The degree of match between the person and the job is controlled through job requirements published in vacancies, see the job search mechanism below.

Timing is discrete with one period representing one month. Most actions on the labour market are done on a monthly basis. The only exceptions are changes in population (inflow of new school or university graduates) and in wages (standard assumption about wage stickiness), which happen annually (every 12 periods). Time-dependent variables are written as $f(t)$ if they change monthly or as $f(\tau)$ if they change annually.

Every year, N new persons come to the model and N are retired after living in the model for $\bar{a}$ years ("retirement age").

The overall view on monthly the labour-market actions of persons and firms related to job search are summarised in Algorithm 1. The following subsections describe its steps in detail.

[3]Delta (Δ) is used here as standard difference operator for time-dependent functions, i.e., $\Delta f(t) \equiv f(t) - f(t-1)$.

A. Job Search

There is a unique vacancy list in the market, which everyone is able to access (e.g., a country-wide job search website). Firms post vacancies on this list and persons may browse it to find new jobs, which is called formal job search. Alternatively, persons can choose to search for jobs informally, using their friends that are employed. Implicitly, I assume that all employees in a given firm are informed about all its vacancies.

A vacancy is a quadruple (f, T, x, w), where

- f is the firm hosting the vacancy
- T is the type of job (manual or non-manual)
- $x \in \mathbb{Z}, 0 \leq x \leq \bar{x}$ is the minimum required working experience measured in years; $\bar{x}$ is the sufficient experience, which is common for all vacancies
- $w \in \mathbb{Z}, w \leq w_m$ is the proposed wage rate at the required experience x; w_m is the minimum wage, which is common for all vacancies

Between the minimum required experience and the sufficient experience, wage changes linearly with experience x_i:

$$w(x_i) = \begin{cases} w[1 + q(T)[x_i - x]], & \text{if } x \leq x_i \leq \bar{x} \\ w[1 + q(T)[\bar{x} - x]], & \text{if } x_i > \bar{x}\,, \end{cases} \quad (3)$$

where $q(T)$ is a constant specific for each job type.

Every person i knows its actual experience x_i and reservation wage w_i^r and, for each vacancy, is able to find out the wage it will be paid. The person decides probabilistically on formal vs. informal search. In both cases, the person creates a list of matching vacancies (i.e., set $\{v|x(v) \leq x_i \wedge w(v, x_i) \geq w_i^r\}$).[4] As information processing capabilities of agents are limited, they consider only not more than K matching vacancies—randomly in case of formal search and the first ones it found in case of informal search. It then sorts this list by descending expected JS and sends application to top k vacancies. Both k and K are the same for all persons.

Small (less than 25 employees) and medium-sized (25–499 employees) firms employ the referral hiring mechanism when choosing candidates to employ. If in the list of applications for the vacancy, there are candidates having friends employed in the firm, the firm chooses randomly from these candidates; otherwise, it chooses randomly from all candidates. Large (500+ employees) firms do not look on the existing social ties of candidates with their employees and choose randomly from all applicants.

Successful candidates receive acknowledgements. If a person receives acknowledgements from several applications, it chooses the job with the highest expected JS. It then starts working immediately on that job.

The vacancy may fail to attract applications if it has low expected JS. For a given person, the firm can increase the expected JS of the vacancy only by increasing the proposed wage, as other components—social support, job variety, and career opportunity—are fixed. At the same time, the firm cannot decrease the required experience to attract additional candidates, as it needs qualified employees. The firm then looks at the average wage for experience x and type of job T on the market. If it is above the wage proposed by the firm, it sets the new wage at market average. If the firm's proposal, w, was already higher than market average, the new proposal is set at $\nu w, \nu > 1$. If the firm still fails to hire anyone for this vacancy in the next month, it cancels the vacancy.

Reservation wage for a working person is equal to its current wage. For a person with no working experience, it is given by the minimum wage. For an unemployed, it decreases with the length of unemployment measured in months, starting from the last wage, but is bounded from below by the minimum wage. The decreases occurs with constant elasticity φ, which is the same for all persons. Thus, the longer the person is unemployed, the lower wage it is ready to accept.

If for an employed person, its current JS falls below the minimum level, which is the same for all persons[5], it starts on-the-job search. In contrast with the unemployed, who consider all matching vacancies, the employed consider only those matching vacancies with the expected JS being higher than their current JS. If accepted for a vacancy, such person quits the current job and immediately starts working on the new position.

B. Dynamics Inside Firms

In the first month of the calendar year, firms plan changes in workforce and wages. Then, every month in that year, they implement these decisions.

If firms decide to change workforce by δ per cent this year, they implement it by changing workforce every month by $\delta/12$ per cent (rounded up or down as required). If the firm decides to expand this year, it publishes the according amount of new vacancies every month throughout the year and also publishes all vacancies substituting the employees who left after on-the-job search.

Each vacancy for a new position is created with the required experience x uniformly chosen from $[0, \bar{x}]$, where $\bar{x}$ denotes sufficient experience, and with probabilistically chosen type of job (manual vs. non-manual). The corresponding proposed wage w is set to the average wage of the firm's employees with that experience and job type. If no such persons are currently employed in the firm, it makes interpolation from the average wage it pays employees with the experience nearest to x and same job type. For companies having no employees of this job type, they take average current wages at experience x and the selected type of job in the economy.[6]

[4]See below on the additional restrictions on the vacancies in this list for persons engaged in on-the-job search.

[5]Individuals start thinking about quitting the job when they feel that their job is "unsatisfactory." What different individuals mean by this is reflected by the combinations of the values of JS facets, but all these combinations lead to JS falling below certain boundary. Using a relative, rather than absolute, measure of JS, it seems realistic to assume that this boundary is the same for everyone.

[6]If there are no such persons in the economy, average wages are interpolated from employees of the same job type with nearest experience.

Firms also publish vacancies to substitute employees who just quit the firm either after reaching the retirement age or due to low JS (contracted workforce is not substituted). In this case, the experience is set below that of the worker who quit (but still keeping it in $[0, \bar{x}]$):

$$x = \max(\min(x', \bar{x}) - 2, 0)\,, \qquad (4)$$

where x' is the experience of the worker who quit, and the type of job is left the same. The wage is set as described above.

If the firm decides to contract this year, its behaviour is slightly different. Every month, the firm has to lay off a certain number of employees. Before actually laying off agents, it looks on how many employees left the company in the previous month and first tries to implement the change in workforce by not publishing substituting vacancies. For instance, if the firm has to contract by 5 employees but 3 employees left it in the previous month, the firm does not publish these 3 substituting vacancies and lays off only 2 employees. All lay-offs are made randomly.

Every firm changes wages once a year, in accordance with standard economic results on the stickiness of wages. Wages are changed for all jobs in the firm by the same factor. That factor is chosen from the set $\{w_d, 1, w_u\}$, where $w_d < 1$ and $w_u > 1$ with the corresponding probabilities $\{\pi_u, 1 - \pi_u - \pi_d, \pi_d\}$. For a given employee, the wage is changed in the month it was hired on the current job (if it occurred in month 3 last year, it is changed in month 3 this year, although the decision to change wages was made in the beginning of this year). In other words, I assume yearly contracts with fixed wages.

C. The Birth and Death of Firms

A new firm can be born when a person probabilistically decides to create one. This probabilistic event occurs monthly, for both employed and unemployed persons. The mechanism of vacancy publication for new firms is the same as for any other firms. The only difference is that if a start-up is given Δt_s periods to find first employees. It allows new firms to search for workforce for more than one period, as otherwise, any new firm not having found at least one employee in the first month of its life would die (see the following paragraph). In other words, new firms are allowed to exist for their first Δt_s periods with zero workforce.

Otherwise, firms disappear when they are left with no workforce. Their owners become unemployed and start searching for a new job. When a firm's owner is removed from the simulation, the firm continues to exist without an owner: no other person is assigned as a new owner.

I assume that such entrepreneurs are not subject to on-the-job search or quitting their companies, which makes the definition of their wages and, more broadly, JS unnecessary.

Initially, the simulation is filled with M firms with no workforce.

D. Dynamics of Social Networks

Some of the persons that enter the model in the same period are interconnected, forming an *initial social network* of, e.g., secondary school or university friends[7]. They also have friendship ties with those persons already in the labour market (irrespective of whether they are employed or not), forming a *mature social network*. These two sets of connections form the social network with which the person enters the model.

This initial social network is generated using the Duplication model [27, Ch. 4] parametrised to build a scale-free social network, having many low-degree vertices and a few high-degree vertices.[8] Empirical research indicates that such networks approximate the real-world social networks quite well [28]–[30]. Both networks are built separately with the same parameter $\rho \in (0, 1)$.

When person i, having a social network of n_i friends, first comes to a new job, it tries to make new friendship ties with $\lceil n_i/10 \rceil$ persons working in that firm; each tie is created with probability $1/2$, as the other party can refuse the proposed friendship. The principle of homophily says that people make friendship ties from those close to them by some characteristics [31]. In accordance with it, persons make friends only with those working in the same job type as theirs.

As the person cannot have an indefinite number of friends, it substitutes the existing friends with these new friends. So if on the first working day, the person makes k new connections, it breaks connections with k its existing friends, firstly removing those with the longest period of unemployment.

IV. Parametrisation

European Social Survey (ESS) Round 5 [32] has individual-level data on the perceptions of the employed in 24 European countries[9] in 2010–11 about their jobs. I use pooled data from these countries for setting parameter values. Tables I and II show the details. Note that, as assumed in this paper, the perceptions of both career opportunities and variety in work are better in non-manual occupations than in manual occupations. Functions $v[\cdot]$ and $c[\cdot]$ are defined according to this table. There are, thus, three categories of firm size, $S(f)$: small (under 25 employees), medium (25 to 499 employees), and large (at least 500 employees).

Wage dynamics is set based on estimates available in the literature, see Table III. The average effect on wages from labour-market experience is around 2.5%. Estimates based on US data show that it is around 1.5 times larger for the tertiary-educated than for the secondary-educated. Assuming that the

[7] Friends in the broad sense, meaning both close friends and acquaintances

[8] In short, the Duplication model proceeds in two-step iterations. At the first step, a new vertex is added to the graph and connected randomly with an existing vertex. At the second step, the algorithm goes over each neighbour of the existing vertex and connects it to the new vertex with probability ρ. Thus, ρ is the probability of an agent creating a connection with a friend of its new friend. It was shown [27, 78] that the model generates scale-free networks with the exponent β that is a solution to the equation $1 + \rho = \rho\beta + \rho^{\beta-1}$.

[9] Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Lithuania, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and the UK.

TABLE I
SHARE OF EMPLOYED INDIVIDUALS BELIEVING THAT THE OPPORTUNITIES FOR ADVANCEMENT ARE GOOD

	Firm Size (# employees)														
	< 25					25–499					500+				
Extent of Agreeing (Fully disagree 1..5 Fully agree)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Non-manual occupations	11%	27%	29%	27%	6%	9%	27%	29%	30%	5%	9%	23%	27%	33%	7%
Manual occupations	17%	30%	27%	22%	4%	17%	33%	25%	21%	3%	15%	33%	24%	24%	4%

Source: calculated from European Social Survey Round 5 pooled data from 24 European countries (see Footnote 9).

TABLE II
SHARE OF EMPLOYED INDIVIDUALS BELIEVING THAT VARIETY IN WORK IS GOOD

	Firm Size (# employees)											
	< 25				25–499				500+			
Extent of Agreeing (Fully disagree 1..4 Fully agree)	1	2	3	4	1	2	3	4	1	2	3	4
Non-manual occupations	7%	26%	34%	34%	5%	20%	35%	40%	4%	18%	34%	45%
Manual occupations	17%	31%	28%	24%	17%	31%	30%	23%	18%	27%	30%	25%

Source: calculated from European Social Survey Round 5 pooled data from 24 European countries (see Footnote 9).

TABLE III
EMPIRICAL DATA ON WAGE RETURNS ON YEAR OF EXPERIENCE

Author	Country	Sex	Education Level		
			Secondary	Tertiary	Total
[33]	Italy	Men			2.9%
		Women			1.1%
[34]	UK	Men			2.2%
[35]	UK	All			7.4%
[36]	9 countries	All			1.06%–3.67%
[37]	USA	Men	1.8%	2.5%	
		Women	1.9%	3.2%	
[38]	USA	Men	3.1%	5.8%	
		Women	3.7%	8.2%	

Estimates correcting for unobserved heterogeneity were taken where available. Where cumulative effect of experience over several years was given, it was converted into annual effect assuming that the effect from every additional year of experience is the same (e.g., a 20% cumulative effect over 10 years would be converted into a 2% annual effect). From [36], data were taken only on countries with positive relationship between wage and experience; the nine countries are Austria, Belgium, Germany, Greece, Ireland, Italy, Portugal, Spain, and the UK.

former work at non-manual jobs and the latter at manual jobs[10], I set the wage-experience coefficient at 3.0% for non-manual jobs and at 2.0% for manual jobs. The relationship between wage and experience is non-linear: returns are diminishing at higher experience levels and after 20–30 [36] years, the wage-experience curve flattens[11]. Here, I assume that wage changes linearly with experience (recall Eq. (3)) and wage stops depending on experience starting with 20 years of experience, which I call "sufficient" experience level.

The distribution of annual workforce change is set in accordance with Amadeus data for European companies in 2010–2013, see Table III. Note that extreme changes (larger than 50 per cent in absolute terms) were filtered out from the sample and are also not allowed in the simulation. In around 70 per cent of cases, firms will change workforce by ± 10 per cent.

According to the job-search theory [39], reservation wage falls with unemployment spell duration. Empirical studies used constant-elasticity models for quantifying this effect, but came to substantially different elasticities, ranging from -10% [40] to -80% [41]. I set the elasticity at -20%, which means that for every 10 per cent increase in unemployment spell, reservation wage falls 2 per cent.

The probability of becoming entrepreneur is set based on the share of self-employed in Europe (ESS Round 5 data), which is[12] 13%, and Proposition A.1.

The Duplication model parameter ρ is set so that the model generates a scale-free network with exponent $\beta \approx 2.61$, which is inside the range $[2, 3]$ typical for social networks [27]. The number of direct connections in initial and mature networks are set so that the average number of friends would be not more than 100–120, the maximum number of Facebook friends with which an individual interacted at least once [30, Fig. 15].

V. RESULTS

The model was implemented in Repast Simphony. At this moment, only preliminary results are available.

The initial number of firms is a major factor affecting the overall employment in all further periods. With $M = 10$, unemployment exceeded 95 per cent for the length of simulation, while with $M = 50$, there was nearly full employment on

[10] In other words, I assume there is no over- or under-education and the education levels of all workers perfectly matches job demands.

[11] In some countries, wages start dropping afterwards.

[12] Share of self-employed from the employed in paid work, in education, unemployed and inactive. Not taking into account the disabled, retired, in military service or doing housework.

TABLE IV
DISTRIBUTION OF ANNUAL WORKFORCE PERCENTAGE CHANGE

% Change	$[-50, -41]$	$[-40, -31]$	$[-30, -21]$	$[-20, -11]$	$[-10, -1]$	[0, 9]	[10, 19]	[20, 29]	[30, 39]	[40,50]
% in Sample	0.7	1.0	2.4	7.0	25.3	45.2	10.4	4.4	2.1	1.5

Data from Amadeus, accumulated over 2010–2013. The sample contains active firms operating in EU-28, Norway and Switzerland. Only firms with annual change in workforce in the interval of $[-50\%, +50\%]$ were selected. The distributions in each individual year in the 2010–2013 interval are very similar to that given in the table.

TABLE V
PARAMETER VALUES

Parameter Name	Notation	Value
General		
Annual inflow of new persons	N	100
Retirement age, years	$\bar{a}$	30
Length of simulation, years		100
Initial number of firms	M	50
Job Satisfaction		
Current job satisfaction disturbance		
mean	$\mu(\xi)$	0
std.dev.	$\sigma(\xi)$	0.1
Critical job satisfaction for on-the-job search		20%
Workforce Dynamics		
Prob. of manual vacancy		0.30
Wage multiplier when updating vacancy	ν	1.05
Wage-experience multiplier	q	
manual jobs		2%
non-manual jobs		3%
Sufficient experience, years	$\bar{x}$	20
Job Search		
# of simultaneous applications	k	5
Max # of vacancies considered	K	50
Prob. of formal job search		0.3
Unempl. length elasticity of reservation wage	φ	-20%
Wage Specification		
Minimum wage	w_m	100
Wage dynamics		
Prob. of increasing wage	π_u	0.6
Factor of wage increase	w_u	1.05
Prob. of decreasing wage	π_d	0.1
Factor of wage decrease	w_d	0.95
Entrepreneurship		
Prob. of becoming entrepreneur		0.95%
How long considered start-up, periods	Δt_s	6
Social Networks		
Duplication model parameter	ρ	0.45
Number of direct connections		
initial social network		30
mature social network		10

the labour market. Further sensitivity analysis will reveal the dependence of unemployment on the initial number of firms.

Next I compare the model with full JS and the model with JS consisting only of the wage component. In other words, the latter model resembles typical economic models, where all decisions are based on proposed wages.

Both models lead to the creation of large firms (less than 5 per cent of all firms) an medium firms (20 to 30 per cent of all firms), see Fig. 1. Over time, the proportion of medium firms increases at the expense of small firms in the model with full JS, but drops in the model where decisions depend on wages only. Further analysis is needed to check for model stability.

The share of employees on manual jobs from all employed

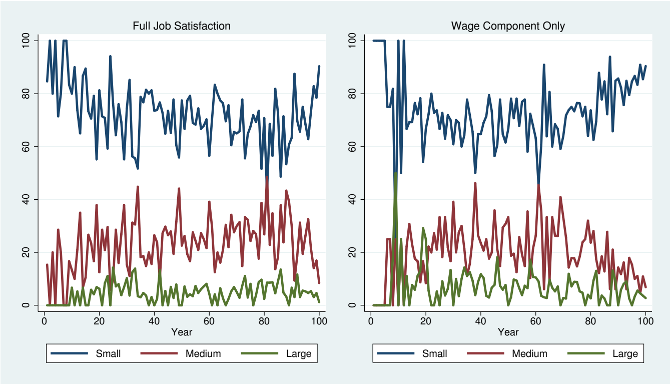

Fig. 1. Share of Firms of Different Size

Note: The size category of the firm (small, medium or large) is defined as in Sect. IV.

is nearly twice higher in the model with full JS than in the model with wage component (23 per cent vs. 13 per cent on average in the last period of the run). By construction, wages grow faster for non-manual jobs. Clearly, in the model with full JS, this is dampened by other factors, but when only wage is important, agents are still more inclined to choose non-manual jobs.

In the update to this version of the paper, I will add the results on the existence of social clustering in firms in both models, as well as comparing the base model with a model where persons use only formal search.

VI. CONCLUSIONS

APPENDIX

Proposition A.1. *Let P be the observed share of entrepreneurs in the population and p be the probability of becoming entrepreneur at any time moment in the model (constant over time). Assume that once the person becomes an entrepreneur, it cannot revert its status at any later time and that all age groups are equally represented in the model population. Let $\bar{a}$ be the maximum age of a person in the population (measured in years). Then the relationship between p and P is as follows:*

$$P = 1 + \frac{1 - (1-p)^{\bar{a}}}{\bar{a} \ln(1-p)} \,. \tag{5}$$

Proof: Consider a random person. After living a periods in the model, the probability of being entrepreneur is

$$\pi(a) = \sum_{k=0}^{a} (1-p)^{k-1} p \quad (6)$$

$$= \frac{p[1-(1-p)^k]}{1-(1-p)} \quad (7)$$

$$= 1-(1-p)^k . \quad (8)$$

To translate it to the whole population, first divide the interval of age, $[0, \bar{a}]$, into subintervals of length Δa. As the function $\pi(a)$ is smooth, for small enough Δa we can assume that $\pi(\cdot)$ is constant in any point inside such subinterval. Then the probability of a random person in the population to be entrepreneur is given by the sum over age subintervals of the products of the probability of falling into a particular age subinterval and the probability of being entrepreneur inside this interval. By assumption, the former probability is constant and given by $\bar{a}/\Delta a$. Then the probability of observing entrepreneur is

$$\pi = \sum_{k=0}^{\bar{a}/\Delta a - 1} \pi(k\Delta a) \frac{\Delta a}{\bar{a}} \quad (9)$$

$$= \sum_{k=0}^{\bar{a}/\Delta a - 1} \left(1-(1-p)^{k\Delta a}\right) \frac{\Delta a}{\bar{a}} \quad (10)$$

$$= \frac{\bar{a}}{\Delta a}\frac{\Delta a}{\bar{a}} - \frac{1-\left((1-p)^{\Delta a}\right)^{\frac{\bar{a}}{\Delta a}}}{1-(1-p)^{\Delta a}} \frac{\Delta a}{\bar{a}} \quad (11)$$

$$= 1 - \frac{1-(1-p)^{\bar{a}}}{1-(1-p)^{\Delta a}} \frac{\Delta a}{\bar{a}} . \quad (12)$$

Finally, take this expression to the limit of Δa (note the use of l'Hôpital's rule):

$$\lim_{\Delta a \to 0} \pi = 1 - \lim_{\Delta a \to 0} \frac{1-(1-p)^{\bar{a}}}{1-(1-p)^{\Delta a}} \frac{\Delta a}{\bar{a}} \quad (13)$$

$$= 1 - \lim_{\Delta a \to 0} \frac{1-(1-p)^{\bar{a}}}{-\bar{a}(1-p)^{\Delta a} \ln(1-p)} \quad (14)$$

$$= 1 + \frac{1-(1-p)^{\bar{a}}}{\bar{a} \ln(1-p)} . \quad (15)$$

This should be equal to P. ■

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The PLS Agent – Agent Behavior Validation by Partial Least Squares

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Abstract—**Agent-based modeling is widely applied in the social sciences. However, the validation of agent behavior is challenging and identified as one of the shortcomings in the field. Methods are required to establish empirical links and support the implementation of valid agent models. This paper contributes to this, by introducing the *PLS agent* concept. This approach shows a way to transfer results about causalities and decision criteria from empirical surveys into an agent-based decision model, through processing the output of a PLS-SEM model. This should simplify and foster the use of empirical results in agent-based simulation and support collaborative studies over the disciplines.**

I. Introduction

Agent-based modeling (ABM) is a promising and increasingly established method in the economics and the social sciences. The basic idea is to model social phenomena based on simplified descriptions of agents and their interactions. The dynamic behavior of these models is investigated based on simulation experiments. This capability of depicting human and societal complexity in a comparatively simple manner makes agent-based modeling very appealing (Macy and Willer 2002). The contribution and relevance of this method is demonstrated by its use in areas such as political science (e.g., policy adoption, voting and demography), technology (e.g., innovation diffusion, technology transfer and healthcare), economics (e.g., public goods, game theory and markets), as well as business.

In typical agent-based models in economics and the social sciences, autonomous agents represent humans. Just as human decision maker, agents have attributes and exhibit behavior, which have to be specified during the modeling process. This specification of agents, however, is both challenging and crucial for a good agent-based model. As model behavior is often driven to a large degree by the properties of agents, a valid and credible agent-based model also requires a valid agent description. Recent surveys on the current practice in agent-based modeling, however, have identified exactly validation as a major shortcoming (Heath et al. 2009). Against this backdrop, one can argue that the question of agent validity is one of the major challenges in the scientific endeavor to advance ABM. When agents and their interaction are not validated, the value and credibility of this research method will depreciate for many modeling domains.

The aim of this paper is to discuss how partial least squares (PLS) path models based on empirical data can contribute to agent validation. This will be done both on a conceptual level and at an applied level, i.e. by the means of an illustration in the area of innovation diffusion and acceptance, where agent properties are crucial for subsequently observed characteristics of the diffusion process.

The paper is structured as follows. First, an overview about agent model validation and its challenges is given (see Section II). Next, an introduction to PLS is given, that provide the empirical foundation for agent models (see Section III). In Section IV, the concept of the PLS Agent is introduced. Finally, the paper ends with a discussion and conclusion.

II. Agent Model Validation

For a successful application of agent-based simulation, some challenges have to be met and resolved. One important issue is the validation of the simulation model. Certainly, (simulation) models can only be approximations of the target system and absolute validity is not possible (Law 2007). However, the model has to be close enough, so that valid conclusions can be drawn and do not lead to costly erroneous decisions. On the other hand, models in the social sciences tend to be complex. The “art of modeling” is to find a level of detail that meets the important aspects of the target system in a treatable model (Gilbert 2008). Too complex models include the risk of over-parameterization. Models with too many degrees of freedom can always be adjusted in a way that they fit to the empirical data (Fagiolo et al. 2007). Thus, the model has to be valid in all necessary details, or validation remains a system-inherent problem of agent-based simulation (Klügl 2008).

Windrum et al. (2007) describe the *“problematic relationship between agent-based models and empirical data”.* In agent-based models, the validation process is the assessment of the simulated data with respect to the quality of representation of the observed data, as generated by the empirical process. A methodological basis for the process of empirical validation is clearly needed. However, there is still little consensus on the empirical validation of agent-based simulation models.

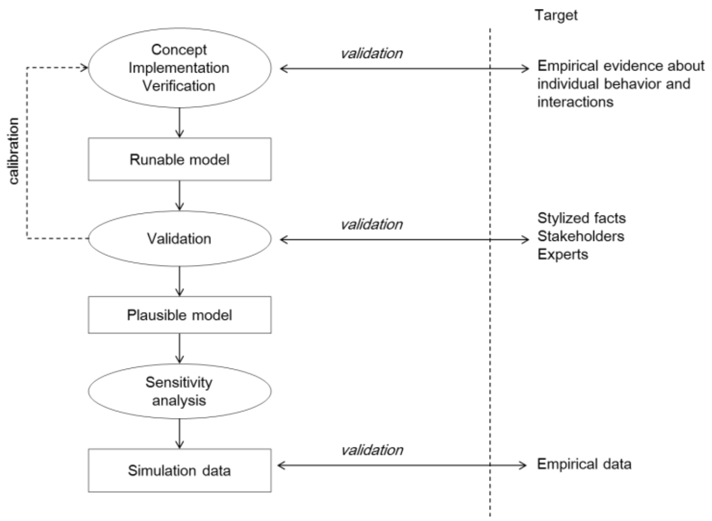


Figure 1: General procedure for validating simulation models (adapted from Klügl, 2008)

Figure 1 illustrates the basic validation process in agent-based simulation research, adapted from the process described in Klügl (2008).

First, an agent model is specified for the given target system. Based on empirical evidence about individual behavior and interactions, the agent concept is specified, implemented and verified in the first step. This determines the micro level of the simulation model. The resulting simulation behavior is assessed for plausibility on the (macro) system level for behavioral validity (input-output behavior). If necessary, the model is calibrated in this stage to fit the stylized facts. The plausible model is analyzed systematically in a sensitivity analysis. The results from this analysis can be verified by empirical data.

The described verification process of calibrating the micro model based on stylized facts on the macro level, is called the *indirect calibration approach* (Fagiolo et al. 2007). This approach is also useful for the reason, that data on the aggregate level are easier to gather than on the individual level (Klügl 2008). It is problematic to achieve data about the internal structure on the individual level. However, such data is necessary for modeling causalities within the agents' reasoning process, and, thus, for achieving a structural validity on the agent level. Overall, the main problem is the missing availability of empirical data (Klügl 2008).

This paper addresses this by introducing the partial least squares (PLS) method as empirical basis for defining the structure and causalities of agent reasoning. By using PLS, an empirically derived model about the internal structure of reasoning on the individual level as well as about the causalities between the variables of the agents' reasoning provides the basis for the agent architecture. This paper shows, how PLS can build a bridge between empirical data on the one hand and the agent architecture on the other.

III. Partial Least Squares (PLS)

A. *PLS-SEM*

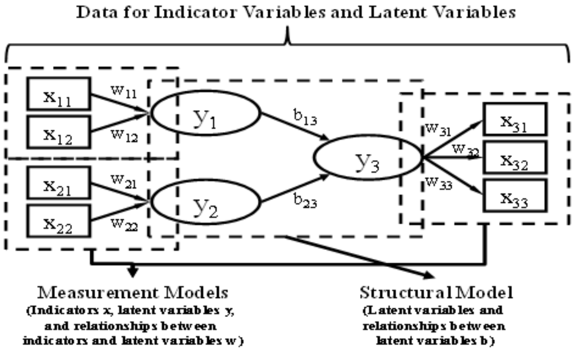
Structural equation models (SEM) appeared in the 1970's (Jöreskog, 1973) and have become a quasi-standard statistical method in the social sciences (Hair et al., 2011). The desire to test complete theories and concepts is a key reason for using the SEM method (Bollen, 1989). Variance-based partial least squares (PLS-SEM; Lohmöller, 1989; Wold, 1982) and covariance-based SEM (CB-SEM; Jöreskog, 1978, 1982) represent two alternative but distinctive methods to estimate structural equation models. In short, CB-SEM and PLS-SEM are different but complementary statistical methods for SEM whereby the advantages of the one method are the disadvantages of the other and vice versa (Jöreskog & Wold, 1982).

In general, a structural equation model with latent variables consists of measurement models describing the relationships between latent variables and their observed indicators, and a structural model of the relationships between the latent variables. In the PLS-SEM context, measurement and structural models are frequently called outer and inner models. Measurement models can comprise formative or reflective indicators (Diamantopoulos & Winklhofer, 2001; Jarvis et al., 2003), whereby only one type of relationship is possible per latent variable, although different latent variables in the SEM may use different types of measurement models. Reflective indicators are seen as functions of the latent variable. Changes in the latent variable are reflected by changes in the associated indicator variables. In contrast, formative indicators are assumed to cause a latent variable, i.e. changes in the indicators imply changes in the latent variable's value.

Figure 2 shows an example of a simple PLS path model, which includes one endogenous latent variable (y_3) and two exogenous latent variables (y_1 and y_2). The term "exogenous" is used to characterize latent variables with no preceding ones in the structural model. In contrast, the term "endogenous" characterizes latent variables that are explained by others in the structural model.

PLS-SEM requires the structural model to be recursive, which excludes the use of causal loops in the relationships between the latent variables (there would be a causal loop in the model in Figure 2 if there were relationships between y_1 and y_2, y_2 and y_3, and y_3 and y_1). The latent variables y_1 and y_2 are measured by means of formative indicators and y_3 by reflective indicators. It is important to note that PLS measurement models consist of one or more indicators. Each indicator can only be assigned once within a measurement model.

Case	x_{11}	x_{12}	x_{21}	x_{22}	x_{31}	x_{32}	x_{33}	y_1	y_2	y_3
1	x_{111}	x_{121}	x_{211}	x_{221}	x_{311}	x_{321}	x_{331}	y_{11}	y_{21}	y_{31}
…	…	…	…	…	…	…	…	…	…	…
n	x_{11n}	x_{12n}	x_{21n}	x_{22n}	x_{31n}	x_{32n}	x_{33n}	y_{1n}	y_{2n}	y_{3n}



	y_1	y_2	y_3
x_{11}	w_{11}		
x_{12}	w_{12}		
x_{21}		w_{21}	
x_{22}		w_{22}	
x_{31}			w_{31}
x_{32}			w_{32}
x_{33}			w_{33}

	y_1	y_2	y_3
y_1			b_{13}
y_2			b_{23}
y_3			

Figure 2: PLS-SEM example: initial set-up

The basic PLS-SEM algorithm - originally developed by Wold (1975) as NIPALS (nonlinear iterative partial least squares) and later extended by Lohmöller (1989) - follows a two-stage approach. This approach consists of the estimation of latent variable scores via the iteration of four steps in the first stage, and the final estimation of outer weights/loadings and path coefficients in the second stage (Figure 3).

<u>Stage 1:</u> Iterative estimation of the latent variable scores.
Do Loop
Step 1.1: Outer approximation of the latent variable scores.
Step 1.2: Estimation of the inner weights.
Step 1.3: Inner approximation of the latent variable scores.
Step 1.4: Estimation of the outer weights.
Until Convergence
<u>Stage 2:</u> Final estimation of outer weights/loadings and path coefficients through (single and multiple) ordinary least squares (OLS) regressions.

Figure 3: Key steps of the basic PLS-SEM algorithm

The goal of Stage 1 of the PLS-SEM algorithm is determining the latent variable scores. After convergence (Henseler, 2010), in Stage 2 of the PLS-SEM algorithm, the final latent variable scores are used to run OLS regressions that determine the final estimates for all relationships in the PLS path model.

B. *Important Characteristics of PLS-SEM to Extend Simulation Methods*

The statistical properties of the PLS-SEM method substantiate its use to extend simulation methods. Primarily, PLS-SEM is a non-parametric regression-based estimation method. Its use focuses on the prediction of a specific set of hypothesized relationships that maximizes explained variance in more or less the way as ordinary least squares (OLS) regressions do. Therefore, the focus is much more on prediction rather than explanation, which makes PLS-SEM results particularly beneficial for simulation methods.

PLS-SEM is also very flexible regarding the modeling properties. The only premise is connected to “predictor specification” (i.e., the systematic portion of all OLS regressions is equal to the dependent variables’ conditional expectations; Haenlein & Kaplan, 2004). In accordance, the inner model must be a causal chain system with uncorrelated residuals and an endogenous latent variable’s residual being uncorrelated with the corresponding predictor latent variables. PLS-SEM is also considered as the primary approach when the hypothesized model incorporates formative measures (Diamantopoulos & Winklhofer, 2001). Moreover, PLS-SEM is also a sensible choice in research situations where few observations are used to estimate complex models with many manifest variables. This holds especially true when formative measures are involved (besides the potential identification issues discussed above). Formative measurement models are often more capacious, as formative constructs should be represented by all relevant indicators that forms it to ensure content validity (Diamantopoulos et al., 2008). Thus, PLS-SEM can be a useful way of quickly exploring a large number of variables to identify sets of latent variables that can predict some outcome variable, underlining the approach’s exploratory character. Hence, PLS-SEM can be used for relatively complex models and has only very few requirements to be met. These features make PLS-SEM particularly suitable in combination with simulation methods.

Finally, in situations when it is difficult or impossible to meet more traditional multivariate techniques’ strict assumptions (e.g. distributional assumptions), PLS-SEM’s greater flexibility with modeling problems is emphasized by the label “soft modeling” coined by Wold (1982). Within this context, “soft” is only attributed to distributional assumptions and not the concepts, models or estimation techniques (Lohmöller, 1989). PLS-SEM’s statistical properties provide very robust model estimations both with data that have normal and extremely non-normal distributional properties (Reinartz et al., 2009; Ringle et al., 2009). Thus, PLS-SEM can also be used when distributions are highly skewed (e.g., Beebe et al., 1998; Cassel et al., 1999; Tenenhaus et al., 2010), especially when formative measurement models are included (Ringle et al., 2009). Moreover, the PLS-SEM algorithm principally requires metric data for the indicators in the measurement models. However, the method also generally works with ordinal scales with equidistant data points - i.e., quasi metric scales (Mooi & Sarstedt, 2011) - and with binary coded data. In the latter case, when using both metric and dummy variables, one must account for the role of dummy coded variables in regressions (Hair et al., 2011b), or the specific considerations provided by Lohmöller (1989) for PLS path model estimations that solely draw on dummy coded variables. This kind of flexibility regarding the data used also represents a beneficial feature when combining the PLS-SEM method with other techniques such as simulation methods.

One of PLS-SEM's most important features relates to the nature of the latent variable scores. Specifically, scores are estimated as exact linear combinations of their associated manifest variables (Fornell & Bookstein, 1982), and PLS-SEM treats these scores as perfect substitutes for the manifest variables capturing the variance that can explain the endogenous latent variables. PLS-SEM builds on the implicit assumption that all the measured variance in the model's manifest variables is useful and should be explained. Consequently, the "correctness" of the model is partly determined by the strength of the structural model relations between the latent variables.

While the strong reliance on latent variable scores has its drawbacks, it also has certain advantages as researchers may use latent variable scores in subsequent analyses. Other research methods already employ the PLS-SEM latent variable score for further analysis (e.g,. latent class segmentation; Sarstedt et al., 2011). Similarly, simulation studies may employ these results for their analyses, as we will show in this paper.

IV. The PLS Agent

This section shows how PLS results may be used as basis for modeling agent behavior. Therefore, this section starts with (A) general requirements for agent modeling. Afterwards, it is shown (B) how a PLS path model can be transferred into an agent decision model. Finally, (C) the implemented simulation framework *SimPLS* is described, by which a direct link between PLS output and ABM initialization is established, so that the concept is ready to be applied for various PLS path models.

A. *Agent modeling*

An agent is specified by its properties and abilities. The basic abilities of an agent are to perceive, decide and act. The agent observes its environment and perceives environmental information. The agent determines its behavior with the information received. Programmed rules relate information sensed by the agent to its decisions and actions (Macal and North 2010). Defined by the rules of decision for the given observation, the agent executes the corresponding action in its artificial environment.

The decision rules may be defined deterministically or stochastically. Furthermore, the complexity of decision rules may vary, so that the implementation of complex decision process is possible. A basic decision rule structure can be described by condition-action rules (see e.g. Holland et al. (2000)). By this concept, the agent may build up a representation about its environment and respond. The condition describes the causal dependency of an action. All possible actions of the agent are assigned to one (or several) condition part(s). In complex situations, where more than one condition is included, some decision criteria may have a stronger link to actions than other.

The design of the agents' decision rules requires a valid foundation. However, the human decision process is an internal process, which is not easy to observe and determine. Therefore, many cognitive agent architectures rely on decision theory and psychological findings (see Brenner 2006). Still, for many studies a more concrete decision model for the given context and situation is needed. PLS path models result from empirical studies, such as surveys. They can provide a modeling anchor for (1) the set of decision criteria that play a role in the given decision process, (2) the existing relationships between the criteria, and (3) their relative relevance. The concept of the PLS Agent will be shown in the following section.

B. *PLS Behavior Model*

The starting point is a valid and calculated PLS path model, based on verified data from an empirical study. This PLS path model provides the basis for the agent model. As the model should be used to define agent behavior, the target concept of the PLS path model has to be a *decision*, such as "adoption". The structural model describes a latent variable network of causalities. This provides a set of *criteria*, which influence the agent decision or preference. Thus, the PLS path model informs the ABM about the components of reasoning by the list of latent variables. The identified significant relationships of the PLS path model indicate the existing *causality paths* of agent reasoning. Finally, the coefficients of the significant relationships provide the *order of criteria* with regard to their relevance for the agent.

For the agent decision process in the simulation model, a representation of the *decision object* is needed. This can be a product or some environmental circumstances. The exogenous variables of the PLS path model can be used as a basis for the set of decision object attributes.

The agent perceives this product type and decides about its adoption. For the agent *decision process*, a probability value for the decision is calculated. Therefore, the implemented causality network provides the basis for a set of linear combinations.

C. *Example: TIAM Model*

To give a concrete example of the merger of PLS and ABM, we apply the PLS path model *"Technology and Innovation Acceptance Model" (TIAM)* to agent based simulation. The TIAM describes the causal impact of product innovation attributes and consumption values on the adoption and use of a technological innovation. This model is a further development of the widespread Technology Acceptance

Model (TAM) developed by Davis et al. (1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003) - (for further studies see for example: Venkatesh and Bala (2008); Wu et al. (2011); Venkatesh et al. (2012)). While both, the TAM and UTAUT, focus on the technology acceptance in an organizational context, the TIAM furthermore emphasize the adoption of an innovation in a consumer context. The TIAM is built on the Innovation Diffusion Theory (IDT) by Rogers (2003) and the Theory of Consumption Values (TCV) by Sheth et al. (1991). Hence, the TIAM explains consumers' adoption intention of a new technology by the five product attributes introduced by Rogers (1983) and the five consumption values introduced by Sheth et al. (1991).

It is important to note that the TIAM study is work in progress and serves here only as an example to show the concept of the PLS agent. For a content-oriented consideration of the model see Pakur (forthcoming).

The agent architecture based on the TIAM model is included in the simulation model INNOAGE (Iffländer et al. 2012). The purpose of the simulation model INNOAGE is the analysis of the diffusion process of innovations in aging societies. Therefore, the influence of varying age distributions within the population on the adoption rate and speed of diffusion is considered. Also, the interaction effects between individual consumer types, network characteristics, and product attributes are addressed.

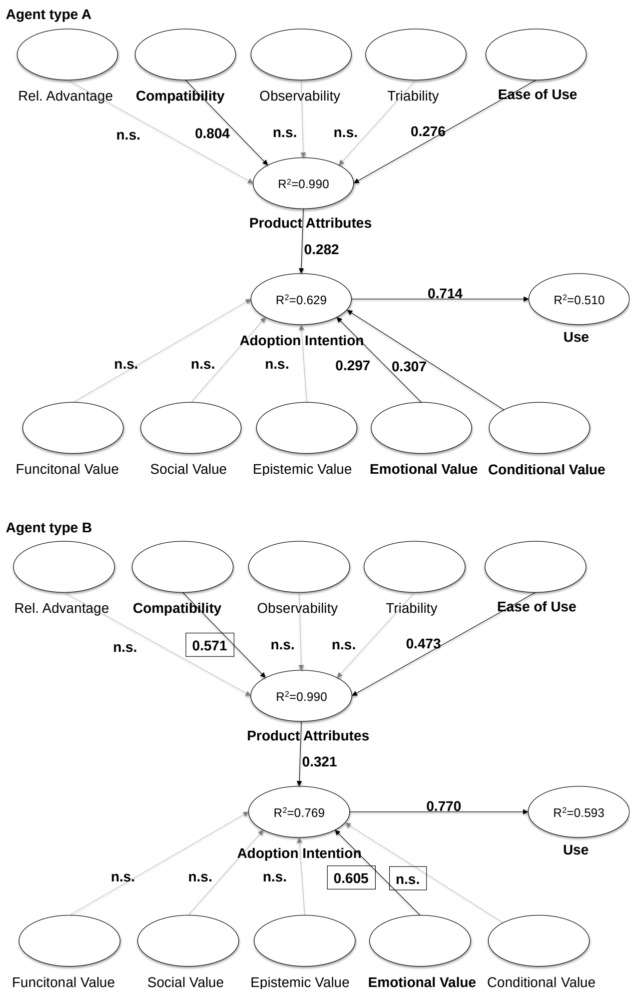


Figure 4 Example: TIAM models as basis for agent type A and B (*work in progress - preliminary results*)

a) Decision Criteria and Relevance

Figure 4 shows that the TIAM has two main fields, namely product attributes and consumption values. Each field is determined by five constructs, to measure consumers' technology and innovation adoption. Adoption intention is the main construct and target variable. Figure 4 does not show the measurement model, which was used for the calculation of the path loadings. Here, only the significant relationships and their path values are relevant for the agent model.

Given the group analyses of the PLS model, more than one agent type might be initialized in this way. If the PLS results identified groups of individuals with varying causality paths and strengths of causalities, those can be included as different *agent types* in the simulation model. Here, the multi-group analysis identified two consumer groups A and B, which were identified by age. Those will be transferred in the simulation model as agent type A (young consumer) and B (aged consumer).

As one can see, the (preliminary) results of the path model for agent type A have shown, that the criteria *compatibility* and *ease of use* influence the evaluation of the *product attributes*, whereas *compatibility* has a much greater influence. The *adoption intention* of the consumer is influenced by the perceived *product attributes*, as well as the *emotional* and the *conditional value*. The other potential criteria for the adoption intention are not significant (n.s.). They have no influence, and can be excluded as decision criteria for agent type A. The *use* of the product is explained to 51% by adoption intention.

For agent type B, however, *compatibility* has a much smaller influence, and is only slightly more relevant than *ease of use* on the perceived product attributes. But, the *emotional value* is a stronger driver for the adoption intention than for agent type A, while at the same time the *conditional value* plays no role for agent type B.

This summarizes the results of the PLS path model being important for the agent model and the simulation analysis. In the agent model, all significant paths are included as a link between the criteria, and the path values are included as link

strengths. This implements a network of causality paths in the agent mind.
At this step, the PLS path model results are included in the agent architecture, and the agent initialization is finalized. The subsequent use and calculations happen only in the agent mind within the run of a simulation model. In the following, the agent decision process based on this causality network is described.

b) Decision Object

For the given TIAM model, the consumers decide about a product. The list of product attributes is given by the exogenous variables. Those are the variables *relative advantage, compatibility, observability, triability,* and *ease of use* on the one hand, and *functional value, social value, epistemic value, emotional value,* and *conditional value* on the other. All these units represent the attributes of the product.

Exogeneous Variables	Endogenous Variable	Scale	Basis Scenario	
Relative Advantage	Product Attributes	[1, 10]	5	medium
Compatibility	Product Attributes	[1, 10]	5	medium
Observability	Product Attributes	[1, 10]	5	medium
Trialability	Product Attributes	[1, 10]	5	medium
Ease of Use	Product Attributes	[1, 10]	5	medium
Functional Value	Adoption Intention	[1, 10]	5	medium
Social Value	Adoption Intention	[1, 10]	5	medium
Epistemic Value	Adoption Intention	[1, 10]	5	medium
Emotional Value	Adoption Intention	[1, 10]	5	medium
Conditional Value	Adoption Intention	[1, 10]	5	medium

Table 1 Product modeling for TIAM

Table 1 shows the description of a *basis scenario*. Within the simulation experiments, the product attributes should vary over simulation runs. Thus, for each exogeneous variable, an input parameter sets the value on a scale between 1 (low) and 10 (high). The combination of these values describes the product type for the respective simulation run. In the basic case, all indicators have the same value (on a medium scale, 5). By holding the product type on the medium level, the effects of various populations and agent interactions may be considered. In further experiments, however, variations of product attributes values allow the analysis of their effects.

c) Decision Process

We know from the PLS path model, that agent type A only considers *compatibility, ease of use,* and the *emotional value* of the product in its decision making process. The agent is ignorant towards variations of other product attributes. The strength of the *adoption intention* value is the result of a linear combination over its relevant criteria and coefficients. Its calculation follows a two-step calculation. First, a *maximum model* provides the basis for the normalized adoption intention strength. This value has only to be calculated once, at the beginning of the simulation run.

Maximum model - agent type A

Exogenous variables	Product values	Coefficients	Results	**Product Attributes**
Compatibility	10	0.804	8.040	**10.800**
Ease of Use	10	0.276	2.760	
				Adoption Intention
Product Attributes	**10.800**	0.282	3.046	**9.086**
Emotional Value	10	0.297	2.970	
Conditional Value	10	0.307	3.070	

Table 2 Calculation of the maximum model for agent type A

The calculation of the maximum model is described in Table 2. Therefore, a scenario with a product type of best quality (value 10) is assumed. The idea is, to weight the relevant attributes with their influence. Hence, the product values are multiplied with the coefficients from the path model and result in a value per criteria. Given this, the value for *product attributes* can be calculated by the sum of all influencing criteria values. Based on this, and the other influencing criteria on adoption intention, a maximum strength for *adoption intention* may be calculated (here: 9.086). In the simulation run, this provides a basis for calculating the normalized intention strength. This will be again shown by an example (see Table 3). The *adoption intention* value for the consumer agent, observing a medium product quality of 5, is 4.543. In the final step of the decision making process, the probability for adoption is determined, based on this calculated value.

Decision model (basis scenario) - agent type A

Exogenous variables	Product values	Coefficients	Results	**Product Attributes**
Compatibility	5	0.804	4.020	**5.400**
Ease of Use	5	0.276	1.380	
				Adoption Intention
Product Attributes	**5.400**	0.282	1.523	**4.543**
Emotional Value	5	0.297	1.485	
Conditional Value	5	0.307	1.535	

Table 3 Calculation of the decision model - agent type A

The probability for adopting a product is given by dividing the calculated intention strength from the decision model with the maximum model. Here, this results in an intention probability of *50%*. This is in accordance with the assumption, that the product type represents a scenario with an average quality. In the next step of the simulation run, the agent observes another product type, and decides about its adoption by the given calculation.

Given this behavior model, it is recommended to conduct a pre-experiment with varying values for the decision object, to do a micro-validation. The causalities of the PLS path model should be recognized in the simulation results.

This section showed, that the PLS agent provides an agent architecture with a direct empirical link. Depending on the focus of research, the behavior may be embedded in a wider decision context, or a network of different agent types, to consider their interactions.

D. SimPLS Framework

To make use of the PLS-Agent concept, a *SimPLS* simulation framework was developed. It is implemented in JAVA/Repast. The default PLS report is an html-file that provides the input for *SimPLS*. By reading the html-file, the agent types are automatically created.

PLS path model	Agent model
Latent variables	Decision criteria
Exogenous variables	Decision object (product) attributes
Target construct	Decision or preference
Significant coefficients	Relationships between criteria
Strength of (sign.) coefficients	Strength (relevance) of criteria
Groups	Agent types

Table 4 Components of the SimPLS Interface

Table 4 shows how the concepts of the PLS path model are transferred into an agent-based model by *SimPLS*. The latent variables are the decision criteria of the behavior model. The exogenous variables provide a list of attributes for the decision object. By the target variable, the agent decision or preference is defined, depending on the focus of research. All paths with significant coefficients are translated into relationships between the criteria of the agent model. By the path values, the relevance of criteria is indicated. Finally, multi-group analysis may provide different agent types. *SimPLS* creates automatically the agent types according to the output files from PLS. Therewith, flexibility for changing SEM models is given.

V. Discussion and Conclusion

This paper presented a way to link agent models to empirical results, by transferring results from PLS path models into ABM. By this, two elements for the agent decision model are provided: (1) the set of criteria, which are relevant for the decision process, also in comparison to other agent types, and (2) the existing causalities and strengths of causalities between the criteria. Furthermore, attributes about the decision object can be derived by the exogenous variables.

One crucial aspect might be the use of the path values as described. This approach involves the threat of an over-parameterization of the PLS path model in the agent behavior model. To address this, the resulting value of the decision model provides a probability value that is used for a stochastic decision. By this, the result is a tendency in behavior instead of a determination. However, further ways about including the distribution of coefficient values might be valuable.

In some cases, the resulting decision model may result in highly stochastic agent behavior. This may be due to the complexity of the PLS path model, such as a high number of decision criteria. This can be limited by focusing on the most relevant influences.

Next to the empirical link, this study may foster interdisciplinary collaboration. The simulation method may include and compare results from different empirical studies and support their communication. Furthermore, not only PLS can be useful to inform ABM, but also *SimPLS* can be useful to further analyze PLS path models, given the questions that arise from the perspective of the empirical study.

In future research, the applicability of the PLS agent should be tested in more depth by additional analyses of the existing model, as well as by including PLS path models from other empirical studies.

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Qualitative spatial representation in agent-based models

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Abstract—**One of the advantages of agent-based models as simulations of social systems is the ease with which it is possible to spatially embed the agents and their interactions. Spatially explicit representations in agent-based models most typically take the form of raster-based representations in which the space is represented as a grid of squares. More recently, vector-based representations have been used, usually importing data for the polygons from geographical information systems (GIS). However, for some models, what matters about the space for the purposes of simulation is less the quantitative spatial relationships among entities (e.g. area, distance or direction) than the qualitative relations these quantitative data are used to determine: neighbourhood, and accessibility (which is a general term covering movement and sensing from one region to another). This paper gives consideration to the use of qualitative spatial representations in agent-based modelling, using a model of everyday pro-environmental behaviour in the workplace as an example.**

I. Introduction

SPATIAL representation in agent-based models typically consists of raster-based representations, if only because popular tools and libraries such as NetLogo [1] and Repast [2] provide default utilities to do so. Neighbourhood functions use a shared boundary or point as a basis, leading respectively to the von Neumann neighbourhood (the four cells sharing a border with a given cell; `neighbors4` in NetLogo), or the Moore neighbourhood (the eight cells sharing a border or a corner with a given cell; `neighbors` in NetLogo) interpretations of cell-based neighbourhood. Vector-based representation, in which the space is divided into irregular polygons (typically, though not necessarily (see [3]) corresponding to real geographical features), is increasingly being used [e.g. 4]. This is true particularly of models with a geographical application, as data may be conveniently read in from a GIS. Indeed, NetLogo provides the GIS extension, which reads ESRI shape files (a popularly used format for vector data), and Repast includes packages and classes to enable modellers to work with GIS data. A raster-based representation can be seen as a special case of a vector-based one in which the polygons are all squares of the same area, forming a grid.

Both of these representations are quantitative, in the sense that the vertices of the polygons are defined using numerical co-ordinates which, in Euclidean spaces, allows the computation of distances between pairs of points and directions from one point to another using the standard formulae of geometry. However, in agent-based models, it is often the relationships that these spatial entities define that are most important: where the agent can move, what the agent can sense, and what the agent can interact with. In some cases, quantitative spatial representations may arguably constitute spurious precision, and create a misleading impression of the accuracy with which the spatial aspects of the model are predicted.

Qualitative spatial representations have been the subject of research for a number of years, the Region Connection Calculus (RCC) [5] being a popular formalism. Qualitative representations capture logical relationships among regions or cells in a space, rather than relying on their quantitative aspects (i.e. bounding co-ordinates) to derive them.

In this paper, we consider the applicability of RCC to agent-based models. Reflecting on the requirements of agent-based models, we find that extensions of these formalisms will be needed if qualitative spatial representations are to have a role in ABMs in the future. We suggest some prototype extensions related to agents' sense perceptions and

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movement, and illustrate the use of one of them in a model of everyday pro-environmental behaviour at work.

II. RCC and qualitative spatial requirements for ABM

RCC builds relations among regions from the primitive mereotopological relation C (connected). Although RCC was originally conceived of as a 'pointless' representation of space [5], regions can be thought of as non-empty open subsets of a universal region conceived of as a set of points [6]. C can be used to define P (part) by saying that region x is part of region y if all regions connected to x are connected to y:

$$P(x,y) \equiv \forall z (C(z,x) \rightarrow C(z,y))$$

P can then be used to define O (overlap) between x and y as the existence of a region z that is part of both x and y:

$$O(x,y) \equiv \exists z (P(z,x) \wedge P(z,y))$$

There are then a number of different ways of constructing sets of jointly exhaustive pairwise disjoint relations among regions. RCC-5 defines the five relations DR (disjoint regions), PO (partially overlaps), PP (proper part), PPi (inverse proper part) and EQ (equal) as:

$$DR(x,y) \equiv \neg O(x,y)$$

$$PO(x,y) \equiv O(x,y) \wedge \neg P(x,y) \wedge \neg P(y,x)$$

$$PP(x,y) \equiv P(x,y) \wedge \neg P(y,x)$$

$$PPi(x,y) \equiv PP(y,x)$$

$$EQ(x,y) \equiv P(x,y) \wedge P(y,x)$$

Note that PO represents what might be more commonly understood by the term 'overlaps' in that (unlike O) it does not apply when one of the related regions is wholly contained within the other. Similarly, PP (as in standard mereology) represents the idea that might normally be understood as 'part', in that it precludes equality of its arguments. (From the above definitions, it is easy to see that PP could equivalently be defined as "*P* and not *EQ*".)

RCC-8 further discriminates DR into DC (disconnected) and EC (externally connected), and PP into TPP (tangential proper part) and $NTPP$ (non-tangential proper part), with inverses $TPPi$ and $NTPPi$:

$$DC(x,y) \equiv \neg C(x,y)$$

$$EC(x,y) \equiv C(x,y) \wedge \neg O(x,y)$$

$$TPP(x,y) \equiv PP(x,y) \wedge \exists z (EC(x,z) \wedge EC(y,z))$$

$$NTPP(x,y) \equiv PP(x,y) \wedge \neg \exists z (EC(x,z) \wedge EC(y,z))$$

Although regions in RCC have no concept of a boundary, EC can be conceived of as the closures of x and y intersecting whilst the open sets x and y constituting the regions themselves do not intersect.

RCC, because of the purposes for which it was designed, focuses exclusively on topological relationships among spatial regions. Embedding agents in space inevitably creates the need for new relationships, which take two forms: one defining relationships agents have with places (e.g. ownership, location); the other defining how relationships among agents are mediated through and interact with space. We consider the former here.

Links between description logics and RCC have already been established through attempts to represent it in OWL [7, 8]. Since there are interactions between the ontology of the model and that of its (qualitative) space, this holds out the hope that existing formalisms could be exploited to achieve the expressiveness needed to meet requirements for qualitative spatial representation in ABMs, particularly since not all of the expressiveness of RCC is necessarily needed for this purpose.

As suggested in the introduction, there are three main areas where agent-based models use space, though specific applications may vary: neighbourhood, sensing and movement. The last two are closely related, and may be considered together under the more general heading of accessibility.

A. Neighbourhood

Neighbourhood in a topological sense is captured by the RCC-8 relation EC: disjoint regions that are connected but do not overlap. As noted in early work with FEARLUS [9], there can be a distinction between topological and social neighbourhood. Suppose a relation Q holds between an agent and a region (such as ownership). Then the social neighbourhood N with respect to Q could be defined in terms of Q and EC thus:

$$N(a,b) \equiv \exists x,y (Q(a,x) \wedge EC(x,y) \wedge Q(b,y) \wedge a \neq b)$$

Indeed, Q forms the basis of an ontologically significant spatial scale, in that a region can be defined as the sum of those regions for which Q holds for a particular agent (i.e., those that the agent owns for the purposes of this example). (RCC does not stipulate continuity of regions.) However, since it seems desirable (for relationships such as ownership) to assert that if Q holds for a region then it also holds for its parts:

$$Q(a,x) \wedge P(y,x) \rightarrow Q(a,y) \quad ,$$

a spatial scale should only apply to sets of regions that are not parts of regions with Q to the same agent. Specifically, we can define a spatial scale with respect to Q as the set of maximal regions S for which Q holds for some agent, where 'maximal' means that members of S are not proper parts of regions for which Q holds:

$$S = \{ x : \exists a (Q(a,x) \wedge \neg \exists y (PP(x,y) \wedge Q(a,y))) \}$$

Although in general Q could be a many-to-many relationship, if Q is an inverse functional relationship (i.e. each region can be related by Q to just one agent, as should be the case with ownership), then we know that no member of S will overlap with any other member of S.

If there exists another relation R between agents and regions (a subproperty or specialisation of Q) such that:

$$\forall a, x (R(a,x) \rightarrow Q(a,x)) \quad ,$$

then we should expect that regions for which R holds are parts of regions for which Q holds. The hierarchy of ontological relationships connecting agents to regions in various different ways form a matching partial ordering of spatial scale.

B. *Accessibility*

One of the issues with movement for qualitative spatial reasoning, given the lack of any quantification of distance, is its relationship with time. Typically, agent-based models feature discrete time steps that are quantitative at least in the sense that they correspond at some level to real-world temporal intervals such as days, months or years. As such, there may be arguments that qualitative spatial representations should only be used with qualitative temporal representations (i.e. simply knowing the (partial) order in which events take place). The knowledge that nothing can travel faster than the speed of light, for example, means that if an agent moves from one region to another in a day, then the distance travelled must be less than 25.9 Tm. Though somewhat extreme, this does mean that the quantification of time allows a 'creep' of quantification into the representation of space.

That issue aside, the location of an agent is another relationship it may have with space. In contrast with the example of ownership explored above, if an agent is located in a region, we would also say that it is located in regions of which that region is a part, but we would not (necessarily) say that the agent is in parts of that region. For example, if Geert is in his office, he is not necessarily in all parts of that office, but he is on the floor on which the office is located, and in the building of which that floor is a part. Using L to represent the location of an agent, note the contrast with Q:

$$L(a,x) \wedge P(x,y) \rightarrow L(a,y)$$

It would be convenient if we could identify a set of regions in which agents could be located, as was the case for S above with respect to Q. A number of issues make this a challenge, not least of which is the fact that the set of regions in which agents are currently located does not exhaustively specify the set of regions in which they *could be* located. Further, the question of which regions agents can meaningfully locate themselves in is part of the narrative of the model, and hence the set of regions may be part of the configuration rather than something that is inferred from other axioms. Finally, it may be required to explicitly represent the *embodiment* of an agent as a region, and the location of the agent is then those regions of which that embodiment is a part.

For the purposes of movement from one region to another, it may be reasonable to stipulate minimally that the two regions are related by EC. Equally, it seems reasonable to argue that if an agent is located in a region that partially-overlaps with another region that the agent is not currently located in, then the agent can move between the two regions. Such arguments do not allow for the possibility of regions acting as obstacles for movement, however, and there is the further question of whether there is heterogeneity in agents' capability to move between regions. In general, it may be simpler to identify as part of the model specification a set of regions in which agents may be described as being located, and then to specify a relation identifying those pairs of regions between which an agent can move in a single time step. Where there are differences in agents' capabilities for movement, this relation will have to be specialised according to the class of agent (where this class is defined using appropriate combinations of restrictions on the agents' attributes).

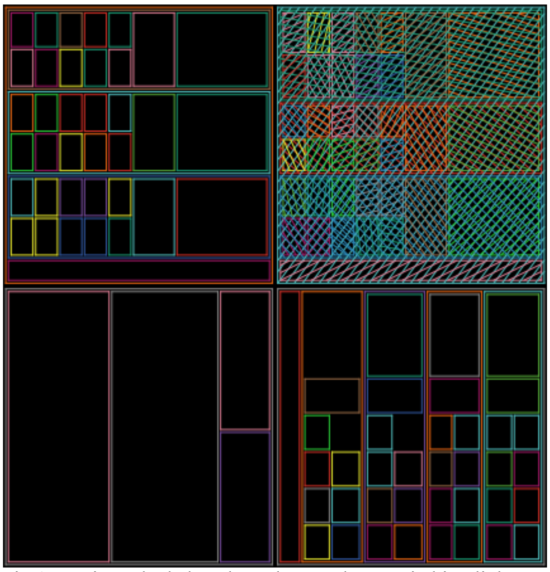
Sensing is closely related to movement in terms of the issues raised, in particular obstacles to sensing, and differences in agents' capabilities to sense. There is also a complicated relationship with time with respect to the synchrony of events in that knowing that one agent can sense another depends on knowing where they are and when, bearing in mind that for some (stigmergic) senses, it is not necessarily the case that the object of the sensing is present within range at the time the subject performs the detection. Stigmergic sensation (such as ant trails, or other chemical or physical alterations of the space) is an interaction among agents that is mediated through space, and requires that regions have (physical) attributes that the agents can detect and modify, a matter that RCC does not address.

Two physical attributes are of potential use in discussing the obstacles to sensing: opacity and transparency. Asserting the transparency of a region could be a way to stipulate that it offers no obstacle to sensing from one region to another of which it is a part. Similarly, stating that a region is opaque could be used to assert that no sensing is possible between agents located in that region. The latter could be used for regions that are the sum of disjoint regions, such as the region comprised of all the houses of employees of a company.

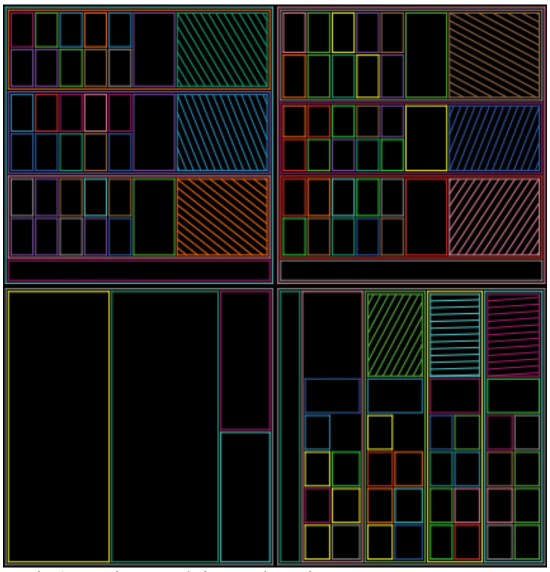
III. Partial demonstration in WERC-M

WERC-M (Worker-Environment Reinforcement Choice Model) is a model of everyday pro-environmental behaviour at work created for the LOCAW Framework Programme 7 project.[1] It was built to model backcasting scenarios aimed at improving everyday pro-environmental behaviour in four case studies of workplaces in the utility and public sector (Aquatim, a water utility in Romania, ENEL Green Power, an electricity company in Italy, Groningen municipality in the Netherlands and the University of A Coruña in Spain).

[1] Low Carbon at Work: Modelling Agents and Organisations to achieve Transition to a Low-Carbon Europe. http://www.locaw-fp7.com/



ig 1: Regions shaded to show they apply to switching lights off in one of the office buildings



ig 2: Regions applying to the using paper cups context

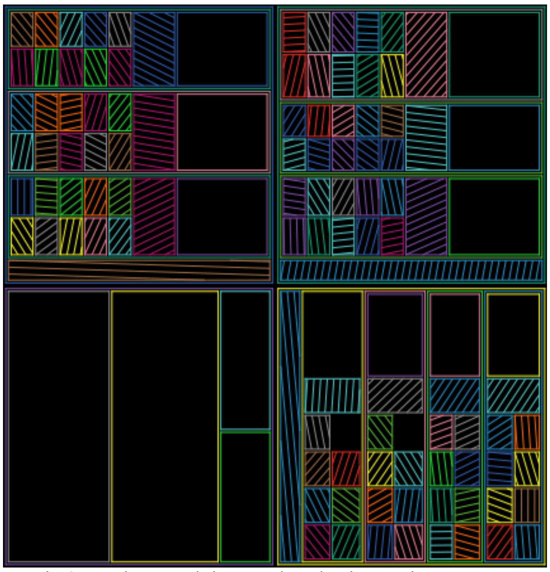


Fig 3: Regions applying to short business trips context

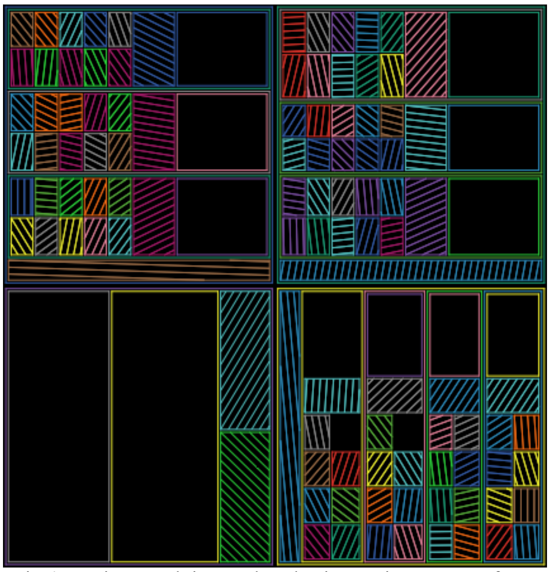


Fig 4: Regions applying to short business trips context after implementing a home-working scenario

A 'context' in WERC-M is a situation in which the agent has to make a decision about whether to behave pro-environmentally or not. Geller et al. [10] have a specification of contexts that is relevant to the use of the term here. This provides details of such things as the conditions under which a context is initialised (which can include another context, as is the case here), the actors affected, and decision making: the actions the agents can perform in the context (here: behave pro-environmentally or not), and how the agent choses which action it will take (here, the appropriate decision tree). However, the specification does not include spatial information, and since some of the contexts in WERC-M apply in specific region types (e.g. meeting rooms), we recommend an update to the context specification that incorporates these considerations. However, the distinction between contexts (situations in which agents have to make a decision) and regions (areas of space in which agents are located and contexts may occur) should be clear.

Detailed quantitative geographies of the workplace layouts were not available from the case study partners, and the model relied on knowing who could see whom for transmission of injunctive and descriptive norms [11]. Descriptive

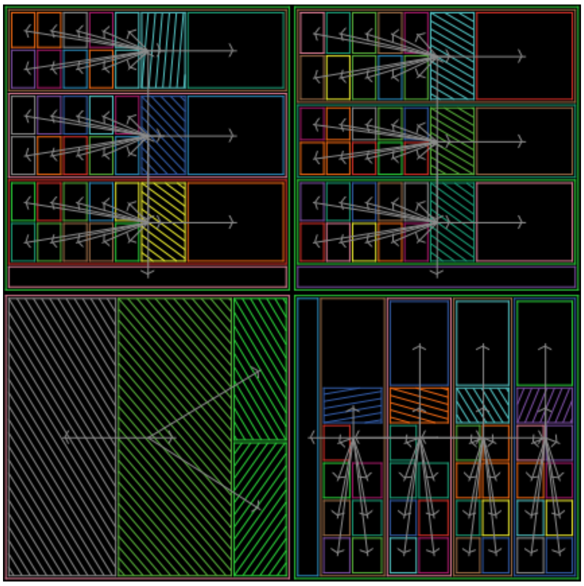


Fig 5: Depiction of the `regions` and `part` links in WERC-M. Arrows point from the centre of regions to their parts. Shaded `regions` have `opaque? = true`.

norms are related to imitation, and rely on the agent being able to observe others to find out what they do. Injunctive norms involve the agent being told what to do, and rely on the agent being seen behaving in such a way that an instruction should be given.

We therefore gave consideration to the use of qualitative spatial representations in the model, defining workplace environments such as the canteen, offices and open-plan areas, and, since the model also had to consider the possibility of spillover effects, home regions. Two qualitative spatial relations proved important: the mereotopological relation proper part (*PP*) in defining where contexts occurred that required a decision to be made about whether to behave pro-environmentally, and a sight relation determining who could observe whom (whether for injunctive or descriptive norm purposes).

The proper part relation allows contexts to be associated with places and all places that are parts of those places. Certain such contexts are associated with the agents' workplace (office or desk), such as switching off the computer at the end of the day, using emails rather than paper-based communication, or adjusting heating or lighting. Other contexts are associated with canteens, such as deciding whether to use a paper cup for drinks; or with home spaces, such as decisions about whether to wash clothes with a full load, or to dry them outside.

In the NetLogo implementation of WERC-M, we defined `regions` as agents (in the '`turtle`' sense of the word), and created the directed link breed `part` to represent *PP*. In Fig 5, the regions for the Netherlands case study are shown, each as a rectangle with a distinct border colour. Regions contain their parts in the diagram. The home region is in the bottom-left quarter of the diagram, divided into four subregions: homes with and without air conditioning on the left and in middle, and on the right hand side, home offices with and without air conditioning on the top and bottom. The three remaining quarters of the diagram each correspond to three separate office buildings, each of which is divided further into a number of floors, with each floor containing an open plan area, or a number of shared and unshared offices and a kitchen for preparing drinks.

In Fig 1, the `part` link is used to show how an everyday behavioural context (switching off the lights) applying to a specific building applies to all regions that are parts of that building. By tying the context to that particular building (rather than the workplace in general), we can implement scenarios where automatic lighting, which removes the need for an agent to make a decision to switch the lights off manually, is installed in different buildings at different times. In the diagram, regions are shaded using a number of parallel lines with a random angle; hence cross-hatching indicates subregions. In the NetLogo model, we also assigned `regions` a `region-type`, to discriminate between home regions, work regions, and 'third' spaces (areas in the workplace where norms associated with leisure or home might be more likely to apply). Kitchens are examples of such 'third' spaces, where interactions among colleagues may be more informal, or pertain to less work-related matters than office or open-plan areas within the building. Fig 2 shows the kitchen areas, shaded because they have been determined automatically to apply to the context associated with deciding whether to use your own cup or a disposable paper cup in the coffee machine.

Agents in WERC-M have an assigned `work-region` indicating their designated place of work, which is a potentially many-many relationship akin to *Q* discussed earlier. Contexts in WERC-M can be designated as applying to agents in their `work-region`, allowing intervention scenarios aimed at increasing pro-environmental behaviour to explore changing the `work-region`. An example of this is increasing the use of home-working. Fig 3 and Fig 4 show respectively the regions affected by the context of choosing a mode of transport for a short business trip (of less than five kilometres) before and after implementing a policy in which 10% of the workforce normally work from home.

Movement in WERC-M is represented simply using `routines`, in which the day is divided up into a series of time chunks (not necessarily of equal length), each of which is associated with a `region` or `region-type` in which agents fulfilling particular roles in the organisation will be located. Movement between certain pairs of regions (such as those between a work region and a home region) as the model proceeds from one time chunk to the next can then act as triggers for contexts to occur (such as commuting).

To address the question of sight, the model gave `regions` the Boolean properties `transparent?` and `opaque?`. The `transparent?` property was intended for the purposes of providing for open-plan areas, in which agents would have a designated region for their workplace (a desk), but would be able to see other agents in the open-plan area. Here, a desk would be defined as a `transparent?` subregion of an open-plan area, and an agent at that desk would be able to see agents in all transparent subregions (i.e.

other desks) of the open-plan area. The principle is shown in Fig 6, where shared offices have been assigned `transparent? = true` (for the purposes of illustration), and `sight` links are created between pairs of regions for which agents in one region can observe agents in the other.

However, in the end it was simpler just to say that everyone worked in the open-plan area, without being specific about where. Of more use was the `opaque?` property, which is used to prevent agents seeing each other if they are in the same region. This allowed the home to be represented as a single region for all agents to live in, whilst ensuring no agent could observe another therein. Similarly, a single region could be used to represent all single-occupancy offices on a floor – the `opaque? = true` setting preventing those occupants observing each others' behaviour while located there. (See Fig 5.)

IV. CONCLUSION

Qualitative spatial reasoning has a potentially important role to play in agent-based models, but work is needed to define suitable formalisms for agent-based models to use so that they can be included in popularly-used agent-based modelling tools and libraries. We have shown how some of these principles can be implemented in NetLogo using existing functionality. In extending existing formalisms for qualitative spatial reasoning, there is the opportunity to draw on social theories defining the relationships between humans and the space they inhabit, and the constraints space imposes on relationships among humans.

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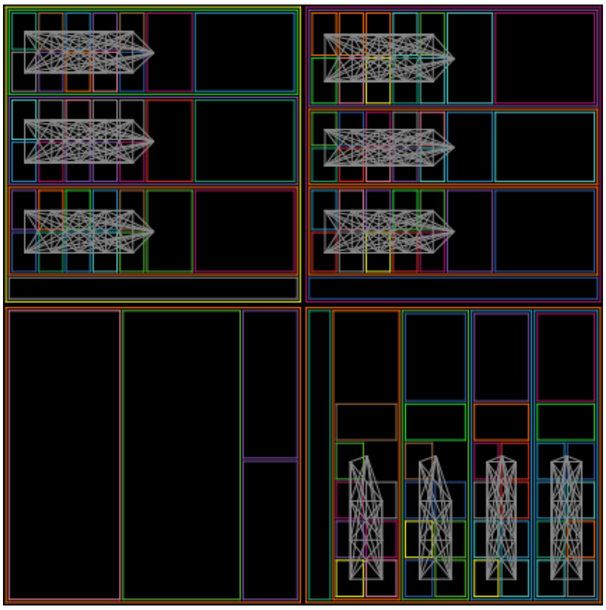

Fig 6: Depiction of `sight` links when shared offices are `transparent?`

Technology development and political and economic power: evolution of global inequality

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Abstract

Global inequality, in combination with various global problems, has been one of the most pressing concerns of today's world. There are numerous models that explain the development of technology, political and economic power concentration, and resulting social inequality within a single society or region. The models that apply global and long-run perspectives having world-systems as a unit of analysis, however, are rare. This study conducts simulation modeling to examine the formation of hierarchies among polities through the expansion of political economic networks and concentration of power having evolving technologies. Two types of technology—subsistence technologies and technologies of power—have evolved for successful economic and political interactions as well as dominations among polities, resulting in the formation of global hierarchy. The dynamics are modeled and simulated by numerically solving partial differential equations and integro-differential equations that describe polity interactions through trade and warfare networks and selection of advantageous technologies. The validity of the model is examined using city population and state/empire size data since 2000BCE to the present. Models with such a broader perspective allow explanation of the fundamental relationship between technological development and political economic power, which will shed light on the issue of global inequality in today's world.

Keywords—world-systems; global inequality; subsistence technology; technology of power

Extended Abstract

There have been a growing number of studies that model the historical dynamics of human societies applying agent-based models to study social, political, economic, cultural, geographic, and ecological processes. The questions of the evolution of complex societies through the interactions and networks with neighboring societies over time (Gavrilets, Anderson, and Turchin 2010) or the issues about the relationship between archaic societies with environmental dynamics (Kohler, Gumerman, and Reynolds 2005; Kohler, et al 2012) are studied with the application of agent-based simulation modeling. Simulation modeling is utilized to test the theoretical, assumptions of the studies with historical, geographic, or archaeological data to advance scientific understanding of the issue. Most of such simulating social dynamics approaches are, however, focused on specific regional spaces or particular historical time. But much recent simulation study addresses the modeling approach over long-run evolutionary history by having world history as a master unit of analysis (Turchin, Currie, Turner and Gavrilets 2013).

Applying the world-systems perspectives, the current study examines the evolution of concentration of power through political and economic interactions and networks. It further analyzes the role of the development of different types of technologies that are significant for the evolution of power concentration.

The growth and decline of polity size and the power of polities reveal cyclical processes in history—states and empires expand and contract their size through conquests and domination of neighboring polities. Yet, the process is not simply a repetitive cycle of rise and fall. It occasionally involves significant changes in the scale of polity sizes. Empirical analysis of the size of polities shows that there are sporadic, yet dramatic, increases in their sizes, forming upsweeps of growth (Chase-Dunn et al 2010). Climate change or epidemic diseases sometimes play a part in these upsweeps of polity size, but more direct cause is internal technological advancements and organizational innovations through that occur in the context of a polity's interactions with neighboring polities. The innovation of technologies allows sustaining and growing populations within a polity, resolving population pressures on resources. The growing polities also develop new organizational technologies to control and dominate other polities, and these new innovations become institutionalized and diffuse. This is considered as a phase in the socio-cultural evolution of institutions in which significant changes occur in the scale of social activities and the sizes of polities. Technology, in this study, is thus broadly defined. Technological change involves not only the innovation of technologies for subsistence production (i.e., subsistence technology) (Lenski 2005) but also the innovation which allows humans to develop institutions to control and sustain much larger-scale societies (i.e. technologies of power). It is further considered that there have been evolutionary shifts in the ways that polities interact—from intensive warfare basis to trade basis—to dominate and control other polities (Chase-Dunn and Hall 1997).

Based on the theoretical assumption that social cohesion develops culturally heterogeneous frontiers in ethnic boundaries where intense competitions and warfare are likely, studies in population ecology explain warfare as the main mechanism for the formation of large-scale states/empires (Gavrilets, Anderson, and Turchin 2010). In combination with the theory of evolutionary biology which asserts that evolutionary selection favors groups with stronger solidarity, they further argue that competition by means of intense warfare helps to diffuse sociality within polities (Gavrilets, Anderson, and Turchin 2010; Turchin, Currie, Turner and Gavrilets 2013), making the polities develop stronger solidarity, and hence to form larger-scale and more integrated polities.

The model we are developing applies the theoretical framework of multi-level selection to political and economic dynamics. Selection operates favorably on polities that adopt technologies and institutions that are advantageous in the competition among polities that occurs through warfare and trade. The goal of this study is to examine the formation of hierarchies among polities based on the evolutionary selection of different types of technologies (—subsistence technologies and technology of power).

Model Design

The model simulates the evolution of world-systems for the period between 2000BCE and the present. The period is divided into three subperiods: 2000BCE to 1500BCE (mixture of settlement/city and state/empires); 1500 BCE to 1500AD (formation of large-scale empire is predominant), and 1500 to present (development of imperial colonialism and neo-colonialism). The period starts from 2000BCE since this is the time the empirical data become available. The period is divided into three periods to analyze the difference in the relationship between technologies and political and economic power

The modeling area includes the whole region of the earth. A unit of analysis is world-systems which comprises multi-layer polities (i.e., settlement/city and state/empire). It starts from the regional world-systems where settlements interaction occur separate locations through trade and warfare. Trading process includes bulk goods for short distance and prestige goods for long distance trade. The networks are bounded by warfare between polities. They are gradually connected to single world-systems after 1500AD. A set of constant world regions are compared for their characteristics.

The model simulates interactions of polities in a two-dimensional spatial grid. The model is two-layered, and the interacting polities have two categories. One is settlement (city), and the other is polity (state or empire). A state is a larger unit, and one or more settlements are located within a state. Settlement can be independent from state if a settlement has enough political and economic power and autonomy. Polities (settlements and states) interact with other polities and create political and economic network connections, extending their interactions. The size of a settlement is determined by the population size residing in the settlement. Each cell in the grid is considered as 100 kilometers times 100 kilometers in size. The territorial size of settlement is determined by how many settlements get together to form a single polity. The size of a polity is determined by the addition of the number of settlements included within the jurisdiction of the polity. Polity territorial size is thus calculated by summing up the number of settlements in the polity in the model, and it is examined with the empirical data of territorial size of polity.

Polities interact with other polities to increase their wealth and territory. Through warfare, polities dominate or sometimes make allies with other polities. Warfare can decrease or exterminate the populations in settlements or take over the land of polities. Through trade, polities dominate other polities by having tributary relationships or making allies of other polities. The model simulates the growth of territory and connections among settlements and polities through trade and warfare.

World-systems are formed with multiple-level political and economic networks. These networks comprise both local interaction processes among neighboring polities as well as extended political and military networks of polities. In grid cells, each settlement has four neighboring cells which can be empty lands or up to four settlements. Diffusion of technology through warfare and trade of neighboring cells is simulated by numerically solving partial differential equations. The partial differential equation thus assumes local interaction and diffusion of technologies among polities. The diffusion of technology through trade and warfare networks with distant polities is simulated by numerically solving integro-differential equations. A kernel used in the equation determines the distance of polities that regulate the network dynamics. The integro-differential equations thus allow the occurrence of interactions over a variety of scales. Partial differential equations and integro-differential equations are both discretized for reducing computational complexity. Therefore, the time step is discrete, and each time step represents a year.

Simulation of the model is conducted to examine the political and economic power concentrations that occur among polities (i.e., global stratification) in the three periods—from regional-scale settlement interactions to global-scale state and empire networks. The model is verified with historical data of city populations and state/empire territorial sizes since 2000 BCE. The simulation study of the evolutionary time span will help understand and explain the underlying processes of political and economic power dynamics that have resulted in the global inequalities of today's world.

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Strategic decision support for marketing communication: an agent-based simulation of consumer attitudes to smart home appliances

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Abstract—**Marketing and communication professionals are responsible for building long term relationships with customers and managing the information exchange. The roll-out of smart energy meters to households presents a particular challenge as network and energy companies would benefit from the smart grid while the advantages for households are less visible. In this study we use survey data from a pilot project on smart home appliances to create an agent-based social simulation which can provide decision support for various marketing communication scenarios. The outcome of a structural equation model based on two surveys (one before and one after an intervention) provides the foundation for the behavioural model of the agents so experiments can be performed in which certain aspects are adjusted and the possible effects studied. Preliminary results suggest this is a useful approach to support decision making on marketing communication as the impact of interventions can be studied and the expected adoption of the new technology in various user groups can be estimated.**

I. Background and goal

IN THIS study we focus on the role of social simulation to provide support for marketing managers in their decisions on how to reach target audiences in the context of long term relationships. Smart decision support for marketing management or marketing intelligence is lacking but its value has been recognised [1][2][3], hence the first step is to develop the simulation part of a future support tool. Simulation of consumer behaviour can be used as a reflective tool for the marketing manager in his or her attempt to design various marketing scenarios. We believe that such a tool eventually contributes to the marketing manager's accountability, which is an important topic in marketing and communication management [4][5].

This paper is structured as follows. First, in Section II the case study of the introduction of smart energy appliances is introduced. Section III describes the methodology, the agent-based simulation model and simulation scenarios. Section IV then shows a number of illustrative results with conclusions and final thoughts presented in Section V.

II. Case study: the introduction of smart energy appliances

The marketing management on consumer acceptance of smart home appliances constituents many decisions on how to involve the consumer in sustainable use of energy in future smart cities [6][7]. A Dutch energy company has launched a trial in which households were given a smart meter, energy display and a smart washing machine. Households were charged variable energy tariffs so they could influence their electricity bill by shifting the demand to cheaper time periods. Throughout this trial not only the energy consumption is measured to see which savings are possible, but also the attitudes of the user to the technology are surveyed to learn how to best approach them and make the technology accessible and easy to use. Lessons learned can then influence the large scale roll-out of smart energy meters.

In an experimental set-up we compared the base situation with the situation after invention for consumers who had a smart washing machine and a smart energy computer installed. The experiment was carried out after the real intervention had taken place. A baseline measurement (before the installation) and a first follow-up measurement (after the hardware was installed) were carried out. Now the marketers have knowledge and insights about the real situation before as well as after their intervention. The question now is whether they would have made different decisions in the interim period knowing what they know now after exploring this data and testing new scenarios. We show how the consumer survey data collected during this pilot can be used to design a social simulation model with which such future scenarios can be investigated "in silico". The next section explains how this model was set up.

III. Methodology: Agent-Based Simulation of Consumer Preferences

Using the results of these consumer surveys as input, an agent-based simulation model of their preferences was constructed, where each agent represents an individual household participating in the trial (n=146). First, the answers to the questionnaires were analysed with a Structural Equation Modelling approach (using SPSS AMOS) to generate a behavioural model of the consumers and the links between relevant concepts such as ease of use, attitude towards sustainable energy, etc. From this model, founded on literature on consumer adoption of technology and communication sciences (e.g. [8] and [9]), the key relationship and coefficients could be implemented in Repast Simphony as behavioural and decision making rules for the agents. This approach is similar to [10], but instead of using a standard decision making model here the model is based on the actual data from the pilot study in before and after scenarios which can be evaluated. We are using data not just as validation but also for the design and initialization of the model [11, Fig 2][12]. Each agent has its own individual characteristics (i.e. the answers given in the survey) and the behavioural rules enable it to interpret these properties and to make a decision on the expected or actual use of the smart technology:

1. Expected use is based on the baseline measurement for which the system-attractor is consumer expectation (at the start of the trial).
2. Routine use if based on the follow-up measurement for which the system-attractor is the consumer routine use of the washing machine to delay laundry based on variable energy tariffs (after the intervention).

First, the stated response is compared with the prediction from the simulation model to support model verification. Next, values of the various concepts can be changed to represent communication activities (e.g. inviting participants to a demonstration session to explain how the technology works) and the effect on the behaviour can be explored: now the assessed models have obtained dynamic properties by which the marketers could test future scenarios. Using these simulations, the marketers can develop insights in the dynamic properties of their target audiences. Examples of scenarios and questions include the following:

- What happens when financial stimuli disappear but the sustainability issues are emphasized?
- How does motivation to use the smart energy technology change over the long term, and is this different for consumers triggered by price or those who participate because of the positive effects on the environment?

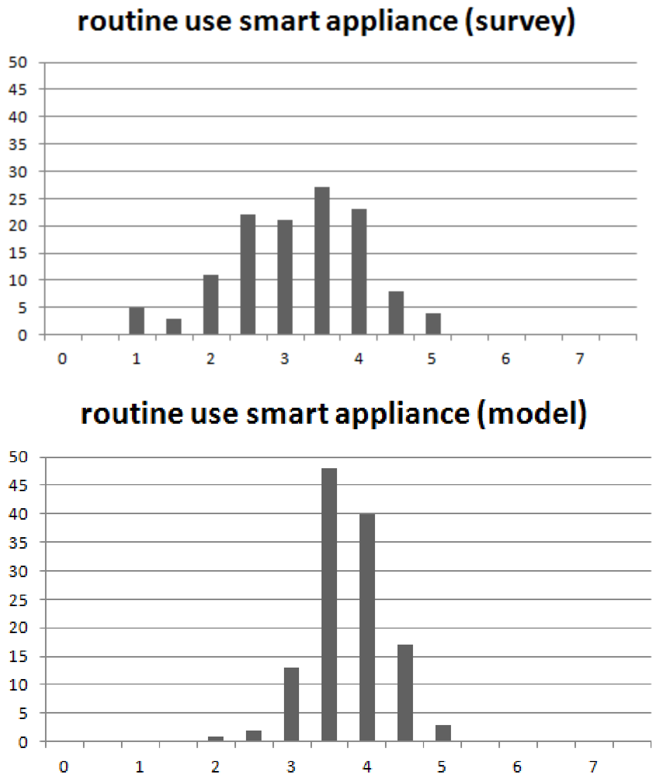

Fig. 1 – Comparison of the stated response on actual useage (top) and the predicted useage from the simulation (bottom)

- How does improving the ease of use of the technology compare with better explaining how the equipment works?

In this study we attempt to simulate the journey and the response to any interventions between the two measurements to see if a possible gap between expected and actual behaviours (as stated by the participants to the trial) can be explained from the interventions that took place. These outcomes have to be validated in follow-up surveys to compare predicted behaviour from the model with the response from the households, but additionally face validation can be used by asking professionals if the scenarios and outcomes are useful in their decision-making process. In addition to simulating the period between the two measurements we consider the first marketing scenario: comparing financial and sustainability related stimuli.

IV. Illustrative Results and Analysis

In this section results of the simulation model are presented, using histograms of the population of 146 agents and their score on a Likert scale where 0 means totally disagree and a 7 means completely agree with the statement that the household expects or is using the smart appliance.

Fig. 1 shows the reported use of the smart appliance from the second survey compared with the prediction from the

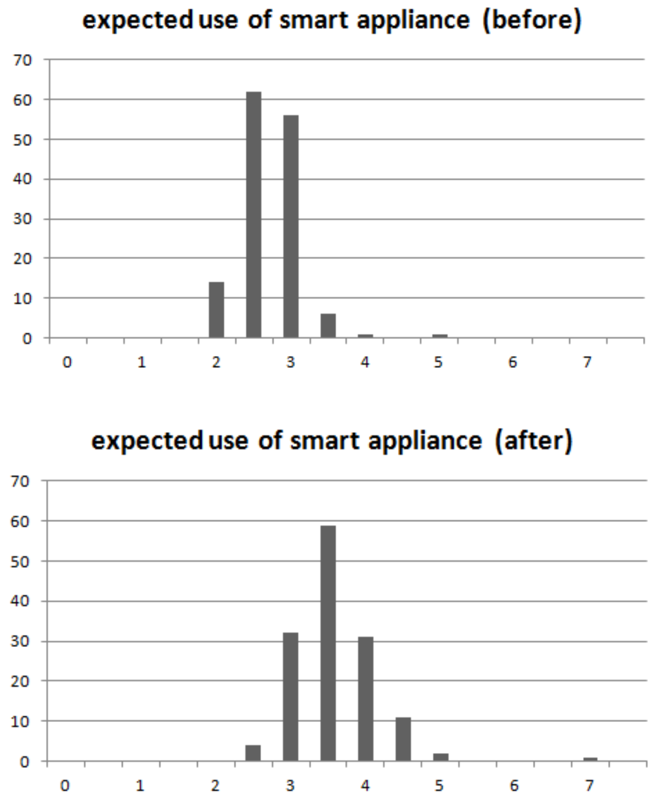

Fig. 2 – Predicted expected use before intervention (top) and prediction after intervention during which “appreciation” of the project was significantly increased (bottom)

simulation model using the individual answers given as input data but using the behavioural model to calculate the use. The peak is in the same position, reporting a mostly positive response, but in the simulated model the peak is higher and the deviation lower. The lower deviation could be explained by the fact that the decision making model was based on the entire population, while in reality some aspects would be more important to one individual than to another, creating more diversity in opinions. Still, the similar general shape of the results give some confidence in the outcomes. With a larger data set it would be possible to analyse segments to create tailored models of various groups, for example based on socio-economic status, housing type, or aspects addressed in the survey such as overall attitude towards sustainability and the impact of households on the environment.

Fig. 2 then shows the simulation of the time period between the baseline measurement and the measurement after the appliance had been installed. The expected use before any intervention (top) was at least one point lower than the stated use several months later (cf. Fig 1, top), in both the surveys as well as our simulation model. The consumer engagement the company undertook before, during and after installation in people’s homes in which the importance of the pilot was stressed could have had a positive effect on the

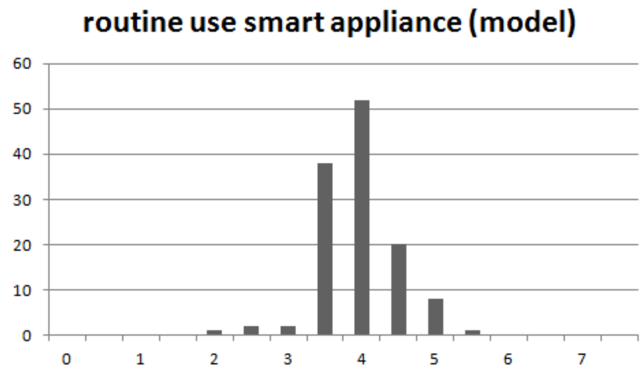

Fig. 3 – Results of the population during a scenario in which financial stimuli are decreased over time while sustainability stimuli are increased.

participants. We simulate this by improving the score for the “project appreciation” factor for each agent and the result is that the new scores (Fig. 2, bottom) are now closer to those of the stated use (Fig. 1, bottom). Alternatively, it is possible to experiment with other factors (e.g. financial stimuli or ease of use) to see how much they would have needed to be improved to establish the same effect.

Finally, to show how such models can be used to explore options for marketing scenarios, the financial stimuli (i.e. the rewards in saving money by using the technology) are decreased while at the same time the sustainability stimuli (i.e. the perceived positive impact on the environment resulting in the use of the technology) are increased and the combined effect on the use of the smart appliance is simulated. Figure 3 shows the results of this scenario as a histogram for the population. Comparing the outcome with the one before the adjustments to these constructs (Fig 1, bottom) shows there is very little change in attitude. Looking at the individual ratings of the agents we see that the decrease in financial stimuli is countered by the increase in the sustainability stimuli and that for some agents this even leads to a higher value for the predicted use.

V. Conclusions

While these results illustrate the possibilities resulting from having a dynamic model made from static survey results and the impact this could have on decision making, it also highlights a number of issues that need to be dealt with. Firstly, the interpretation of a change in value for a construct is not straightforward and open to debate. Secondly, there could be limits to how often a change may have a positive or negative effect. Thirdly, the behavioural model is based on the whole population while inputs are unique for each agent, so the responses will vary as well. Follow-up studies jointly with decision-makers to track interventions and measure their effects are required to further validate the findings.

Having said that, the results already show that the development of the model and using it for experimentation can help test scenarios and support decision-makers understand the uncertainties and interdependencies better. They can reflect on what really happened and what they would like to change in future interventions. Moreover, they can simulate various interventions by comparing real time measured expectations and desired outcomes and establish where uncertainties or sensitive thresholds lie, based on the data collected from a target audience and a systematic analysis of the results. This supports the marketer in developing various scenarios by combining variables and discussing this with colleagues and peers, which eventually leads to a better marketing and communication performance as well as improved accountability.

Work in progress includes tracking the outcomes of follow-up surveys and including new insights from literature and using those to update the models and enrich the properties for the agents (e.g. mutual influence), as well as testing boundaries for the simulation though e.g. sensitivity analysis. Doing this in close cooperation with marketing communication professionals will allow direct feedback when they experiment with the simulation during a project to understand how the outcomes can be part of the decision making and thought processes. If they indeed state that this is helpful for their work we can build on the face validity of the work.

The main contribution presented in this paper is the process of translating survey results into a dynamic social simulation tool by populating an agent-based model with agents representing the participants to the survey. We showed that this can be used to test realistic scenarios over time as they happened as well as possible future directions and responses of the agents.

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The urbanization process in Central Italy. A network approach.

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The period between the Final Bronze Age and the Orientalizing Age is a time of great changes and developments in the Italian Peninsula which led to the creation of regional ethnic and political groups and to the formation of the first city-states in Western Europe.

This time between the end of Pre-history and the beginning of proper history has been called by Renato Peroni as Proto-history, because at this time there is the development of all more important features of later urban societies (settlement centralization, social differentiation, craft specialization, creation of central ritual places, incipient market economy) but only at a potential or not fully developed level.

In particular in middle Tyrrhenian Italy (Latium, Etruria and Campania) it is possible to observe the formation of large Early Iron Age nucleated settlements (proto-urban centres) from the merging of numerous dispersed Final Bronze Age villages (pre-urban centres), converging on the same plateaux that later will be occupied by the cities of the Archaic Age.

This process happens almost emblematically and paradigmatically in southern Etruria, where the shift from small dispersed villages to big nucleated centres is rather abrupt and revolutionary; while is rather more gradual and slightly later in Latium vetus, where Early Iron Age proto-urban centres develop from the enlargement of smaller Acropoleis.

When the intra-regional organization of these systems of settlement is considered both in Etruria and Latium is possible to observe a certain degree of hierarchy. During the Bronze Age both in Etruria and Latium vetus there seems to be a 2-3 level hierarchy with settlement larger than 6 ha likely functioning as redistribution centres and providers of central services. While in the Early Iron Age a settlement hierarchy of 4-5 tiers seem to be in place with larger proto-urban centres functioning as central. However in this respect there is a clear difference between Etruria and Latium vetus: in Etruria major settlements are generally larger than 100-200 ha; while in Latium vetus only Rome reached similar dimension and other primary order centres are generally between 20 and 25 ha and in some cases between 40 and 80 ha.

We are applying a network approach to investigate this process in both regions (1) to determine the influence of river and terrestrial routes in the development proto-urban centres, (2) to predict the importance of settlements, (3) to characterize the evolution of the communication patterns before, during, and after the urbanization process at a local as well as global level.

The considered networks have been identified in the following way [1]. Settlement directly connected by a terrestrial route or by a river have been connected in the network via a bidirectional unvalued link; in fact, for simplicity, it has been assumed that movement of goods, ideas and people would flow in both directions in an equal measure.

Our analysis takes advantage of many different methodology developed within the framework of social network analysis and network theory. We started by characterizing the nodes through centrality indexes and the topology of the networks by means of

usual measures such as network diameter, density, average clustering coefficient, and average path length [1, 2]. We have thus been able to confirm that rivers connection, at least at an intra-regional scale, were more relevant during the Bronze Age rather than in the Iron Age since in this last phase the river network seems to be unable to add anything valuable to the information provided by the terrestrial routes.
We are currently elaborating a model for the evolution of system. A proper choice of the set of parameters will hopefully allow us to reproduces different scenarios by tuning their values. A final step will be to reconnect the output of the model to our present case studies.

[1] Fulminante, F. 2012. Social Network Analysis and the emergence of central places: A case study from central Italy (Latium vetus). BaBesch 87: 1–27.

[2] Fulminante, F., Prignano, L. and Lozano, S. (in press). Social Network Analysis and Early Latin cities (central Italy). In Attema, P. and Seubers, J. (eds), Urbanization and State Formation in the Italian Iron Age, Groningen 31-01-2012/01-02-2013. Groningen: Groningen University Press.

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An Agent-Based Model of Consensus Building

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Abstract—our model, **CollAct is built around the question how people gain a shared understanding and reach consensus in an interactive group setting. This is an important question which is rather difficult to analyze within case studies. We model agents in a cognitive way, including substantive and relational knowledge in mental models, which may change through learning. The agents in CollAct discuss with each other and produce a group model (consensus). Factors identified to have an important influence on the results of a group discussion include group size, the level of controversy within the discussion, cognitive diversity, social behavior in form of cognitive biases (Asch and halo effect), and, depending on group size, the existence of a leading role at the beginning. Furthermore, the integration of topics into the consensus follows a saturation curve, thus the ending time of discussions should be carefully chosen to avoid a loss of information.**

I. Introduction

How do people develop a shared understanding and reach consensus in an interactive group setting? Interactive participatory settings are widely promoted in natural resource management and policy making [1],[2]. They are expected to promote social learning, and thus help to adapt to the growing complexity and uncertainty of today's world [1],[2],[3]. Therefore building a shared understanding of the issue at stake as well as reaching consensus is often considered a worthwhile goal. However, up to now only limited empirical research on the effectiveness of social learning and the development of a shared understanding is available, one reason being the difficulties in measuring and qualifying internal changes in individuals [4]. Limiting analysis to a specific event and thereby reducing context factors seems to be one reasonable strategy to enhance knowledge [5]. Furthermore, there is evidence which suggests that the process (e.g., group dynamics) may have more influence on the result than the choice for a specific participatory method applied to facilitate social learning [6]. These are arguments for the use of an explorative agent-based model, in which internal changes can be tracked and different processes and group dynamics can be simulated.

With **CollAct** (modeling **coll**aborative **act**ivities) we present such a model. CollAct allows to explore group dynamics in interactive discussion: When and how individual views on a problem converge into a shared understanding, how individual and group properties interrelate, how roles shift and emerge, and how a consensus can be achieved through discussion. However, economic factors and norms are not considered. Instead, CollAct builds upon speech processes, cognitive and social-psychological theories. Hence, our agents are modeled in a rather complex, cognitive fashion. To be in line with social-psychology, they consider both relational/social and cognitive aspects (own knowledge) to interpret incoming messages and to decide on their next action. As far as we are aware this has not been done so far.

We start with an overview of the conceptual framework our model is based on, also discussing empirical findings and concepts. In the next section we describe the conceptual model of CollAct, and discuss some important implementation details. This is followed by a presentation of simulation results and their interpretation. We end with a discussion of our approach, conclusions and an outlook on further research.

II. Conceptual Framework

CollAct is based upon an analytical framework of social learning facilitated by participatory methods [7]. This framework was developed to support an in depth understanding of processes underlying social learning. Our interpretation of this framework is presented in fig. 1. A core component in it, used to link individual and group perspectives, is the mental model concept. Mental models refer to "personal internal representations of the surrounding world" [7, p.6]. Every actor has a mental model. Mental models influence how information from the environment is interpreted, and therefore influence the relationship to the environment. They can change through learning. Thereby mental model is divided in two parts: the substantive model, which includes knowledge about the topic at stake, and the relational model, including

This work was not supported by any organization

knowledge about other actors (e. g. personal characteristics) and self-perception. Actors come together and interact an a discussion. In this discussion every actor has a role (e.g., being active or passive), and change in the relational mental models of actors can manifest through the shift or emergence of roles. The substantive models influence the content of the discussion. Events in the discussion, on both relational and substantive levels, have a feedback on the individual mental models, which may again change through learning. Possible outcomes include relational outcome (e.g., better relationships), the building of a shared understanding, and, in our case, a group model as substantive outcome. In this group model we model the consensus which may be reached during the discussion. Consensus and shared understanding are not the same: Consensus refers to the result of the discussion (modeled as group model in CollAct), while shared understanding refers to the overlap of mental models of participants.

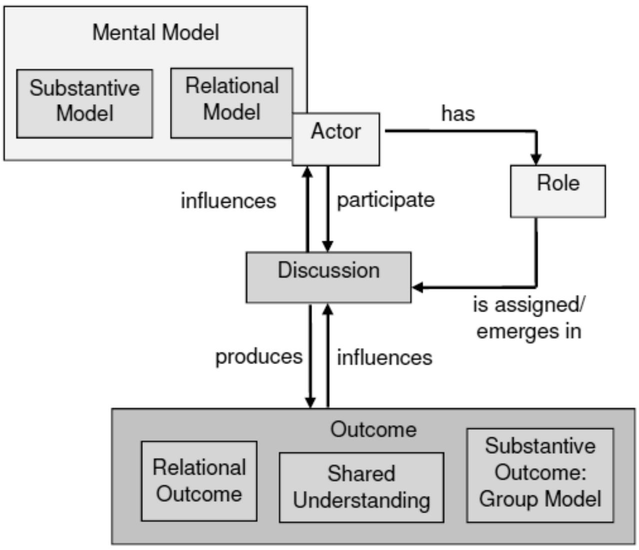

Fig 1. Conceptual framework underlying CollAct, derived from [7]

A. *Theories used for CollAct*

For learning and mental models a lot of research exists, e.g., [8],[9],[10]. To encounter new knowledge can lead to a change in concepts, respectively in the mental model [8]. People develop new concepts fast and on little evidence, and tend to keep these without strong evidence against them [9]. And, people are more likely to notice information that supports their assumptions (confirmation bias) [10].

We use two cognitive biases to model influences of the relational model: the Asch effect and the halo effect. The Asch effect [11] describes how people conform to obviously wrong judgments under perceived group pressure. The halo effect describes how a positive judgment of a person in one dimension (e.g., good looking, or sympathetic) creates a positive bias in the judgment of this person on any dimension (e.g., intelligent) [12]. These two cognitive biases are particularly useful because they help to include the relational influences included in the underlying framework in the decision part of agents. Furthermore, they help to model two main processes in group interaction: Conformation and the influence of roles.

An overview of included theoretical assumptions is provided in Table I.

III. Model Description

CollAct models an interactive group discussion. Thereby the discussion is modeled in a turn-taking manner, only one agent can speak at a time. Furthermore, all agents listen to every message. No facilitation or moderation of the discussion takes place. The agents discuss about a problem exchanging messages. If sufficient messages support a certain topic, it is included in the group model (consensus). The discussion goes on until either a sufficient long silence period occurs (20 steps per default), or time is over.

CollAct is implemented using Java in Repast Simphony [13]. Fig. 2 provides an overview of the speech process in CollAct. In the following, we give a short description of all classes, a more detailed description for the main decision part in participant, an overview of implemented concepts, and an overview of all parameters included.

A. *Overview of classes*

Model

Model is used to represent participants' substantive models and the group model. The group model represents the consensus of the group. The group model is held by the facilitator (which does not have an active part in the process), while the individual substantive models belong to participants. Model is arranged as a simple array with a predefined size (which can be set in the GUI), in which topics can be saved as Integers. Every field in the array refers to a specific topic. A one in this array fields means that the participant has this topic in her substantive model, respectively the topic is included in the group model (consensus), while a zero means the topic is not included. Model offers methods to add and remove topics, to check if a certain topic is included, to get the number of included topics, and to get a random topic included in the model.

Facilitator

The facilitator has no active part in CollAct (this may be changed in future implementations). The facilitator acts as an observer, who provides information about the current status of the consensus. This is done in the group model. The facilitator holds the group model, and adds new topics if a consent level is reached. This consent level is set to the number of participants. To keep track of the consent on topics, the

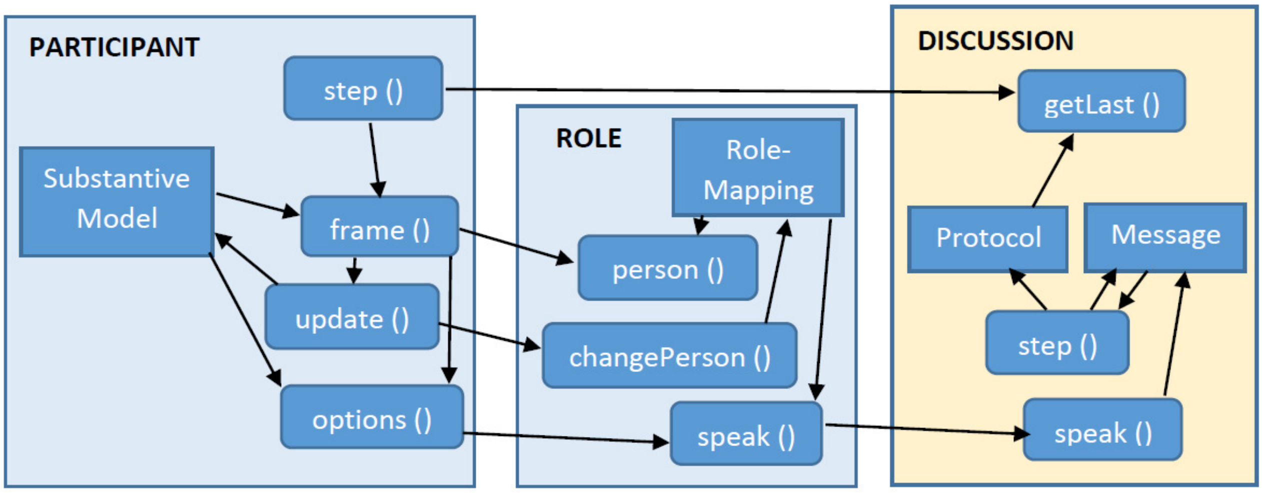

Fig 2. The speech process as modeled in CollAct. Details for participant, role, and discussion are described in the text (type of illustration based on [14])

facilitator sums up all messages in favor and against topics. Hence, in our implementation not all participants have to agree on a topic to be included. If sufficient supporting messages are counted without dissenting votes, a topic is included in the group model. If the consent on a topic falls 2 below the consent level, topics are removed again out of the group model. Furthermore, the facilitator has a method to check whether a topic is included in the group model, and provides methods for the graphical display of model results and end routines for evaluation.

Participant

Participant is the main class of CollAct. Participants hold a model in which topics are saved, representing their substantive model. Furthermore they have a role, including self-perception and perception of others, representing their relational model. Participants interpret the last message concerning to the content (is the topic included in their own substantive model?) and the speaker. On these results they are able to learn (update their own substantive and relational model) and decide on further actions. During the update method participants can learn about roles depending on the similarity of opinions (if the topic proposed from participant A is also included in the substantive model of participant B), and about their substantive model. The probability of change in the substantive model depends on the perception of the speaker. Possible actions are implemented in the options() method, which is described more in detail later on.

Message

In message the inputs of participants to the conversation are modeled. Messages are tuples (speaker, topic, in) [based on 15] that provide methods for returning the value of each element (e.g., speaker). *Speaker* identifies the participant who sent the message, *topic* is a number and identifies the topic the participant talks about, and *in* is a boolean which indicates if the participant wants to include or exclude this topic from the group model.

Role

A role belongs to a participant. Role provides the roleMapping in which the relational model of an agent is stored. RoleMapping is implemented as an array, in which the perception of other participants and self-perception are presented as real numbers between zero and one, one being the most positive and zero the most negative value. For simplicity, all kinds of different relational dimensions are summarized in this value, e.g., sympathy, competency, power, and attraction. Role provides a speak method that is called up by participant. Role then increases or decreases the probability for the message to be passed on, depending on the perceived position of the participant in the discussion. If a participant sees herself in a strong position (high role value compared to the rest of the group), the speech probability rises. If she sees herself in a weak position the probability decreases. Role then evaluates if the probability is high enough (by comparing it to a random number), and if so, calls up the speak method of discussion to register the message for the next step.

Discussion

Discussion represents a virtual room. All participants and the facilitator know their discussion, and can call up a method of discussion to "hear" the last spoken message (see fig.2). Furthermore, they can pass a message via their role. Role can register the wish to take part in the conversation by

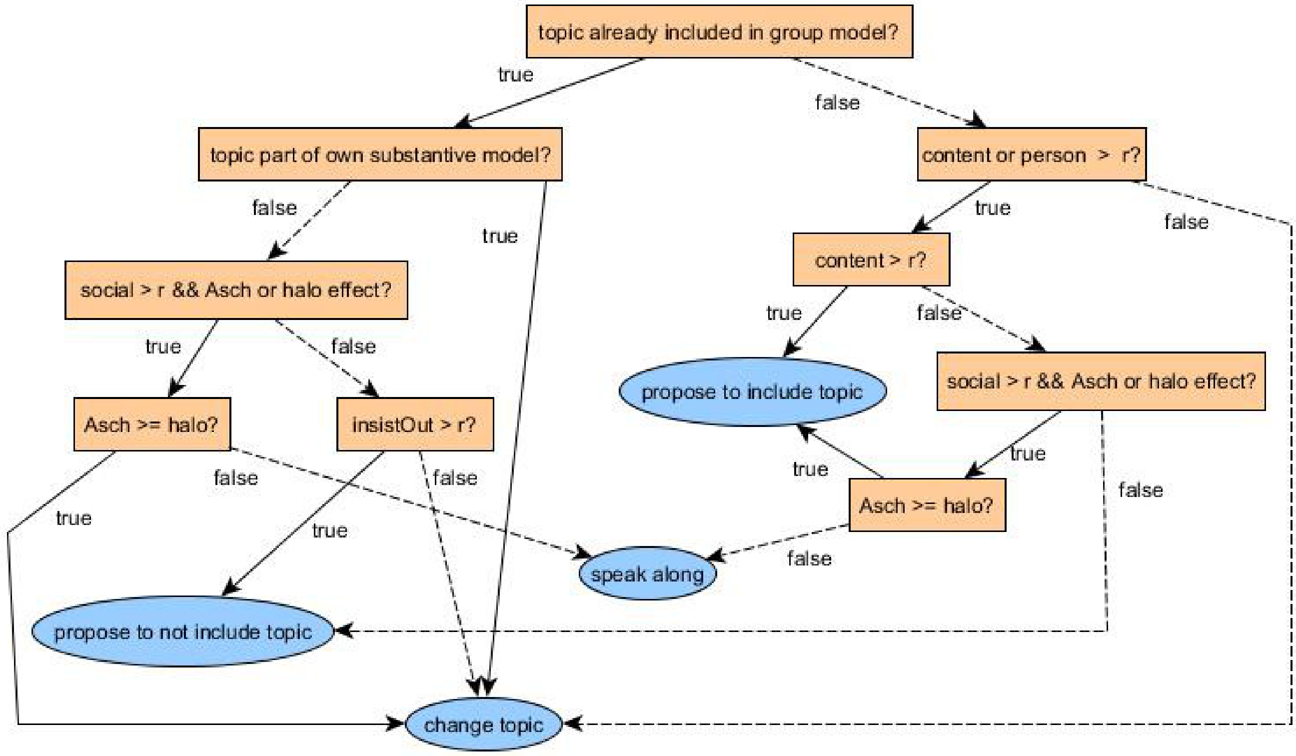

Fig 3. Decision tree in the options method of participant

sending a message. Because CollAct models a turn-taking conversation, only one registered message per step is chosen by the discussion to be spoken out "aloud". Thereby it is decided upon randomly which message is chosen, using the implementation of Repast Simphony, which calls up the step methods of agents in a randomized way. Discussion saves chosen messages in a protocol, providing a shared memory. Furthermore this class provides end routines for the model evaluation.

Protocol

Protocol belongs to the discussion. It saves the last n (this depends on the parameter *forget*, which is set on 3 per default) messages with different topics in a consecutive order. Furthermore it saves n possible occurrences for each different topic. For example protocol may save three messages with topic A, one message with topic B, and two messages with topic E. When a new entrance is added, protocol restructures. Furthermore protocol provides a method which returns the most probable topic to speak about concerning the protocol. Thereby the probability for a topic to be chosen depends on its location in the protocol (higher for more recent topics) and its number of entrances. Another method provided by protocol returns how many different actors wanted to include a certain topic. The returned number depends on the number of possible entrances (forget).

SessionBuilder

SessionBuilder is a class required to run a Repast Simphony model. SessionBuilder manages the simulation by reading in parameters from the GUI, instantiating the other objects, and placing them in a context.

B. Detailed description of options

Here we describe one method more in detail: the decision method of participant, options(). Options() is implemented as decision tree. This may be best understood via pseudo code and a graph. Fig. 3 displays the decision tree implemented in options(). The ovals are possible actions: participants can propose to include the topic of the last message, propose to not include this topic, speak along (whatever the previous speaker said), or change the topic. The rectangles represent decisions on the way to a possible action. Thereby some of the values which are evaluated have been calculated by the interpret () method: content and person. Others, like *social* and *insistOut* are parameters which can be chosen in the GUI at the beginning. Finally, Asch and halo are calculated by asking how many other actors wanted to include a topic, respectively by looking at the role value of speaker. For example, one way trough the decision tree could be: the last message had a topic not included in the group model so far. Neither content nor person are higher than a random number,

TABLE I.
CONCEPTS IMPLEMENTED IN COLLACT

Concept	Implemented in Participant in
Mental models influence perception, cognition and behavior	interpret(), options()
Asch effect	options()
Halo effect	options(), update()
People develop concepts quickly on little evidence and stick to them without strong evidence against them	update()
New knowledge can lead to a change in concepts	update()
Confirmation bias	options()

this means that the participant is just not interested in what has been said and who said it. Therefore the decision is to change the topic.
The change of a topic is implemented in another decision tree. In this, the protocol is asked for the most likely next topic, which is saved in the variable pt. The following pseudo code illustrates the further procedure.

pt = most likely topic from the protocol
p, pm = parameter (see Table II)

If (pt is included in own mental model and pm > random)
propose pt
Else if (p > random) propose to exclude pt
Else propose new random topic of own mental model

C. Implemented concepts

Table I provides an overview of the theoretical considerations that were integrated in CollAct. These can be found in participant, where the most decisions take place. Table I also shows in which methods the concepts are used.

D. Parameters

All parameters used in CollAct are listed in Table II. The first seven parameters are placed in the GUI. We tried to keep the number of parameters as low as possible and base them on theory wherever possible. We concentrate on the parameters placed in the GUI to explore model dynamics. The results are described in the next section.

IV. RESULTS

To give a first impression of the model and highlight general results we start with some illustrations of a typical run (for certain parameter conditions) and describe general results. Next we give an overview on indicators we measured. To exploit the first advantage of modeling, the availability of data, it is important which data is measured and compared.

TABLE II.
PARAMETERS

Name	Description	Default
howMany	number of participants	6
ModelSize	capacity of substantive models	40
topicQuantity	to what extend are mental models of participants filled (randomly)	0.2
social	probability for halo and Asch effect	0.3
insistOut	probability to insist to exclude certain topics out of the group model again	0
learning	probability for learning	0.2
endAt	stopping time (end of session)	1000
forget	gives the amount of memory capacity for messages	3
freqProb	multiplier for frequency of a topic (in ProtocolItem, inner class of Protocol)	0.3
pm	probability to join in a topic also represented in myModel	0.3
p	probability to bring in a topic not represented in myModel from the protocol (to be not included in the group model)	0.05
openness	openness to topics not included in myModel	0.3
	evidence against concepts has to be ten times stronger to take them out as the evidence needed to include new concepts (in update)	
silenceStop	after this number of steps without speech CollAct is stopped	20
k	proportionality constant for logistic growth function for roleMapping update (learning)	0.5

We then present the results from two parameter sweeps, and illustrate them in correlation tables. The data is processed with R [16].

A. Some general results and examples for output

We show examples of a run with the following parameter setting: endAt = 2000, howMany = 6, insistOut = 0.1, learning = 0.1, ModelSize = 40, topicQuantity = 0.2, social = 0.2.

Fig. 4 illustrates a sequence of messages during the model run. The upper line displays the topic, while the lower line refers to the respective participant speaking. It can be seen that participants talk about a topic for a couple of steps before switching to the next one. -1 is an error value which denotes that nobody was speaking at this time step. With a higher value of *insistOut* longer discussions on the same topic arise, because participants disagree more. The parameter *social* is also important for long speech sequences, because participants realign with the rest of the group.

Fig. 5 displays the share of possible topics, referring to the share of all topics available from participants substantive models that is already included in the group model. Fig. 5 shows a saturation curve, which is a robust result of CollAct. Hence, in such a discussion it should be carefully considered when to end. If it is stopped to early, interesting points may

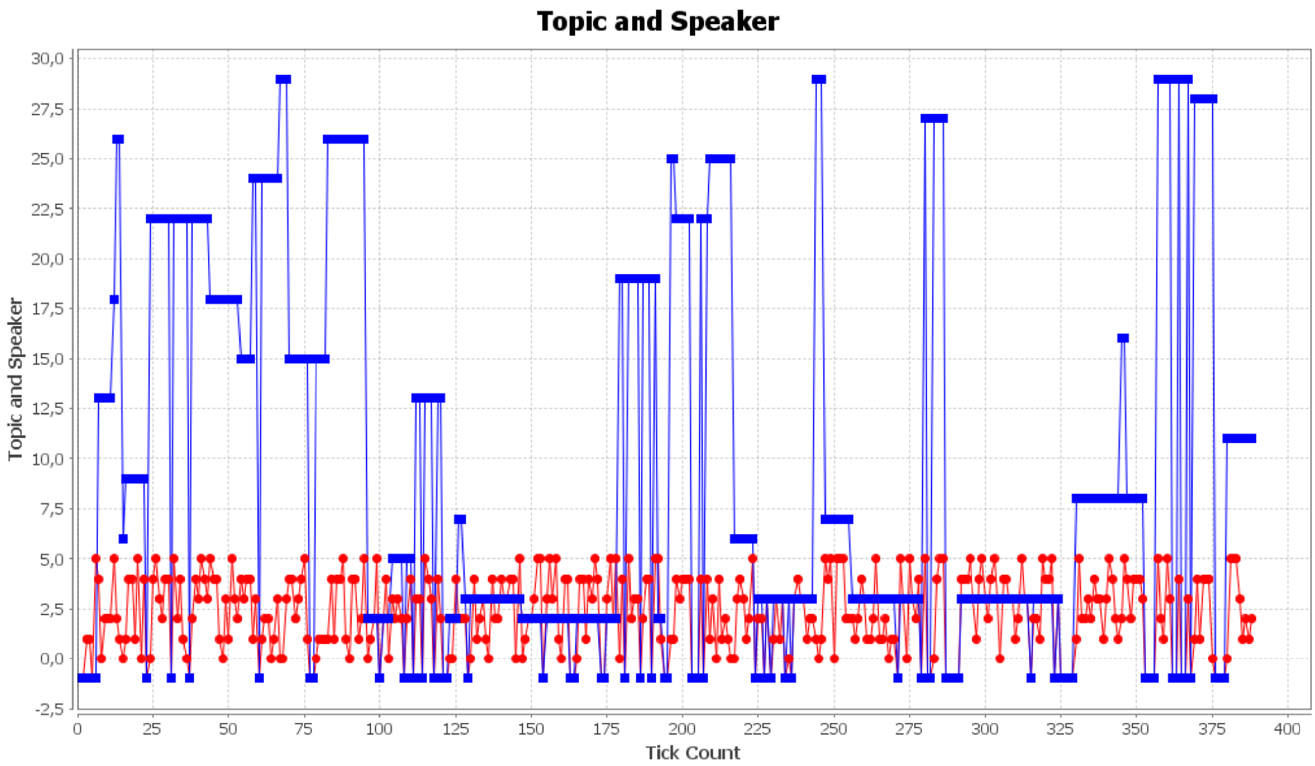

Fig 4. The first part of a run of CollAct. The upper line (blue) represents the topics, while the lower line (red) refers to the speaking participant. As it can be seen, CollAct produces sequences of messages with the same topic, sent from various speakers (participants).

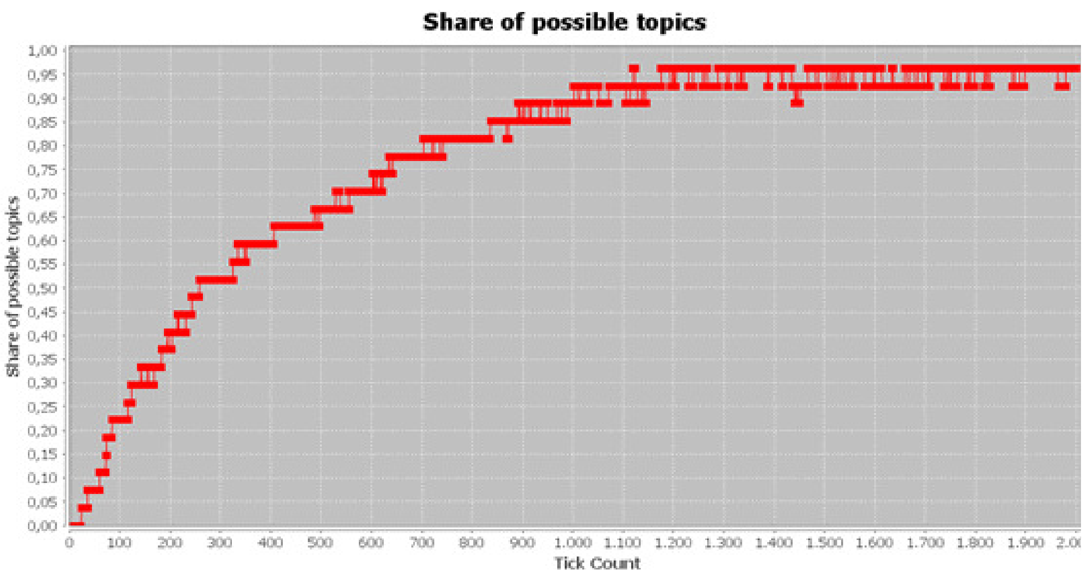

Fig 5. The share of possible topics (of all topics that are represented in the substantive models) in the group model

be overseen, while after a certain point none (or only marginal) additional information is included.

Fig. 6 display how roles change over time. To accomplish this the role value of participant X is looked up from every participant and summarized. This number is divided by the

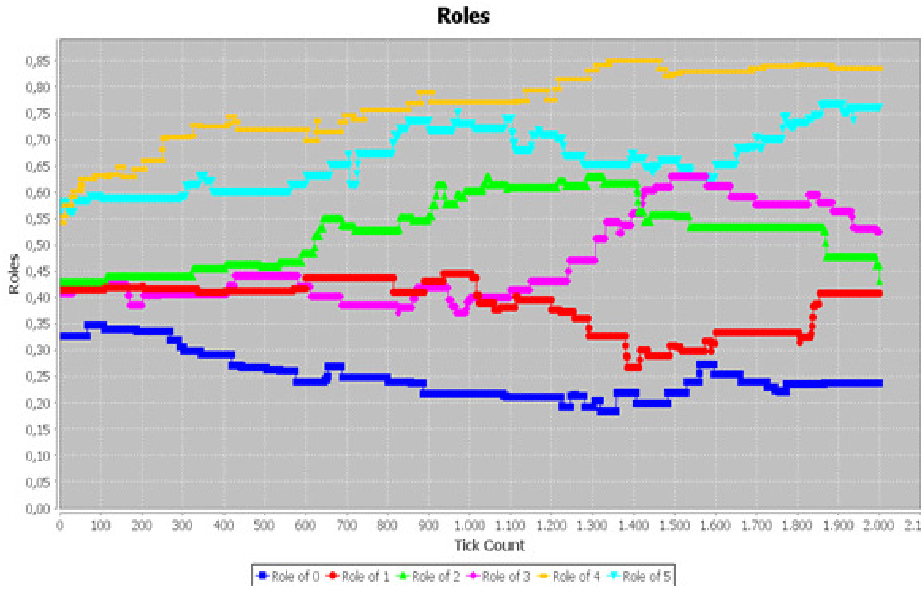

Fig 6. The progress of average roles over time with *insistOut* = 0.1

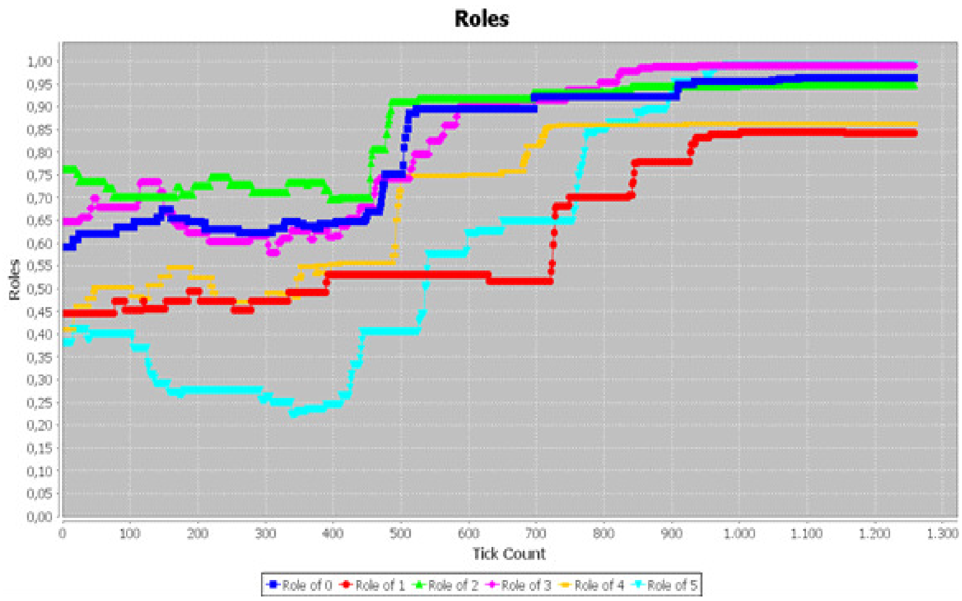

Fig 7. The progress of average roles over time with *insistOut* set to zero

number of participants, to gain the average perceived role of X. Fig. 6 illustrates strong change in roles. This observation raises the question if relational learning is implemented to strongly. Nevertheless, this might be realistic for participants who did not know each other before entering in a discussion. For fig. 7 we changed the value of *insistOut* to zero. This means that participants don't insist to take out topics that have already been included in the group model. In fig. 7, roles tend to become very positive and stabilize at a high level. Participants don't stick to conflicting topics and have a greater probability to talk about topics on which they agree, rising the probability for learning in roles with a positive direction. This eventually leads to a high average role value.

B. *Indicators*

The results discussed before are of qualitative nature. Due to the high number of randomized decisions only typical patterns can be described. To evaluate CollAct in a quantitative way we needed indicators to measure and compare. Table III displays the indicators we chose. These are based on [7] and [17].

TABLE III.
INDICATORS

Time	Name	Description
Start	S_averageRole	average role value over all participants
	S_leadingRole	distance highest role to next role
	availableTopics	number of possible topics (listed in individual mental models) – this relates to cognitive diversity
	S_rangeRoles	range of roles
	averageTopicsPer-Participant	average number of topics per participant
End	substantiveLearning	change of averageTopicsPerParticipant
	rangeSpeech-Distribution	range of speech distribution (% of messages linked to a specific participant)
	rangeRoles	range of roles
	topicsInGM	number of topics in final group model
	leadingRole	distance highest role to next role
	averageRole	average role value over all participants
	tick	step count (length of model run may vary because of silence counter)

C. *Parameter sweep and correlations*

After setting indicators we conducted a parameter sweep to explore correlations of GUI parameters and output indicators. We used the Spearman rank correlation. We varied the following parameters:

howMany	2 – 10, step:1
social	0 – 0.8, step: 0.2
insistOut	0 – 0.8, step: 0.2
learning	0 – 0.8, step: 0.2
endAt	500, 1000, 1500

This parameter setting leads to 3375 variations, with which we simulated one run. Modelsize was set to 40, and topicQuantity to 0.2. Table IV presents a subset of the correlations identified for the results. To keep it well organized Table IV only displays the parameters and indicators with the highest correlations.

The highest influences are visible for *howMany* (the number of participants) and *availableTopics*. *AvailableTopics* indicates the number of available topics out of all substantive models of participants, and thus the two start indicators are highly dependent. However, the number of available topics, which also relates to cognitive diversity (how are topics distributed along participants) has a strong influence. Group size is known to have a strong influence [18], thus the reproduction of this with the model is a promising start. Some correlations are rather trivial, but still support the soundness of CollAct. E. g. *learning* leads to high substantive and relational (*averageRole*) learning.

The presence of a leading role at the beginning leads to a lower level of substantive learning. This may be due to one participant dominating the discussion, resulting in less possibilities to learn from diverse perspectives. Furthermore, a leading role at the beginning correlates with a lower average role at the end, which is interesting and may be due to the same mechanism discussed above.

InsistOut, which may be interpreted as a high level of controversy in the discussion, leads to a lower number of topics in the group model. Furthermore, a high level of controversy leads to a lower amount of substantive learning. Some claims in the literature see constructive conflict as a way to foster learning [19]. This may relate to the diversity of knowledge, which would match findings from CollAct, and not to the level of controversy as we use it here, which is about insisting to exclude others' opinions. A high level of controversy is correlated to a lower average role which confirms the qualitative finding for roles by checking the opposite direction (see section on general results). Interestingly, a high level of controversy also leads to a higher probability of a leading role at the end. This may be due to the lower average role: if all roles are lower, there is a higher probability of one single role rising above the others.

TABLE IV.
HIGHEST CORRELATIONS OF FIRST SWEEP

	insistOut	learning	howMany	availableTopics	Start_leadingRole
topicsInGM	-0.52	0.26	0.40	0.45	-0.17
substantiveLearning	-0.13	0.63	0.47	0.52	-0.17
averageRole	-0.34	0.61	0.34	0.33	-0.13
leadingRole	0.19	-0.15	-0.40	-0.38	0.38
rangeRoles	0.41	0.00	0.06	0.06	0.10
rangeSpeechPart	-0.10	0.02	-0.34	-0.31	0.18

To test our assumptions on these correlations we conducted another sweep with 5000 variations, setting the number of participants to 6. We varied parameters as follows:

social 0 – 0.9, step: 0.1
insistOut 0 – 0.9, step: 0.1
learning 0 – 0.9, step: 0.1
endAt 500- 1500, step: 250

Resulting correlations are displayed in fig. 8 (only those which have a value of at least 0.05 respectively -0.5). The second sweep underlines the findings of the first sweep. The influence of the amount of available topics, relating to cognitive diversity, is now corrected from the influence of a varying number of participants. Still it has a strong influence on the number of topics in the group model as well as on the substantive learning. The influence of the level of controversy of the discussion is even more obvious, emphasizing the previous findings. Furthermore the influence of *social* (Asch and halo effect) becomes visible. This was neglected in the first evaluation, because the influence of *social* seemed rather small compared to other factors. *Social* has a positive influence on the number of topics in the group model and on the average role value. Furthermore it hampers the rise of a leading role and the growth of a broad rang of roles.

The influence of a leading role at the beginning does not seem significant in the second sweep. It only correlates with indicators referring to the end situation of roles, which is rather trivial. The result that there is a strong influence of a leading role at start when the number of participants are varied presents an interesting point for further explorations.

	social	insistOut	learning	endAt	available Topics	average TopicsPer Participant	S_average Role	S_leading Role	S_range OfRoles
tick	0.05	0.07		0.95					
topicsInGM	0.15	-0.73	0.27	0.33	0.28	0.23			
substantiveLearning	0.07	-0.28	0.75	0.25	0.30	0.26	0.06		
averageRole	0.16	-0.43	0.71			0.08	0.28		
leadingRole	-0.10	0.23	-0.23				-0.08	0.18	0.07
rangeOfRoles	-0.15	0.46				-0.08	-0.14	0.08	0.22
rangeOfSpeechParticipation		-0.08	0.05	-0.14					0.06
availableTopics						0.72			
averageTopicsPerParticipant					0.72				
S_leadingRole									0.40

Correlations of input and output,
and input and input (parameters and indicators)

	tick	topics InGM	substantiv eLearning	average Role	leading Role	rangeOf Roles	rangeOf SpeechPar ticipation
tick		0.30	0.25				-0.14
topicsInGM	0.30		0.69	0.59	-0.25	-0.33	
substantiveLearning	0.25	0.69		0.78	-0.26	-0.16	
averageRole		0.59	0.78		-0.38	-0.41	0.05
leadingRole		-0.25	-0.26	-0.38		0.37	
rangeOfRoles		-0.33	-0.16	-0.41	0.37		
rangeOfSpeechParticipation	-0.14			0.05			

±(0.15 - 0.24)
±(0.25 - 0.34)
±(0.35 - 0.44)
±(0.45 - 0.54)
±(0.55 - 1.00)

Correlations between output indicatos

Fig 8. All correlations from the second sweep which have a value of at least 0.05 respectively -0.05

V. Discussion

The decision for a complex cognitive model embraces some difficulties, because many design decisions are required and results may be difficult to interpret. Although there are good arguments to keep agent-based models simple, in some cases a more descriptive approach is reasonable [20]. Simulating micro-level relations among people who hold the knowledge in participatory processes might be important [21], as well as the interpretation of messages, the modeling of memory and path-dependency, and deliberation processes [15]. CollAct comprehends these points. Furthermore, we argue that in our case a complex cognitive model is reasonable, because a higher level of abstraction would absorb the processes we are interested in to model consensus building.

Because of the explorative character of our model the validation is not described in a separate section. While building CollAct we discussed in an expert round whether assumptions are realistic, and improved the model in an iterative way. The model has been tested for errors. While interpreting the results, some validation can be done "on the way": every reasonable result which is confirmed through empirical finding is a further little step for validation.

The significance of group size is also reflected on in empirical work [17], thus this result is a promising start. The level of controversy in the discussion presents another important influence, leading to a lower number of topics in the group model, a lower amount of substantive learning, and to a higher probability of a leading role at the end. With a low level of controversy roles tend to become very positive and stabilize at a high level. On the contrary, a high level of controversy is correlated to a lower average role.

The number of available topics, which also relates to cognitive diversity (how are topics distributed among participants) influences the number of topics in the group model as well as the substantive learning. *Social* (the probability for Asch and halo effect to occur) has a positive influence on the number of topics in the group model and on the average role value. Because participants tend to conform to topics they do not favor themselves, more topics can reach the necessary consent level to be included in the group model. Furthermore, it hampers the rise of a leading role and the growth of a broad range of roles. These are interesting findings for the function of (empirically proved) cognitive biases in group processes.

In the parameter sweep with a varying number of participants, a leading role at the beginning has a strong negative influence on substantive learning, and the average role at the end. This influence does not seem significant in the second sweep, were the number of participants was set to six. Hence, in CollAct the influence of a leading role at the beginning depends on group size.

Another, straight forward result is, that the integration of topics in the group model follows a saturation curve. Thus, in such a discussion it should be carefully considered when to end.

VI. Conclusion and Outlook

CollAct presents a new approach to explore group dynamics via simulations. On the basis of the results presented some first conclusions about important influences in group discussions could be drawn. This was only possible with the integration of cognitive complexity. Especially the integration of substantive knowledge and relational knowledge and their interaction within the agent rules produce interesting dynamics, but also a large amount of data which has to be interpreted in an illustrative way. The results discussed in this paper are only a first start to demonstrate the scope of this model. These results will be further elaborated and backed up with empirical findings in future work. Thereby, the interrelation of a consensus, conformation, and the development of a shared understanding are central to our future model exploration. Shared understanding is a key aspect of many social learning theories (e.g., [7]), and consensus and shared understanding are not necessarily the same (see above). The influence of different role settings as well as different mental model combinations are subject of future research as well.

Possible extensions include topics which are assigned a negative opinion, to model conflict. Furthermore, learning in the substantive and relational models could be split up, e.g., to model situations were substantive learning takes place while participants know each other from previous meetings. Another possibility is to model agents heterogeneous in some attributes, e.g., *insistOut* or *social.* An important extension would be the integration of an active facilitator. At the same time such an extension would produce the need for further complexity.

Another interesting direction is the coupling with network theories to create larger learning communities, grown from the ground.

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The evolution of cooperative versus non-cooperative governance of small-scale fisheries

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Abstract— **Small-scale fisheries (SSF) around the world are often organized in patron-client relationships (PC), where fishers deliver fish to a fishbuyer who sells it at regional markets. PCs have recently been criticized as being unequal, exploitative and unsustainable. Many governments have thus developed measures to promote fishing cooperatives. Despite these efforts, PC relationships appear to be increasing globally. The aim of our work is to shed light on why this social organization is very persistent. To this end we combine in depth empirical research on fishbuyers and fishers in an SSF in Mexico with agent-based modeling. This allows us to test hypotheses about the role of actor characteristics, such as their social skills, and the resources, as well as the institutional environment in which these interactions take place, for the establishment and persistence of PC relationships versus cooperatives.**

I. Introduction

Small-scale fisheries around the world are often organized in patron-client relationships (hence forth PC), where a fishbuyer (the patron) provides loans to fishers (the clients) who in turn deliver their fish to the buyer who sells it at local or regional markets [1]. This relationship goes beyond the commercialization of the fish by providing monetary security and insurance to the fishers in times of personal needs or hardship. In recent years, they are being increasingly criticized as unequal, exploitative and unsustainable. Fish-buyers can strongly influence the choices and actions of fishers because of the dependency of fishers' livelihoods on their patron. It has been hypothesized that this relationship can contribute to overfishing as fish-buyers determine fishers' target species and effort based on market demands rather than the condition of the fish population [1]. Governments around the world have thus introduced policies to foster the establishment of fishing cooperatives (hence forth Coops) as an attempt to move away from PC relationships towards more cooperative governance arrangements such as Coops. However, the introduction of Coops has often failed indicating a high resistance of PC relationships. Globally, PC relationships within small-scale fisheries appear to be increasing.

The aim of our work is to shed light on why this social organization is very persistent and which conditions could facilitate social change towards more cooperative, and possibly more sustainable, governance of small-scale fishers. The interplay of social and ecological factors and processes for shaping the dynamics of cooperation in natural resource management is a fundamental question underlying the development of sustainable social-ecological systems [2], [3]. To this end we address the question which social and ecological factors influence the evolution of a PC versus a Coop. We hypothesize that attributes of the fishers and fishbuyers, such as their social skills and reliability as well as the loyalty between a fisherman and his fishbuyer, or fishers within a Coop, are important factors for determining whether PC relationships or Coops will dominate a fishing community. We base these hypotheses on expert knowledge and extensive empirical research within fishing communities in Baja California, Mexico (e.g. [4]) as well as insights from the study of self-organization in common pool resource management [5].

II. A model of small-scale fisheries governance

In the following we briefly describe the model following the overview section of the ODD+D protocol [6]. The purpose of the model is to enhance understanding of the social and ecological conditions that facilitate the establishment of cooperative governance arrangements in small-scale fisheries (such as Coops) versus the commonly found non-cooperative arrangements (fishers working for fishbuyers). The model has two types of human agents: fishers and fishbuyers, one ecological entity: a fish population and an economic entity: a fish market. Fishers can work with fishbuyers or form a Coop with other fishers. All agents are characterized by the attributes social skills, managerial skills, reliability and fishing skills, and the state variables financial capital and loyalty. The fish population is modeled using a standard logistic growth function.

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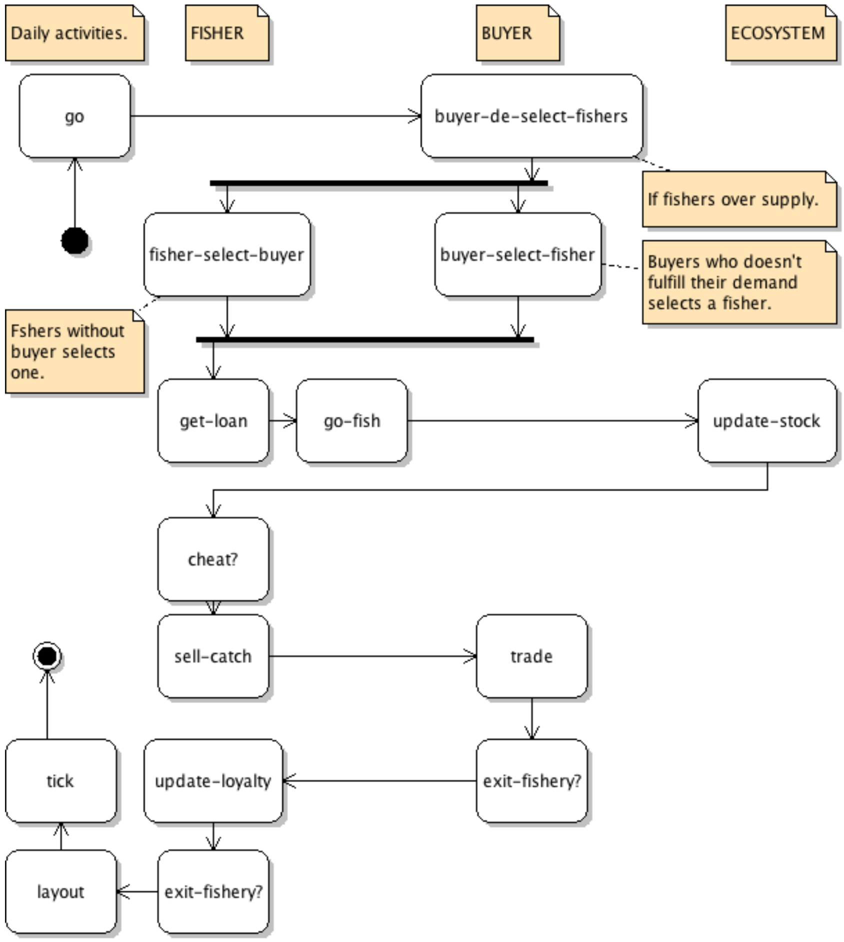

Fig. 1 UML activity diagram of daily activities. A coop or a fishbuyer enter the fishery every 3 years.

At selected intervals (e.g. every three years) the fisher with the highest financial capital can become a fishbuyer and start searching for fishers to work with him. Fishers will select a fishbuyer to work with based on his social skills and the price he offers. The fishbuyer will select a fisher to work with based on its reputation, which is a combination of its fishing skills and reliability. At every daily time step the buyer will assess whether he needs to increase or decrease the number of fishers he works with (see figure 1 for an overview of the scheduling of activities within a daily time step). If needed, he will get rid of the fisherman with lowest loyalty. A fisher will select a buyer that has expressed demand if he is not already working in a Coop. At the same interval five random fishers get together to form a Coop. The Coop provides the financial means to go fishing and sells the fish to the wholesale market. Fishers have to pay back the loan they received as well as a coop fee. Successful interactions between fishers in a Coop will increase the loyalty of the fisher to the Coop.

Each day the fisher will get a loan from the fishbuyer or the Coop he is working with to go fishing. He fishes and the fish stock decreases. The fisher can sell his catch to the fishbuyer or bring it to the Coop respectively; or cheat and sell it to another fishbuyer offering a higher price. The decision to ‘cheat’ is based on the fisher’s reliability and its loyalty to the fishbuyer or cooperative. Loyalty between two agents increases with every successful interaction, i.e. when the fisher does not cheat, and decreases with cheating. A fishbuyer or Coop will sell all the received catch to the market and pay their fishers. Fishers pay back their loan if they did not cheat. Fishbuyers or coops whose budget goes below zero exit the fishery.

The model was calibrated such that when keeping everything equal, e.g. no heterogeneity in skills, PC relationships and Coops had an equal chance of establishing. The model is also calibrated such that the fishery is sustainable when 50 fishers are actively fishing, i.e. they take out fish at a fixed effort, in a community of 100 potentially active fishers.

To operationalize this question we develop an agent-based model (ABM) of fishers and fishbuyers in a small-scale fishing community to study the social and ecological conditions, under which cooperative versus PC strategies can establish and persist. An ABM is suitable because it allows us to explore attributes of both individual fishers and the community in order to assess their relevance for the establishment of Coops. The study is innovative in that it studies natural resource use and management taking multiple levels of governance into account (fisher to fishbuyer to market versus Coop to market). This allows us to study the impact an intermediary level i.e. the fish-buyer (linking fishers to the market), has on the sustainability of a small-scale fishery and the well-being of the community (see Crona et al. (2010) for an empirical investigation of the role of fish-buyers in small-scale fisheries in Kenya).

III. First results – the coexistence of PC and Coops in a community

In the following we show first model explorations that investigate how PC and coops evolve. Under the given setting the number of fishers equilibrates around the sustainable level of 50 fishers with slightly more fishers in Coops than PC. At this point no more PC or Coops can successfully enter the fishery because they will not be able to earn enough to survive. Coops and PC however differ quite strongly in their loyalty. It grows strong in the Coops because they are persistent, i.e. they do not go out of business and form again as often as the PC. Particularly those that were in the fishery from the beginning can continuously build up loyalty while new ones are struggling which is visible in the fluctuations. The PCs fluctuate stronger and thus the loyalty of their fishers remains at a lower level. As a result of the social dynamics the fish stock converges to the optimal level (Figure 3, left); however the community, which had a rather equal distribution of wealth at the beginning, develops into a community with a high level of inequality (Figure 3, right).

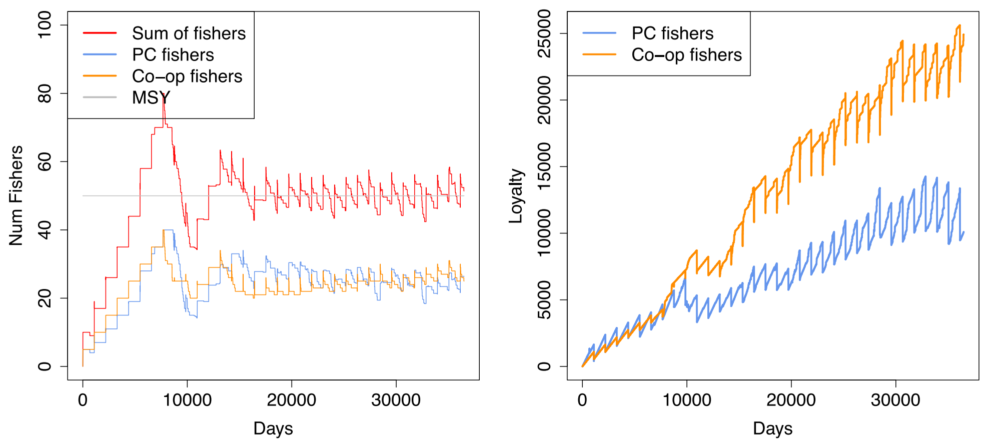

Fig. 2 Number of active fishers in PCs, Coops and the community (left); loyalty of PC and Coop fishers. Scenario settings correspond to the calibrated conditions of generating coexistence of PC and Coops. However, these scenarios include variable prices offered by the fishbuyers. The price acts as an incentive for cheating. Average of 10 runs, cheating depends on reliability only.

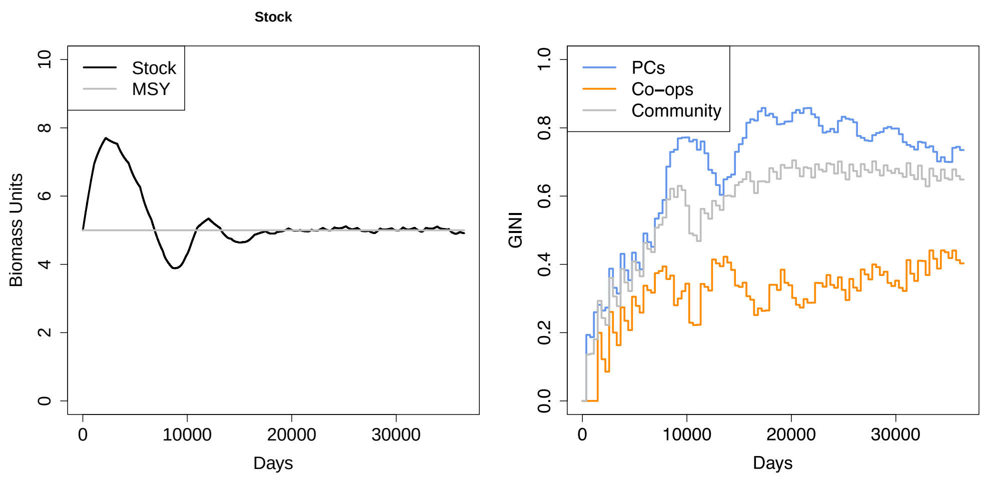

Figure 3: Size of the fish stock over time (left), Gini index (measure of inequality in the community) for PC, Coops and all active fishers in the community. Scenario settings as in Figure 2.

IV. Discussion

These preliminary results show the behavior of the model under very homogenous settings (all agents are initially the same) which is our basis to deploy the model to investigate the effects of social and ecological factors on the social structure of the fishing community and their consequences for the well-being of the community and the state of the fish population. These factors include agent attributes such as managerial skills, social skills and community attributes such as inequality in assets at the beginning of the simulation as well as ecological characteristics such as the growth rate of the fish population or fluctuations in fish abundance. The first results show the implications of variable price offered to the fishers on the generation of loyalty between fishers and fishers and fishbuyers. The model is consistent in its behavior and even with these very equal settings shows some interesting differences between PC and Coops that we will investigate further.

The model builds strongly on empirical data and knowledge that informed the hypothesis, particularly which variables are considered relevant for explaining the performance of PC and Coops, as well as the model structure, parameterization and calibration. We for instance use information on the average number of fishbuyers in this community and the general level of cheating obtained from interviews with the main fishbuyer to calibrate the model. Extensive sensitivity analysis and the use of empirical data for validation (where possible) will be performed to test the robustness of the model. Already at this early stage the joint process of model building has sharpened the analytical approach to the case study and has raised numerous additional questions that will be addressed in future field work. The close cooperation between field experts and modelers was perceived by both as a very enriching experience, and a promising way forward, to address complex real world problems in these complex social-ecological systems (SES). Ultimately we hope that our results contribute to understanding of social and ecological factors and their interactions that can keep SES trapped in a particular governance structure and to identifying leverage points for supporting the establishment of Coops in small-scale fisheries around the world.

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A theory driven, spatially explicit agent-based simulation to model the economic and social implications of urban regeneration

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***Abstract*—We model the economic mechanics of housing regeneration employing the rent-gap theory proposed by Neil Smith in 1979. We discuss the conditions for successful regeneration in theory, using an abstract representation of a city, then try and evaluate the possible outcomes of an actual regeneration programme in Salford, England in terms of property prices and area social composition.**

I. Introduction

The present work suggests a possible agent-based approach for capturing and making sense of the economic mechanics of urban regeneration programmes and their possible social outcomes.

Urban research is one of the fields where the tools of complexity science and the modelling approach have most convincingly penetrated. Micromodelling and agent-based modelling have been challenging linear regression models in representing urban dynamics and are making their way as standard planning tools, as Giffinger and Seidl (2013) suggest. In the last two decades agent based models have been extensively used to reproduce the evolution of the urban form (Stanilov and Batty, 2011), to model the urban dynamics typical of western cities - such as segregation (from the work of Schelling (1971) onward) and gentrification (the recent work of Jackson et al. (2008); Semboloni; Giffinger and Seidl (2013); Torrens and NARA (2007) among the others) - as well as some typical of the megacities of the developing world, such as the emergence and evolution of informal settlements (Patel et al., 2012; Feitosa et al., 2011). Recently, there have been fruitful attempts at employing agent-based models to evaluate urban regeneration policies. Jordan and Birkin (2011) focused on the residential mobility processes of households to predict the social composition of a regenerated area in Leeds, Malleson et al. (2013) concentrated on the effects of regeneration on criminal networks.

The preferred approach in most residential mobility models (for an exhaustive review see Huang et al. (2014)) is to centre on individual or household-level agents as the main actors and describe emerging patterns as purely bottom-up outcomes of the interaction of such agents. Also models that include economic constraints on individual residential mobility tend to implement price formation in the form of localised bidding mechanisms on land and property(Magliocca et al., 2011; Filatova et al., 2009). This approach poses a risk, in our view, of underestimating the broader economic processes that impact the urban form and constrain individual behaviour. A traditional line of research in human geography that has seen recent revival (Harvey, 2012; Smith, 1996), sees the socio-spatial phenomena that shape contemporary cities - suburban sprawl, income segregation, gentrification - as consequences of the varying influx of capital towards urban systems, as opposed to strictly originating from individual-based residential choices.

We constructed a model inspired by this approach, derived from the rent-gap theory (RGT) - a specific economic hypotheses on the dynamics of investment in housing - in an effort to integrate structural, supra-individual factors that affect the residential process and explore their effect on cultural and economic diversity of urban areas. In a previous paper we discussed a preliminary exploration of the model - we looked at the price dynamics triggered by different levels of capital flowing in a city and the patterns of spatial inequality that may emerge (Picascia et al., 2014). We now use the framework of the RGT to implement a conceptual representation of housing regeneration, centred on the economic aspect and mechanics of urban renewal. We then apply such model to a real world regeneration programme taking place in Salford, England and monitor the possible outcomes of the plan in terms of house price and social composition of the area. A description of the theoretical base and the model implementation are provided in section II and III. Section IV explores the dynamics of housing regeneration in the theoretical framework of the RGT and section V reports on our attempt to apply the model on a real world regeneration programme.

II. The "rent-gap theory" and its computational implementations

The *rent-gap theory* (RGT) is a supply-side approach to housing investment proposed by the late Neil Smith Smith

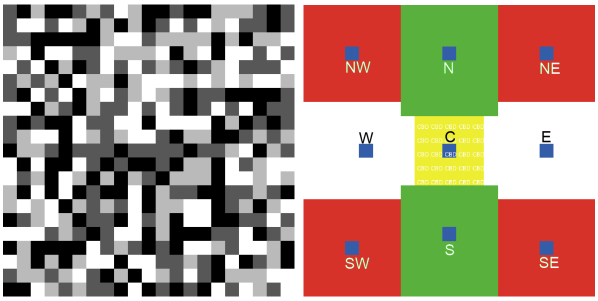
(1987), specifically for the study of the phenomenon of gentrification. In Smith's terms the rent-gap is

> the difference between the actual economic return from the rights to use the land that is captured given the present land use and the maximum economic return that can be captured if the land is put to its highest and best use

The gap between *actual* and *potential* economic return is due to progressive decline in maintenance which properties undergo, together with changes in technologies which render dwellings obsolete. Restoration or rebuilding increases the economic return that a portion of land or a dwelling generates, bringing it to the maximum possible. The locations with the highest difference between *actual* and *potential* economic return will be the ones more likely to attract investment capital and be put to "highest and best use". Although the rent gap theory was proposed to explain a specific phenomenon, gentrification, in our view it can serve as a good conceptualisation of general housing investment behaviour, suitable for a broad exploration and not incompatible with other approaches, including standard economic theory, as pointed out by Bourassa (1993). There have been a number of agent-based models inspired to the rent-gap theory in which the problem of identifying the *highest and best use* has been addressed by employing the notion of *neighbourhood effect*. Here, the highest possible revenue achievable by a given property after redevelopment is bounded by the average (or maximum, in some implementations) price charged in the vicinity of the redeveloped property, so that, irrespective of the state of the property, the maximum obtainable rent or sale price is practically determined by the overall state of the neighbourhood. This intuition embeds the principle that the state of the surroundings strongly affects a property and builds in the model the "*location! location! location!*" mantra that is familiar to property investors. Such interpretation was proposed by Wu (2003) and later O'Sullivan (2002) in his abstract, pure cellular automation model of gentrification. Subsequent work of Diappi and Bolchi (2008); Diappi (2006) concentrated implemented the RGT with a finer grained set of agents (property units, owner-occupiers, landlords, tenants and developers) and modelled investment capital as an exogenous factor. The authors tested different levels of capital and observed variations in the average price of properties and the share of under maintained properties in the city. This model is to date the most complete implementation of the mechanics of the RGT, although it lacks any consideration of the demand-side of the housing market.

III. Abstract model

Our implementation of the rent-gap theory follows the intuition of the aforementioned works, although we try to move away from the purely supply-side approach of Smith and add some demand-side considerations. We model a city in its entirety, divided in multiple districts (figure 1). The entities represented in the model are: (a) individual locations (residential properties), defined by their value and repair state; (b) individual agents that represent households, characterised by an income, mobility propensity and cultural configuration; (c) economic forces, represented in the form of exogenous "capital" level, aiming at profiting from redevelopment/restoration of residential locations.



(a) (b)

Figure 1: The city is composed of 441 residential locations, each with a maintenance level and an economic value, divided in nine neighbourhoods. The colour shade of locations represents maintenance state from white (best condition) to black (worst). Depicted in (a) is the typical model initialisation with random values assigned. The nine neighbourhoods (C, N, NW, NE, E, W, S, SE, SW) have a local centre (b). The district boundaries are "soft", they do not constrain the agents' behaviour. Only when an *allure* emerges (see III-A) a district is represented as a recognisable entity in the agents' residential decision process.

We represent a city as a 21x21 square grid of 441 residential locations (Figure 1a) characterised by a value V and a maintenance level, or repair state, r, grouped in 9 districts (Figure 1b). r is initially set at random in the 0-1 range and V is set at $V = r + 0.15$. Dwellings progressively decay in their condition by a factor $d = 0.0012$ meaning that, if completely unmaintained, a location goes from 1 to 0 in 70 years (1 simulation step = 1 month). The value of the dwelling is assumed to follow the price curve theorised by Smith and shown in figure 2. For the first five years after renovation the price doesn't change, for the subsequent 50 years it is assumed to depreciate by a factor of 0.02 / year. In case of prolonged emptiness of the dwelling (>6 steps) both decay and depreciation factors are increased by 20%.

The model represents investment in housing renovation/redevelopment as the fundamental economic force operating in the city. This is implemented by the "Capital" parameter,K, which represents the maximum number of locations that can be redeveloped in the current economic climate, expressed as a fraction of the total number of residential locations of the city, similarly to the approach proposed in Diappi (2006). For example, $K = 0.02$ means that every 12 steps $441 * 0.02 = 8$ locations are redeveloped. A high level of K represents a large inflow of investment in the housing market which results in more locations being redeveloped and gaining value. The selection of the locations where the

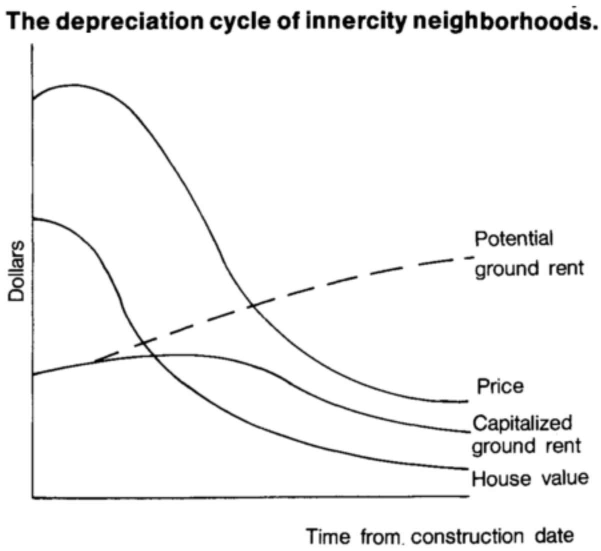


Figure 2: The depreciation cycle in inner city neighbourhoods (Smith, 1987)

investment lands is carried out deterministically, based on the value-gap of a location with the neighbouring properties, in accordance with previous implementations of the RGT. The relevant value gaps are determined in accordance with the *neighbourhood effect*, the principle that the amount of rent or the sale value attainable by a given location is always bounded by the characteristics and the desirability of the area where the property is located. When investment lands on a certain property p we assume that the new value nV after redevelopment will be the neighbourhood average, plus a maximum of 25% (representing a premium for a newly restored property) as in equation 1. In order to model the possible varieties of neighbourhood effect, we also consider a vicinity to be either the Moore neighbourhood of a location or the entire district that the location falls in, *whichever is bearing the highest values* and therefore grants the highest return for an investment.

$$nV_p = 1.25 * max\left(avg(V_{moore}), avg(V_{district})\right) \quad (1)$$

The value gap for location p will be $G_p = nV_p - (V_p + C)$, or 0 if $G_p < 0$. Here C is the cost of removing the present resident if the location is occupied. Once a location is selected for investment its value is set at nV_p and its repair state is set at $r = 0.95$. Table I summarises the variables associated with location.

The "premium for newly restored property" is assumed to be variable and depends on the density of neighbourhood. Investing upon a property in a very densely populated area (i.e. a neighbourhood with more than 80% of locations occupied) will grant the whole 25% premium over the neighbourhood average, as we consider density as a proxy for desirability. Similarly, if the occupancy rate is less than 50%, restoring a property will only attain the neighbourhood average.

Table I: Location variables

Name	Type/Range	Description
r	float, {0,1}	Maintenance state
V	float, {0,1}	Value
G	float, {0,1}	Value-gap: difference with neighbourhood value
d	integer	Distance from the neighbourhood centre
te	integer	Time empty
o	boolean	Occupied?

Table II: Agent variables

Name	Type/Range	Description
m	float, {0,1}	mobility propensity
c	list t=10,v=4	culture: memetic code
i	float, {0,1}	Income level
d	float, {0,1}	Cognitive dissonance level
th	integer	Time here: steps spent in the current location

A. Agent model: cultural exchange and residential mobility

Agents in the model represent individuals or households. They are endowed with an income level, i a mobility propensity m and a numeric string that represents their cultural configuration (table II). The agent's income level is set at random, normalised to the interval $\{0, 1\}$ and represents the highest price that the agent is able to pay for the right of residing in a property. The model, ultimately, implements a pure rental market. The agent's culture is modelled as a n-dimensional multi-value string of *traits*, inspired by Robert Axelrod's classic agent-based model of cultural interaction described in Axelrod (1997) and originally applied to the urban context in Benenson (1998). The string represents an individual's "memetic code", or "cultural code": an array of t cultural traits, each of which can assume v variations, giving rise to v^t possible individual combinations. In our model each trait is susceptible to change under the influence of other agents. Cultural influence is localised: agents that have been neighbours for more than 6 consecutive steps are likely to interact and exchange traits, thus rendering the respective cultural strings more similar. At the same time a cultural "cognitive dissonance" effect is at work, implementing a concept proposed by Portugali (2004, 2011) under the label of *spatial cognitive dissonance*: this is, roughly, the frustration of being surrounded by too many culturally distant agents. Similarity between two agents is the proportion of traits they share:

$$sim_{ab} = \frac{\sum_{i=1}^{t} xor(index(i, agent_a),\, index(i, agent_b))}{t} \quad (2)$$

Agents who spend more than six months surrounded by neighbours with few common traits ($sim < 0.3$) increase their mobility propensity each subsequent time step. The mobility propensity attribute represents the probability that an agent

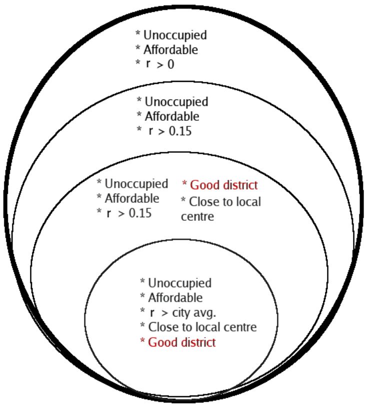


Figure 3: The residential choice process. A dwelling has to be affordable, free and habitable ($r > 0$) for an agent to consider moving into it. If these requirements are met, other characteristics are considered. If any district has developed an allure, agents who are relocating consider whether it suits them, based on a homophily preference. When no dwelling meets the out most requirements the agent leaves the city.

will abandon the currently occupied location in the subsequent time step. This parameter is set at a low level in the beginning of the simulation, drawn from a Poisson distribution centred at $m = 0.0016$, meaning that, on average, agents have a 2% chance of moving each year. Mobility propensity is affected by the conditions of the currently occupied dwelling and the aforementioned cognitive dissonance level. One agent's m is increased as follows: $m_{t+1} = 1.5m_t$ in the following circumstances:

- After 6 consecutive steps (months) in a dwelling with $r < 0.15$ (excessive time is spent in a dwelling in excessively bad condition)
- the cultural dissonance level exceeds a threshold for a period of 6 consecutive steps.

A special circumstance is when the price of the dwelling currently occupied exceeds the agent's income. In such case the agent is automatically put in "*seek new place*" mode. This represents an excessive rent increase, unsustainable by the agent. The process of finding a new location is bounded by the agent's income: a new dwelling has to be affordable ($V \leq i$), in relatively good condition, and as close as possible to the centre of the district which contains it. The selection process is represented in Figure 3. If no affordable and free location is to be found, the agent is forced to leave the city. As figure 3 shows, in certain cases the residential choice process of an agent includes the cultural configuration of the district as a factor. A special district-level variable called *allure* is set when the degree of cultural uniformity within a district exceeds a threshold, thus making the area recognisable for some of the features of its inhabitants. We measure cultural uniformity, u, as the average distance in terms of cultural traits (t) between the x agents residing in a certain neighbourhood.

Table III: District-level variables

Name	Type/range	Description
u	float,{0,1}	Cultural uniformity
a	list	Allure (cultural makeup)

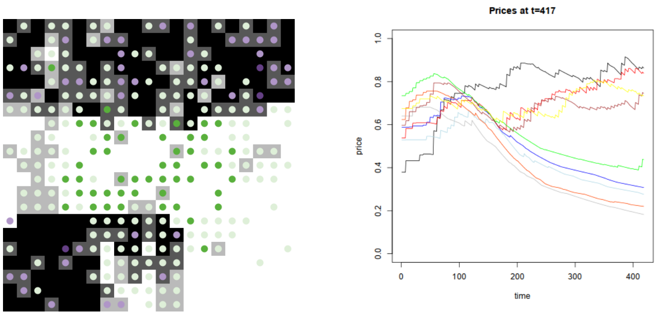
$$pairs = \frac{x(x-1)}{2}$$

$$u = \frac{\sum_{i=1}^{x} \sum_{j=1}^{x-1} sim(agent_i, agent_j)}{t * pairs}$$

The allure of a district is represented as a string of cultural features, similar to that of individuals, where each element of the string is the most common value for that trait in the district population. A district's allure is therefore an emergent feature of the model, which may or may not appear. This reflects the fact that not every neighbourhood has a special connotation visible to agents, but only those with a recognisable population do. The allure attribute can be thought of as the *reputation* of a neighbourhood in the eyes of agents. The attribute is sticky, after its emergence it is updated seldom and doesn't necessarily reflect the current composition of a district, representing the fact that reputation is a nearly permanent feature, difficult to eradicate or to replace Conte and Paolucci (2002), a characteristic that applies to places' as well as humans' reputation. Once a district's allure has emerged, agents include it in their residential decision under a homophily constraint: the agent will seek to move to a district with an allure similar to her culture string.

IV. The economics of housing regeneration

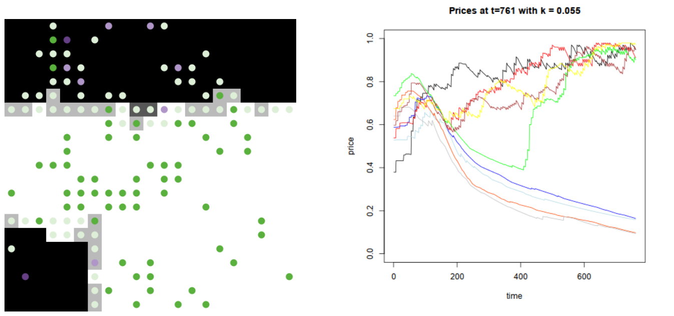
In a previous exploration of the model dynamics (Picascia et al., 2014) we described the spatial dynamics emerging from different levels of capital invested in the city and different methods of computing the rent-gaps. Starting from a random situation such as that in figure 1a, the model highlighted the tendency of capital to spatially concentrate and subsequently "move" in waves around the city in pursuit of the highest profit, producing enduring inequalities in investment and therefore in maintenance state, between areas. Prices across the city reproduced the oscillations theorised by Smith. In cases of low inflow of capital the model showed certain areas of the city suffering permanent under maintenance, because the rent-gaps that develop in such areas are too narrow to guarantee a profit. It is the situation depicted in figure 4, which represents the city at t=417 with k=0.035. That of figure 4 is the typical situation that calls for a urban regeneration programme: an under maintained area with very low property values and ongoing de-population. We take that as a starting point to simulate the regeneration of a run-down area under the theoretical constraints that we assumed.



(a) t=417

(b) Evolution of price levels from t=0 to t=417

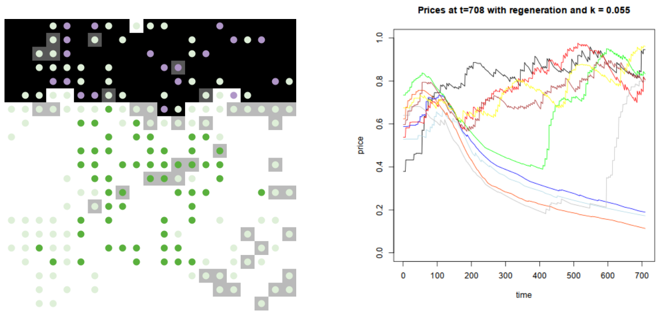
Figure 4: k=0.035. Neighbourhoods C,E,W and SE capture all the investment capital available, achieving high maintenance and high prices. Neighbourhoods N, NE, NW and SW (bottom grey line) see prices and maintenance condition decline and progressive depopulation, as agents leave undermaintained properties.



(a) City situation at t=761

(b) Price levels across the simulation. SW is the grey curve

Figure 6: Capital increase without regeneration t=761 - k=0.055



(a) t=664

(b)

Figure 7: Regeneration, plus capital increase at t=664. In this case we regenerate 9 locations in SW and set k=0.055. The white area spreads to all the declining neighbourhood and prices rise very quickly, as capital has moved in.

Urban regeneration in neoliberal economies

Broadly, urban regeneration is usually described as a set of policies and interventions aimed at the improvement of neglected urban areas, with the intent to revitalise deprived communities, renovate the housing stock, varying the social composition and, ultimately, rendering the area more palatable for private sector investment. Urban regeneration takes often the form of mixed public and private partnerships, a formula known in the UK as "private finance initiative", or PFI, whereby the government invest public money in buying properties in decaying areas from private owners and hand them to developers for very little o no price, for restoration or rebuilding (Blackley and Evans, 2013). The effect is that an area incapable of attracting investment is suddenly *kick-started:* the properties are upgraded, the prices generally increase, the social composition changes and sometimes the effect reverberates on neighbouring areas.

Within our conceptualisation of the city and its economic dynamic, we could conceive publicly funded regeneration programmes as having the ultimate effect of *artificially* raising the prices of near zero-value areas - such as run down parts of a town, or brownfield - outside of the normal private investment mechanic described in section III, with the effect of generating rent-gaps where there are none, in the hope that private capital will move in to close them and, as a consequence, bring a wider area to higher maintenance conditions and economic value. To represent such an intervention in the model we raise the level of maintenance of a decayed area - the 9 contiguous locations with the lowest value and maintenance level of the city - to $r = 0.95$ and bring the price of such area to the city average. In the case in question the locations with the lowest value and maintenance level fall all in neighbourhood SW, the bottom left quadrant of figure 4a.

The effects of such measure vary depending on the level of decline of the affected area. In the example provided, regeneration alone proved insufficient to trigger a renaissance of the area. In most cases, as figure 5 shows, the regenerated area couldn't sustain the new price and maintenance levels and ended in decay. A level of investments that has not guaranteed development across the whole city, in this model, cannot be overturned by simply restoring an area. The reverse is also true. A substantial increase in the capital available is also not enough to rescue a neighbourhood that has reached the lowest level of price and maintenance, because if the area is not capable to attain lucrative rent-gaps, the higher capital level will have the effect of ending up elsewhere in the city, raising the prices there. Figure 6 shows this circumstance. Capital has been raised to k=0.055 at t=418, the effect is prices going up in the already well developed districts of the city and falling further in SW. However, we found that the combined influx of capital and regeneration has the effect of bringing a completely declined district back into the investment cycles in most runs (figure 7).

(a) t=418 - The 9 location at the top of the SW quadrant become white (well maintained)

(b) t=692 - The regeneration hasn't had a beneficial effect on the rest of the SW area, which stayed in bad repair (black) and the locations restored are declining again (they are now grey).

(c) Price levels in the 9 neighbourhoods across the simulation. SW is the grey curve. An increase is visible at the time of the regeneration, but in the longer term the prices continue their decline

Figure 5: Regeneration without capital increase - Increasing price and maintenance level for 9 locations in neighbourhood SW at t=417. This intervention has a marginal effect, limited to the interested area, nine locations at the top of the SW quadrant, which turn white (=well maintained) and attract new residents, but decline in the long term.

V. Modelling Pendleton(One), Salford

PendletonOne (http://www.pendletonone.co.uk) is a vast scale regeneration project ongoing in the Pendleton area of Salford, in Greater Manchester, England. Pendleton lies 2 miles west of Manchester city centre, has a population of 18,000 and is one of the areas with the highest indices deprivation in the country. The area was entirely built in the 1960s and 70s replacing hundreds of streets of Victorian terraced housing in the extensive slum clearances that wiped out unsuitable dwellings. Today's architecture sees a variety of heights, with imposing tower blocks sitting next to maisonettes and terraced homes. Pendleton has attracted a bad reputation and, despite the proximity to MediaCity and Salford Quays, the area failed to attract the necessary investments and sits in bad conditions. The £400m redevelopment plans under way involve, again, like in the 1960s, extensive demolitions which will change again the face of the area, along with refurbishment of existing dwellings and building of new housing. The new builds expected to complete by next year range from a price of £115,000 to £155,000. What could be the effect of such an intervention in 10 years time? Will the price levels substantially increase and sustain the new level? What will be the social composition of the area?

A. *GIS model and data sources*

We constructed a GIS model of the whole Manchester urban area, embedding vector data on house prices, average household income, ethnicity and religion of the inhabitants employing data gathered from the various sources shown in table IV. The data were integrated in the shapefiles of the Manchester area provided by the Ordinance Survey, which were then imported in Netlogo Wilensky (1999) via the GIS extension, generating the initial situation shown in figure 8. The modelled city is composed of 5,583 locations, all of which assumed to be residential, endowed with a maintenance state and a price and grouped in 44 districts. The study area interested by the PendletonOne regeneration is marked in green and consists of 20 locations. The initial population is of 4300 agents with an income derived from the census and a cultural string of 10 dimensions, the first two of which map ethnicity and religion derived from the 2011 census. The first two features are fixed and the remaining eight are susceptible to change as a consequence of interaction with neighbours, as in the abstract model. We also built a reserve population matching the ethnic composition and income structure of the Uk at large in order to simulate a plausible immigrant population. Population growth is set at 0.7% per year, as in the actual Manchester area. For the time being we assume a maximum of one agent per location, therefore assuming equal density for all the areas. Another crucial assumption is that we consider a location affordable if the price is less or equal to 6 times the annual income of an agent. This parameter will have to be explored further, especially in the light of the government encouraging the substantial expansion of credit to new homeowners.

B. *Results*

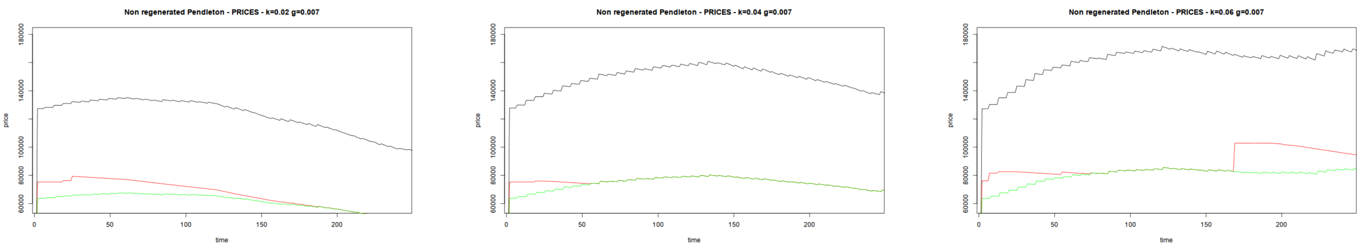
We run the model described in section IV on the Manchester urban area. Being able to represent the whole city is crucial to model the assumptions of the RGT: capital will flow where it is profitable, and in our model, as in reality, Pendleton is in competition with the rest of Manchester to attract investment. We modelled the regeneration process by replacing 50% of the existing dwellings with restored housing (i.e. housing with condition m = 0.95) and a price range determined stochastically in the range prospected by the developer (115,000 - 155,000 GBP). The regeneration happens at time step 24 and we monitored the evolution of prices for the subsequent 20 years (480 time steps) in the PendletonOne area and in the surrounding locations in radius 10. We compare the evolution

Table IV: Data sources. LSOA (lower level super output area) and MSOA (medium level super output area) refer to boundaries extent in the UK census.

Datum	Variable	Level	Source
House prices	V	Postcode	Zoopla.Com (retrieved October 2013)
House condition	r	LSOA	2011 Census - Living environment deprivation
Ethnicity	item 0 in {culture}	LSOA	2011 Census
Religion	item 1 in {culture}	LSOA	2011 Census
Share of social housing		LSOA	2011 Census - Tenure
Income	i	MSOA	2007 Estimates based on 2001 census

(a) (b)

Figure 8: The Manchester urban area represented in Netlogo. The color of the patches represent their maintenance conditions, as in the abstract model. Red patches represent social housing areas. The circles in (a) represent households, coloured according to their income levels: violet represents a below average income, green above average. The green area in (b) is the study area of PendletonOne



(a) k=0.02 (b) k=0.04 (c) k=0.06

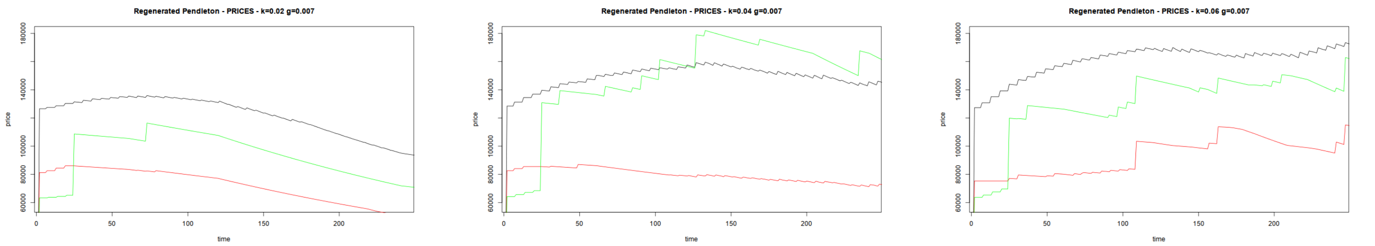
Figure 9: Median price in Manchester as a whole (black), PendletonOne (green), and PendletonOne proximity (red) in case of no regeneration taking place for three levels of capital. In absence of regeneration the amount of capital that flows into the city is irrelevant to Pendleton and its surrounding area. The profitability of these parts is too low, compared to other parts of the city, to attract any investment.

of the price dynamics in the case of regeneration taking place and no regeneration happening at all and we test three levels of capital (0.2, 0.4 and 0.6).

As figure 9 shows, if no regeneration were to happen, prices in Pendleton would decline as investment would never reach the area for any of the levels of capital tested. In the case of k=0.6, after about 13 years prices would rise in the area surrounding Pendleton, sign that for that level of investment, it would take more than 10 years before investing around Pendleton will be profitable. In figure 10 we see the effects of regeneration for the same three levels of capital. In this case the outcomes differ according to the level of capital flowing into the city.

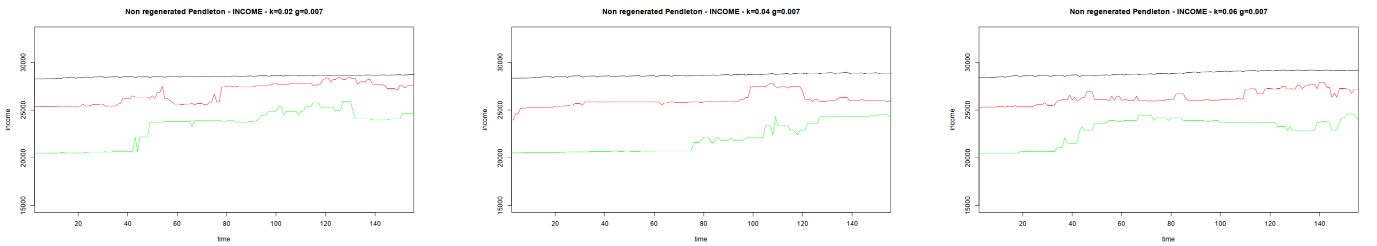
In figure 11 we take a look at the income levels of the study area. In the regeneration case, gentrification can be spotted, as the higher prices drive out some of the original population that has the lowest median income in Greater Manchester.

It is worth noting that, while the 6x limit may be too restrictive or unrealistic, gentrification is often a byproduct of state sponsored regeneration programmes, especially in the

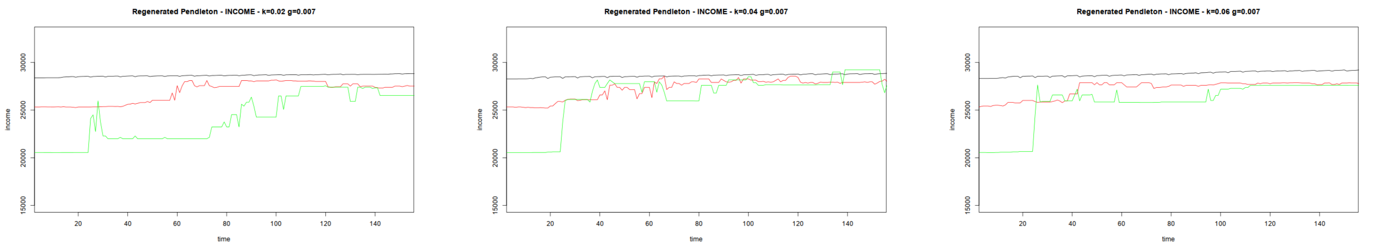


(a) k=0.02 (b) k=0.04 (c) k=0.06

Figure 10: Median price in Manchester (black), PendletonOne (green), and PendletonOne proximity (red) for three levels of capital, with regeneration taking place at step 24. At k=0.02 all prices decline and the regeneration has no long term effect. A level of k=0.04 grants higher prices for a longer term, but has no effect on the area around Pendleton; k=0.06 sustains high prices in PendletonOne and triggers investment in the surrounding area as well.



(a) (b) (c)



(d) (e) (f)

Figure 11: Median income in Manchester, PendletonOne and proximal area for three levels of capital in case of no regeneration taking place (a-c) and with regeneration taking place (d-f)

UK and in case of extensive demolition, as in Pendleton. The demolished properties are generally forcibly bought from the owners via a legal instrument called Compulsory Purchase Order for a price set by the local authority. Once the regeneration is completed, previous owners may find that no property is available in the local area for the amount they received and therefore, in order to stay in the neighbourhood, have to take up debt and many choose to move elsewhere. It is the case of many regenerations in London, notably the last Elephant and Castle, but there is evidence that this phenomenon is happening in Pendleton as well. As Allen (2008) points out, this phenomenon amounts to a form of government-driven gentrification, when not social cleansing.

VI. Conclusions, limitations, future work

The work presented here is still in progress and presents a number of obvious rough spots: the representation of the housing market is still extremely stylised, most of the model analysis and exploration is still underway - the ultimate purpose for which the model was developed is to investigate the effect of the change in prices triggered by the regeneration on the level of cultural diversity of the study area.

The role of land use change, particularly crucial in postindustrial cities, is also overlooked, not to name the lack of a systematic validation of the results, which is challenging in absence of adequately detailed historic data. Also the notion of "capital" expressed as the fraction of locations invested upon is problematic. The levels employed in the case study were derived from the exploration of the abstract model and not empirically tested (although we tend to believe that they are not completely devoid of relationship with the reality of Manchester economy: house building has been increasing the dwelling stock by 1.5%/year for all the the last decade, adding to that an estimate on restoration of existing housing easily takes us to the values of 0.02 - 0.06 that we have been testing in the model).

Nonetheless, this work serves as a demonstration of the possibility of embedding theory and data in a detailed and descriptive agent-based model, in an effort to understand and possibly predict the mechanics and outcomes of certain urban dynamics.

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Beyond Simulations: Serious Games for Training Interpersonal Skills in Law Enforcement

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***Abstract*—Serious games can be used to improve people's social awareness by letting them experience difficult social situations and learn from these experiences. However, we assert that, when moving beyond the strict realism that social simulations offer, techniques from role play may be used that offer more possibilities for feedback and reflection. We discuss the design of two such serious games for interpersonal skills training in the domain of law enforcement. These games feature intelligent virtual agents with which trainees have to interact across different scenarios to improve their social awareness. By interacting with the virtual agents, trainees experience how their behaviour influences the course of the intervention and its outcomes. We discuss how we intend to improve the learning experience in these serious games by including meta-techniques from role play. We close by describing the current and future implementations of our serious games.**

***Index Terms*—Social simulation, serious games, role playing games, meta-techniques.**

I. Introduction

In both interviews and street interventions, police officers strive to get witnesses, suspects and civilians to cooperate. Regrettably, people are not always open to this. Therefore, police officers are taught how to get them to assume a more receptive stance. Our long-term goal is the development of serious game prototypes in collaboration with the Dutch police so that these games assist in the training curriculum of police trainees by letting them practice with such interactions. The first of these is *POINTER* (POlice INTERview game), in which trainees train their interviewing skills with crime suspects; the second is *LOITER* (LOItering Teenagers, an Emergent Role-play), which lets trainees enact street interventions with loitering juveniles.

In this paper, we describe the *status quo* of our research efforts toward these serious games. Of prime importance to the attainment of social awareness is insight into the thought processes that drive people. Therefore, we are building a cognitive model based on a corpus of police interviews to determine the factors underlying people's behaviour (described in Section III). We use this model to inform the behaviour of the virtual agents that enact the roles of suspects and juveniles in our games. In Section IV, we discuss the relations between social simulations and serious games. We explain how we sacrifice the realism usually found in social simulations in the design of POINTER and LOITER to provide more explicit feedback and moments of reflection. We elaborate on the work involved in implementing these games in more detail in Section V. We wrap up by discussing future research directions in Section VI.

II. Related Work

There are several research projects in which social interaction between human and virtual agents has been researched for educational purposes and serious games. The negotiation training systems of [1] revolve around US military training for peace missions in the Middle-East. Their *Stability and Support Operations* system features extensive modelling of the emotions of virtual characters, letting them appraise and cope with user actions. An application called *FearNot!* was designed as a virtual drama for anti-bullying education [2]. This system is also based on virtual characters that can appraise and cope with user actions, but adopts an unscripted emergent narrative approach to let users have freedom of choice. Focusing on 'bad news' conversations between employees and managers, the serious game *deLearyous* models the interpersonal relations between the two interaction parties [3]. In deLearyous, virtual characters base their behaviour on their attitude towards the user. As a result, users (the managers) are required to learn how to behave to not let the virtual employees erupt in tears or anger. *JUST-TALK* is a prototype training application designed to help police officers interact with mentally ill people [4]. As in the previous systems, the focus of JUST-TALK is on the realism of the simulation. Unlike our games, the above systems do not directly address the importance of feedback and moments of reflection to stimulate learning.

III. Towards a Cognitive Model for Social Interaction

We strive to use theories and concepts from social psychology to inform the behaviour of our agents in order to create a cognitive model that is both believable and explainable. Using a data-driven approach, we have investigated which theories and concepts are relevant to describe the interaction in a police interview [5]. Using an annotated corpus of enacted police interviews (from actual police training) we were able to link theories and concepts to the observed interactions. We found that we could describe the majority of the interactions between police officers and suspects in concepts from three theories, namely those of *interpersonal stance*, *face*, and *rapport* [6]–[8]. The theory of interpersonal stance describes how people assume a certain stance toward the other when they interact. Leary uses the orthogonal dimensions of dominance and togetherness to explain how different combinations of these dimensions lead to stances and how people are influenced by stances of others [6]. The notion of face boils down to the needs for approval and autonomy a person has. For example, when a suspect is questioned about his whereabouts on a particular day, this may be unwelcome to the suspect, because he feels that his freedom is being restricted by the police officer [7]. Rapport revolves around the bond two people share: when they are attentive and coordinated to each other, they will feel as if they are 'in sync' [8]. To be able to describe all interactions in the corpus, we used the meta-concepts of *information* and *strategy* to cover actions related to lying or withholding information, and using explicit strategies.

Currently, we are building and evaluating a computational model that relates the mentioned theories to each other. We carried out an evaluation experiment in which we let participants interact with our model in an abstract way. We explained that they would interact with one of three virtual suspect *personas* of which we gave descriptions, and that their goal was to discover which of the three suspects communicated with them. They were able to interact with a virtual suspect in a turn-based fashion. First, participants indicated what kind of utterance they wished to perform by setting parameters related to the theories such as stance, rapport, and type of question. Then, we let the model interpret this combination of parameters by calculating how that utterance would influence the mental state of the persona. This persona subsequently responded with a set of parameters at the same level of abstraction as the input of the participants. Then, the participants had to interpret these parameters and create a new utterance based on this interpretation. This continued until the participants wished to guess which persona they were interacting with. Preliminary results indicate that the majority of participants correctly determined their interaction partners.

IV. Design Possibilities for Serious Games

Social simulations try to offer strict representations of situations they are intended to model. In their current training curriculum, police trainees practice with professional actors to simulate and experience possible scenarios. We regard such simulations as a form of role play and see several possibilities for the design of serious games based on role playing games. We believe that the design of serious games only depends to certain degree on the domain for which they are intended. The learning goals are the most important factor when designing serious games and must first be determined. In our case, the overarching learning goal is that police officers should have social awareness: they should be able to explain how their behaviour influences that of others and *vice versa*. The computational model we described in the previous section should help trainees understand why people behave as they do. It is through our serious games that trainees then learn how this model functions. Ultimately, in order to secure and strengthen the knowledge they have gained from an experience with a simulation or a game, it is vital that trainees reflect on their behaviour [9]. Of course, experiential learning can be achieved in simulations, yet simulations by themselves lack methods for explicit feedback and reflection. Police officers in training already use after-action-reviews to discuss how interactions played out, but for our serious game we plan to take the idea of role play a step further.

A. Beyond Simulation, Towards Learning

We assert that the extent to which a serious game reflects the situations from the domain can be varied. In other words, the realisation of the role play can be more loose or imaginary than strict as in a simulation [10]. This means that the created scenarios may be less realistic—even metaphoric. Nonetheless, the important point is that the model underlying the interaction with the game should remain the same. Tipping the scales towards either fantasy or realism in the design of serious games has advantages as well as drawbacks in both cases. These advantages and drawbacks relate to the capability to reflect on the experience and possible inhibition in the behaviour of players. To let players reflect on what has happened in the game, they need to transfer the knowledge gained from their experience to knowledge related to the real world. When opting for realism in a serious game, the gap that needs to be bridged between the simulated world and the real world to transfer the attained knowledge is smaller than when the simulated world less closely represents the real world. On the other hand, this distance from the real world is at the same time an advantage of less realistic scenarios. This is the case because players are more free to do what they want—not because of the possibly larger amount of actions they can perform in the game, but because they may be less inhibited by the design of the system. For example, when police trainees practice using a 'strict' simulation, as in the enacted interviews from the previous section, they will feel the need to do everything correctly. Serious games allow for experimentation as they may put less pressure to perform on the trainees. The crux lies in the actual design of serious games so that they still provide a challenge and convey their learning goals. To assist us in the design process, we have created a hierarchy of learning goals that our games should support [11], based on Bloom's revised Taxonomy of Learning Objectives [12]. Below, we explain how we intend to use two techniques to support the attainment of these learning goals in our serious games.

B. Techniques for Improving Learning in Serious Games

In our serious games, we do not opt for maximum realism or fantasy, but for a balance between the two. To do so, we take inspiration from techniques used in improvisational theatre (improv) and live action role play (larp) [10], [13]. This is not merely an attempt to 'gamify' a social simulation by adding some simple game mechanics to the whole. Instead, we combine techniques from various fields together during the design process of POINTER and LOITER, with feedback from the Dutch police.

We take the point of view that when a simulation or role play is carried out, the people involved in these events have two different roles: that of the actor, who has knowledge about the simulation, and that of the character, who is being simulated by the actor. Both in improv and role plays, this distinction between *in-character* (IC) and *out-of-character* (OOC) roles can be utilized by the players. For example, a player may know, OOC, that another character has deceived his character—but this player's character may not know. The player can then use this OOC knowledge to steer the play IC in a certain direction.

In the design of our serious games, we expand the distinction between in-character and out-of-character by looking at so-called *meta-techniques* used in larp [11]. These are techniques with which players can communicate OOC information—information that would normally not be available to them IC. Effectively, these techniques impinge upon the otherwise simulated nature of larp as they can not take place in-character. An examples of such a meta-technique is the *inner voice*, which lets players speak out their IC thoughts so that the other players get insight into how these players feel. *Act breaks* can serve as intermissions during a larp in which the IC play is paused and the players discuss OOC what has happened and what may happen in the play. With the help of such meta-techniques, players of a larp can 'deepen' a larp by exploring the feelings and motivations of their characters.

As explained above, reflection and feedback on their actions constitute a large part of the learning process for trainees. Therefore, when police trainees practice their skills with actors, their experience is evaluated during an after-action review. We choose a similar approach in our serious games by implementing meta-techniques that offer moments for reflection and feedback during gameplay. In our games, when players interact with virtual characters, we will enable these characters to express their thoughts to players in the form of comic-like 'thought bubbles', alike to the inner voice technique. Such information would assist players in determining the attitude and feelings of characters as a supplement to the signals they read from the nonverbal behaviour and utterances of characters. We are also exploring how act breaks can be implemented. For example, at set points during gameplay, the interaction can be paused to give players and characters the opportunity to ask each other questions. These questions include asking the reasons for certain actions or inquiring about the feelings of either the characters or players at specific points in the interaction.

Key in implementing these techniques is the decision when they should be used. As in all games, there needs to be a balance between the challenge of the game and the skill level of the player. Therefore, we propose to monitor the progress of players during the game and provide them with help in the form of the above meta-techniques when they seem not to be up to the challenge. For example, when players keep acting aggressively in an interaction with the effect being that a virtual character does not cooperate, this character may use a thought bubble to give feedback on why the interaction is unsuccessful. Alternatively, an act break may be used to have a more in-depth discussion as to what went wrong. Both techniques may also be used together to reinforce each other. For example, if a character shows a thought bubble during gameplay to provide feedback, it can explain its thoughts in more detail during a subsequent act break.

Aside from providing feedback and reflection, we are investigating ways to let the virtual characters adapt their behaviour to help players achieve their learning goals. This adaptation reflects the methods used in improv and role play as well: the virtual characters are able to adapt their behaviour to the learning goals of players. For example, if it turns out that a player has difficulties to negotiate with withdrawn people, the virtual characters can choose to behave more withdrawn, providing the player with the possibility to gain more experience with such interactions.

V. Implementations

As said above, we are designing two serious game prototypes: POINTER for interview training and LOITER for street intervention training for police officers. Until now, we have largely focused on the conceptual and technical aspects underlying these systems. Currently, we are exploring how to implement our games. The balance between realism and fantasy plays an important role in visualising the interactions. We do not choose a highly realistic appearance for our games, as this will stand at odds with the meta-techniques we wish to use. Additionally, it may evoke false expectations when players expect behaviour from very realistic looking characters that may be more complex than our cognitive model supports. Therefore, we opt to keep things simple in terms of graphical quality, but we do investigate the effects of different types of visualisations. Using AGENT, the Awareness Game Environment for Natural Training [14], we are able to let players play the same scenario with different user interfaces. The two types of interfaces we are developing have different fidelities. One is a 2D visualisation with a comic-like style and interaction through button commands, see Fig. 1. The other is a 3D visualisation with higher fidelity, see Fig 2. In an improved version, this visualisation will offer multi-modal input to attempt to stimulate the feeling of presence in the virtual world. While providing a more realistic environment in terms of graphical quality, the 3D environment is not intended to feature strictly realistic character behaviour.

To experiment with different game mechanics and concepts that we can incorporate in POINTER and LOITER, a board game called *Sequacious* was created, see Fig. 3. This was done to give an indication that a very playful system can already give rise to reflection and can be used to improve the players' awareness of social interaction. In this game, players

Fig. 1. The prototype 2D environment for LOITER.

Fig. 2. A prototype 3D environment for LOITER.

(police officers in training) can experience and experiment with different ways of interacting with loitering juveniles. This can be done through letting them assume either of two roles in the game: the role that they normally play, namely that of a police officer, or the role of the group of juveniles. The game is played on a gridded board with the juveniles trying to form groups and grow in numbers and the police officer having the goal of keeping the groups of loitering juveniles as small as possible by dispersing the juveniles and stopping them from taking over control of the board. Together with more game mechanics that are related to the needs of both parties, Sequacious lets players explore this conflict. After play sessions, we observed that players were enthusiastic about the game and discussed tactics for winning the game by either side and how the gameplay could relate to the real world.

VI. Conclusions and Future Work

The approach we take in designing POINTER and LOITER, our serious games for interpersonal skills training in the domain of law enforcement, expands the possibilities of social simulation by infusing it with techniques from the fields of improv and role play. Our next step is to implement and evaluate our ideas in more detail. The serious games will not replace the teachers of the Dutch police, but serve as addenda to the training curriculum. Through evaluation and further cooperation with the Dutch police, we seek to fit our games in their curriculum and find the correct balance between fantasy and realism so that they will be accepted by the trainees. Additionally, we wish to iteratively improve the

Fig. 3. The board game Sequacious with a juvenile pawn on the far left and a police pawn next to it.

cognitive model we have created by letting players provide feedback on the virtual characters in the system themselves. Lastly, we hope to encourage other researchers to look beyond simulations by investigating other ways to design educational systems, such as serious games and techniques from the arts.

Acknowledgements

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Modelling cooperation in Bali irrigation

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***Abstract*— In social-ecological systems research the use of natural resources is typically studied on either a conceptual (theory) or a detailed level (case studies). We use agent-based modelling to take an approach that is situated in between. With this we aim to generate understanding that goes beyond the case, while being sensitive to contextual aspects of a given social dilemma situation. Our model combines a theoretical model of norm-driven cooperation with a case-specific model of an irrigation dilemma. The theoretical model is contextualised by using case empirics to investigate the role of cooperation for the performance of a rice growing community. Particularly, for this conference, we focus on the effect of introducing ecological complexity by embedding empirical based resource dynamics.**

I. Introduction

The behaviour of humans affects and is affected by the natural environment and other living beings. Human behaviour strongly shapes ecosystems while at the same time being dependent on them. This makes human-environment systems tightly coupled social-ecological systems (SES). SES studies typically focus on real world problems, such as sustainable use of natural resources with a complex adaptive systems lens. However, much SES research is often based on either simple abstract models or complex, rich descriptive case studies. This limits our capacity to develop solutions to real world problems that take both complexity and context of a SES into account while being applicable to a wider range of SES. There is thus a need to generate understanding that taps from both theories and case studies. Particularly, to identify what level of complexity and what contextual factors are relevant.

We apply agent-based modelling (ABM) to connect theoretical explanations with real world problem situations in complex SES to respond to the need for context sensitive approaches [1]. We require our model 1) to address a challenge that is common across a wide range of SES, 2) to incorporate relevant theoretical explanations and 3) to include relevant contextual variables, without losing the ability to systematically explore the challenge [2].

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In this talk we will present this approach using an agent-based model that combines a theoretical model of norm-driven cooperation (CP-norm) [3] with a model of an irrigation dilemma that captures the main features of irrigation in Bali [4], where farmers (self) manage their water resources to grow rice while avoiding pest outbreaks by synchronising their cropping schedules [5]. We contextualise the theoretical model using Bali empirics [5] to investigate the role of cooperation for the performance of one irrigation community. We do so by slowly adding relevant contextual details, such as aspects of the natural resource dynamics or social interactions to the theoretical model. Particularly, for this conference, we focus on the effect of introducing ecological complexity by embedding empirical based resource dynamics from the Lansing-Kremer model [4] reproduced by Janssen [6] in CP-norm.

II. Background

A. SES challenges exemplified by the Bali case

The Bali case was selected because it represents a classical SES challenge, namely a social dilemma that has already been intensively studied empirically [5]. The Bali case represents a case of successful resource management. It is in that sense an example of a solution to avoid a 'tragedy of the commons', through a self-organised process that restrains actors from taking the amount of water that would be (short-term) optimal for an individual, but harmful for the collective [7]. However, despite its successes on watershed level, on the level of individual farmer communities (subaks) differences in performance can be observed in situations with similar social and ecological conditions [8]. Our hypothesis is that the ability to engage in collective action is a major factor explaining these differences [2]. The combination of available empirical knowledge and an open question exploring the circumstances for successful self-organisation allows us to develop and test our approach to develop context sensitive (not too generic, not too specific) understanding of SES social dilemmas.

B. *Theory of cooperation & the CP-norm model*

The capacity for collective action, particularly with respect to sticking to a chosen cropping plan (cooperation), has been identified as a possible factor explaining differences in performance of communities in Bali. Cooperation research studies how people decide to act cooperative or not and how this arises/adapts over time, i.e., evolution of cooperation, see [9]-[13] for an overview. We are particularly interested in theories identify mechanisms that can sustain cooperation in a social dilemma (see e.g. [14]). .

CP-norm is an agent-based implementation of an evolutionary game theoretic model [15] that explores the conditions under which a social norm enforced through ostracism (social punishment driven by disapproval) facilitates sustainable use of a common-pool resource, see Fig. 1. Cooperator agents need to restrain from selfish profit maximization to achieve socially optimal resource extraction levels. Defectors that extract higher levels are punished if the frequency of cooperators is large enough, hence when the community has the social capital to act against defectors. The strength of punishment depends on the level of cooperation and the degree of norm violation. Under certain conditions full cooperation, full defection or a mixed equilibrium can be sustained.

We have selected this theoretical model because it includes the mechanisms that we consider most relevant for explaining the capacity of Bali farmers to collectively adapt and manage their resources. Ostracism or social disapproval has been hypothesised as an important mechanism facilitating collective action in Balinese communities [16]. Additionally, graduated sanctioning has been identified as an important variable for self-organisation in empirical research on common pool resources [17], [18].

III. A MODEL OF COOPERATION IN BALI IRRIGATION (COBA-I)

The agent-based model of cooperation in Bali irrigation (COBA-I) aims to capture relevant contextual details in the Bali case while addressing a social dilemma.

In COBA-I we adopt the social mechanism for cooperation of the CP-norm model and gradually introduce complexity. In other words, we gradually introduce more details of both the social and ecological contexts, using the descriptive knowledge of the Bali context [5] and elements of the Bali3/Kremer-Lansing model of Bali irrigation [4], [6]. As a first step we test the role of the social mechanisms of cooperation within an environmental context that is based on the ecology of Bali. The ecological dynamics are represented by the water flow variability and pestdynamics. Water availability is affected by rainfall-scenarios as well as the characteristics of the landscape (elevation, groundwater flow). Pest dynamics that affect rice harvest depend on the level of synchronisation among the farmers (having crops and fallow periods at the same time).

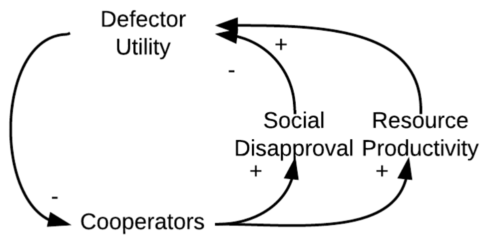

Fig. 1. The main feedback mechanisms of the CP-norm model. The inner positive social feedback loop leads to an increase in cooperators, while the outer negative ecological feedback loop leads to an increase in defectors.

The main elements of the model are the resource (water), the agents (farmers) and the world they live in (Balinese irrigation context). The group of farmers represents one farmer community, i.e., Subak. Farmers can choose between one of two behavioral strategies: the cooperative strategy where they stick to the agreed upon cropping plan of the community and the non-cooperative strategy where they choose a different cropping plan with an additional crop rotation. Fig. 2 describes the main processes of the COBA model. *Each month* (= time step) the farmers have a water demand determined by the needs of the crop (rice) depending on where they are in their cropping plan. The water availability is determined by rainfall (scenario-based) and groundwater flow (elevation based). Water is either extracted or flowing out downstream. The rice crop grows according to the amount of water each farmer can extract. *Once a year* (every 12 time steps) two farmers meet randomly and evaluate their behavioural strategy, i.e. cropping plan, by comparing their success with that of the other. The success or utility of each farmer is calculated based on the returns from its rice harvest and the incurred costs. Rice harvest is a function of water availability, i.e. water scarcity leads to less rice to harvest. Costs may arise when a farmer is ostracised (sanctioned) because it deviates from the agreed cropping plan, i.e. followed the non-cooperative behavioural strategy. Sanctioning, however, only occurs if the group of agents following a cooperative strategy is large enough (social capital) to collectively sanction the farmers that deviate from the agreed cropping plan. Costs can also arise due to the outbreak of pests. Pests can only be 'managed when fallow periods are synchronised. The non-cooperative strategy farmers can

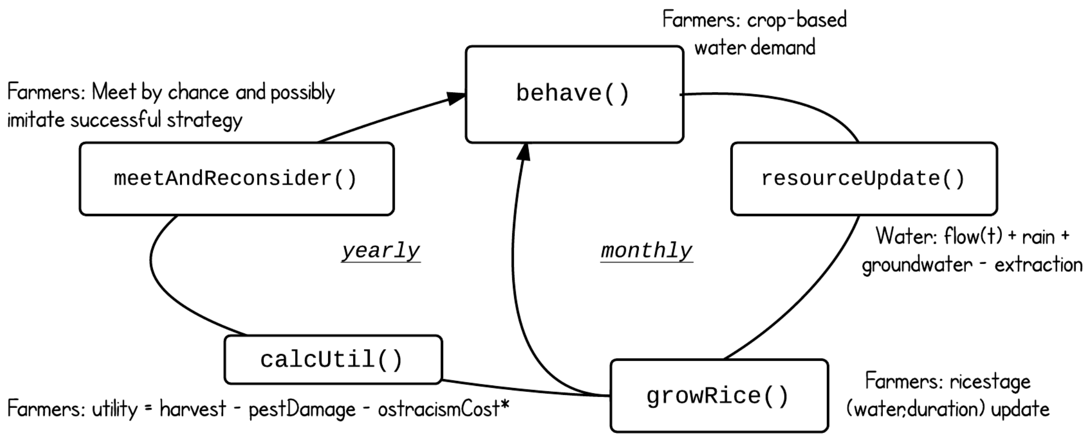

Fig. 2. Proces diagramme of the COBA-I model. Every time step (a month) farmers behave (take out water), resource is updated and rice grows. Every 12 time-steps (a year) each farmer calculates its harvest and has a chance to meet and update its behaviour strategy.

choose favors pest growth that affects every agent (regardless of their strategy).

When introducing the Bali rainfall patterns we expect that the model will still show the 3 outcomes of the theoretical model (full-cooperation, full-defection and a mixed equilibrium), however given the fluctuations of the system state regions will differ. The model is currently in its verification stage. This includes tests of the reproduction of the resource dynamics from the Bali3 model as well as the cooperation mechanisms of the contextualised CP-norm. The social mechanisms are of particular interest. Fig 1 illustrates some first explorations of these interactions. The cooperation behaviour strategy becomes dominant (blue line on top) in the community over time when the initial proportion of cooperative strategies in the community is high. The rainfall scenario, however, seems to effect the speed at which a dominant cooperative strategy converges. Particularly, the presence of waterstress (low rainfall scenario) increases the convergence to a cooperative strategy (compare Fig 1a and 1b). This is consistent with the unpublished findings of CP-norm [3]. Under water stress the costs of non-cooperation weigh in stronger, as returns from harvesting are reduced.

Although these are just initial explorations, they are a sneak preview for our further explorations. These explorations will focus on reflecting on the cooperation mechanism in CP-norn by contextualising. For instance, CP-norm shows overall high dominance of the non-cooperative strategy. Particularly, when relaxing the strength of the ostracism, with low resource variability CP-norm converges to non-cooperative behavioural strategies. In general, COBA-I behaviour is consistent with CP-norm by reproducing the importance of the size of the initial proportion of a particular behaviour strategy (affecting the ability to ostracise) as well as the response to low levels of resource affecting all and particularly taking away the advantage of the non-cooperative strategy. We were able to reproduce the community patterns of all cooperative strategies, all non-cooperative strategies and a mixed equilibrium, however the regions seem to differ. We will explore under what conditions cooperation arises in COBA-I,compare the difference with the conditions of CP-norm and reflect on the role of context in explaining these differences between the theoretical model (cp-norm) and the contextualised model (COBA-I).

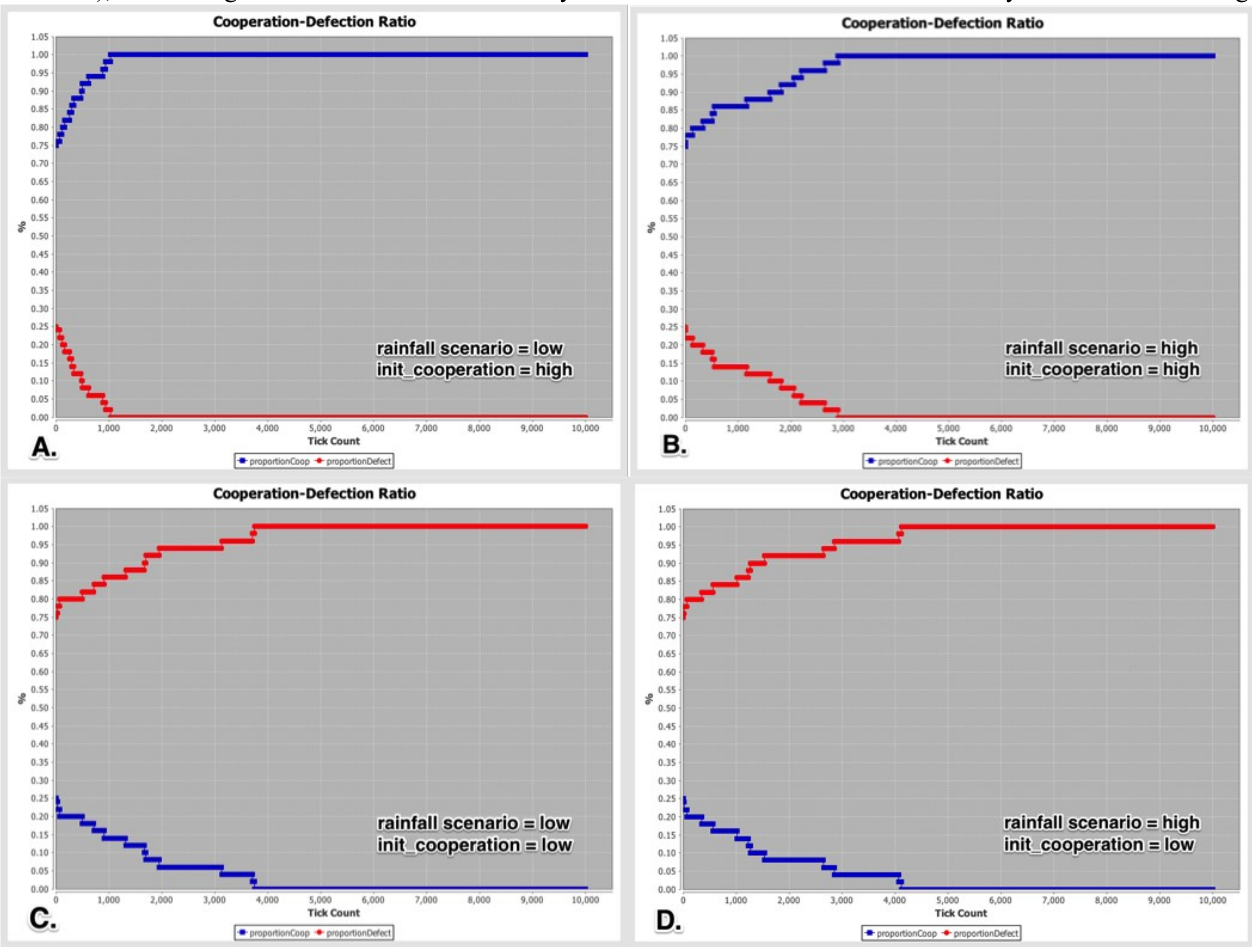

Fig 3. First explorations of the COBA-I model varying the rainfall_scenario {low, high} and the initial amount of farmers with a cooperative behaviour strategy {low, high}.

IV. Conclusion

Our presentation at the conference aims at demonstrating our approach of developing tools to understand the dynamics of coupled social-ecological systems at a level of complexity that does justice to real world contexts while still allowing us to draw some more general conclusions. The iteration between abstract, general models and a given context raises a lot of food for thought in reflecting on the consequences of model design choices.

The process of contextualising CP-norm triggers both theoretical and empirical questions. On the theoretical side exploring the effect the increased complexity of the resource dynamics has on CP-norm in itself, e.g. it might explore situations that were outside of the scope of the theoretical context. The other way around, the choices we make in for instance operationalising cooperation raise empirical questions. For instance, what is 'cooperation' in the case? It can refer to different types of processes in groups, can be studied on many levels. Which aspect of cooperation in resource use is most relevant for explaining performance differences in the Bali context? For instance, in the Balinese context cooperation involves more than just sticking to a particular cropping plan. It also involves attending weekly subak meetings, perform rituals, maintain canals etc. [5]. Furthermore, cooperation in our model only refers to the community level. In future it will be important to investigate different (possibly conflicting) levels of cooperation (within community, between communities and system level).

Our immediate next steps involve more systematic sensitivity analysis and experiments to understand COBA-I. From there we will continue with gradually increasing the richness of the context so that we can explore what level of complexity is needed to explain the observed differences in performance between communities. Particularly, we will focus on including more realism on the social side by for instance, introducing social structure. This will directly affect who the farmer is more likely to meet and thereby the reconsideration of the behaviour strategy will be based on the social vicinity.

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Modelling the impact of beliefs and communication on attitude dynamics: a cognitive agent-based approach

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***Abstract*—In the context of military training for stabilization operation of a crisis zone with civilian population, understanding the formation of attitude and its dynamics is a key issue. This paper presents a multi-agent model for simulating attitude formation and change based on individual's perception of information and its diffusion through communication. We represent the attitude as object-evaluation associations of varying strength proposed by Fazio [1]. Individuals observe military operations. They exchange and revise beliefs about social objects depending on multiple criteria deriving from social psychology theories. They compute their attitude value based on analytic assessment of these beliefs. We illustrate, through several simulation experiments, the role of communication on attitude dynamics.**

***Index Terms*—multi-agent system, social simulation, social psychology, attitude dynamics, information diffusion.**

I. Introduction

Industrial Context

The new paradigm of war: During the last two decades, stabilization operations in Former Yugoslavia, Somalia, Timor, Western Africa, Iraq and Afghanistan have brought to light a deep shift that occurred in the military affairs from industrial war to a paradigm identified as *"war amidst the people"*[2]. Today, most of the military operations involving western Forces face irregular opponents. These new types of opponent (insurgents such as guerrillas, rebels or terrorists) use asymmetrical tactics (Improvised Explosive Device, ambush, hostage taking, night letters) and blend themselves into their "human environment", where they find some support based on ethnic, political or religious affinities. In order to counter them and stabilize the crisis zone, one must restore security and governance and provide grounds for economical development. In this context, stabilization does not consist only in tactical success in combat operations, but also relies on what is known as "non-kinetic" actions (*i.e.* that do not rely on effective usage of force). The so called "civil-military" actions and specific communication actions[1] aim at altering the perception, attitudes and behaviours within the population and at hindering pro-insurgent dynamics. Several recent military doctrines in US [3], UK[4] and France [5] have emphasized these new capabilities in support of stabilization and counter-insurgency operations. The understanding of the human terrain and its dynamics is the key for answering those new operational needs and obviously calls for a modelling effort.

Needs for new systems: The command and control systems and the training simulation systems currently in use by the military Forces have all been designed for conventional warfare. They show little relevance to capture or simulate population-centric phenomena and human dynamics. More specifically units specialized in non-kinetic actions do not appear to have any digital tools to plan or evaluate their operations and no computer aided training is available to them. Moreover, conventional combat unit and command staff lack training for human terrain awareness when attempting to plan and run "full spectrum operations"[6]. Several industrial research projects based on multi-agent simulations modelling social phenomenon in an insurgency situation were realized in order to address these new needs. They tackle various issues such as forecasting irregular warfare, training soldiers to befriend the population or modelling impacts of stabilization operations on populace beliefs [7],[8],[9]. Although the major need that is to model the perception-attitude-behaviour dynamics toward Forces actions and peculiarly communication actions remains unsolved. The first part of this problem which corresponds to the building and adaptation of population attitudes according to their perceptions and communications call on a well known topic by academics: the research field of attitude dynamics.

[1] Also known as Psychological Operations [NATO], Military Information Support Operation [US], Military Community Outreach [UN]

Scientific Context

The concept of *attitude* derived from social psychology could be defined as "a mental and neural state of readiness organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related" [10]. Therefore attitudes have been at the heart of models that anticipate behaviour as in the military approach we have showed in the previous section. The latent characteristic of the attitude implies that at least two levels exist: the genotypic level (*i.e.* its formation and transformation level) and the phenotypic level (*i.e.* where it is expressed). The opinion is located at the latter level by enabling the inference of its underlying attitude: it represents one of the behavioural expression form of the attitude. In other words, the quantification of the opinion concerns epistemologically only the verbal expression of the subject and is under no circumstance a transparent reflection of the attitude [11]. In some scientific research on the topic of "opinion" dynamics, the words attitude and opinion are often confused, despite their clear distinction in social psychology. In our model we will avoid such confusion and focus on attitude dynamics only. By attitude dynamics we refer to the propagation and evolution of attitudes in a population of individuals. This field interests various disciplines such as social simulation, social psychology, social physics or complexity science. The process of attitude dynamics can be modelled as the result of communications and influences between members within a group. Thus, agent-based modelling constitutes an appropriate approach to study complex social phenomenon as it is funded on micro modelling of individuals and their interactions to analyse emergent macro trends [12].

Objectives

In this context, our aim is to propose a multi-agent based simulation model that will help the Forces to understand populations' attitudes dynamics by considering three aspects :

1) People construct and adapt their attitude according to their perception, evaluation of the social object. In order to account for such a mechanism, our model will take inspiration from social psychology theories, following the methodology of psychomimetism [13]. In particular we will follow the Fazio's approach of attitude as object-evaluation associations [1] as a basis for our modelling framework.
2) Facts are witnessed by only a small part of the population, while some of them are known by the majority. This could be due to the spreading of the information among some social networks. Therefore it would be crucial to account for these communication factors if we aim to understand the attitude dynamics.
3) Social tensions (*e.g.* ethnic or religious conflicts) that can fracture the human terrain alter the information interpretation of individuals depending on their affiliation. The model will integrate such tensions by including attitudes between potentially conflicting social groups.

In summary, our model will address the problem of attitude construction and adaptation toward Forces based on the perceptions that have individuals on their actions, inter-personal factual communication and populations' social preferences. The present paper is organized as follows. After presenting the related works in social simulation of attitude dynamics, we will detail our model of attitude dynamics. The conceptual objects will be described in the Static Model section, and the Model Dynamics section will detail how we manipulate the concepts to enable our population construct, revise and then communicate their beliefs and attitudes. Finally, we will show experiments through some scenarios using the model and their results before concluding.

II. Related Works

Attitude dynamics studies diverse complex social phenomenon such as the vote [14], the expansion of extremism [15] or the diffusion of information and its effects [16]. Despite this variety of subjects studied, it is generally possible to classify the literature along three different axes [17]: the model of attitude itself, the diffusion/communication mechanism and the impact of the network topology constituting the social environment. However, in our work, as discussed in the previous section, we propose to focus on two aspects of attitude dynamics: the model of attitude and the communication mechanism. The following paragraph shows some contribution in these domains and pinpoints some limits. Subsequently, we will propose a model that could fulfil these shortages.

A. Attitude model

Attitude dynamics first depends on the representation model of attitude. In the first known models of attitudes (*e.g.* [18]), attitude was represented as a binary or real value. During the last decade, several works proposed more complex representations of attitudes. For instance, in their study on political attitudes and behaviours dynamics, Kottonau *et al.* [14] construct attitudes based on multiple social psychology theories encompassing the ten dimensions of attitude strength such as its extremity, intensity, certainty, importance *etc.* [19]. However, as was pointed out by [20], most of these models choose to represent information as attractive or repulsive forces. The reason is that they focus only on the individuals' interactions and the resulting changes in attitude (through diffusion): they do not consider the construction mechanism of the attitude itself. Other research in social psychology study the formation of attitudes at an individual level: in these models, an attitude is based on information concerning the social object, acquired through experience [10], [21], [22], [**?**]. Based on this, Urbig and Malitz [15] propose to represent attitude as the sum of the evaluations of the aimed object's features. This approach is derived from the attitude theory of Fishbein and Ajzen [22], [23]. While Urbig and Malitz' model constitute an interesting view on attitude formation, it has two limits with respect to our objectives. First, the attitude revision is based on the bounded confidence model [24], [25]: when two individuals (selected randomly) have attitude values close to each other (with a fixed threshold), each one modifies its attitude so that it gets closer to its peer's. As a consequence, the attitude value after the initialization phase is no longer connected to the beliefs of each agent regarding the social object (it is mainly influenced by the peers' values). d Second, this model does not consider the limited rationality specific to a human being [?], all the evaluations are equally accessible within the memory whether these information are recent or old, important or not from the individual's point of view. As a result, individuals could retain not pertinent information forever instead of forgetting it (*i.e.* exclude it from the attitude construction).

However, the model proposed by Fazio, based on object-evaluation associations with varying strength, seems a promising approach to overcome these two weaknesses [1]. The main idea of this model is to represent an attitude as a set of evaluations of the social object. Each evaluation is based on information about the object, called memory association, and is weighted by an accessibility value determining the evaluation's degree of reminiscence. By essence, this model maintains the connection between cognitive representation of object's and the corresponding attitude, following Heider's recommendation [26]. Moreover, it takes into account the reminiscence capability of individuals, *i.e.* the limited rationality [?].

To our knowledge, Fazio's model has not been implemented and evaluated in multi-agent simulation. In this paper, we propose to implement this concept of attitude. More precisely, the model will base the attitudes on the evaluation of individuals' beliefs about actions done by the object of attitude. For modelling purposes and for the sake of simplicity, beliefs refer to informations held by individuals and do not encompass incorrect beliefs, intentional deception *etc.* The accessibility value will be computed using the impact of the action and the credibility of the source.

B. Communication mechanism

The second dimension we consider in our research for attitude dynamics is the diffusion mechanism of attitude through which simulation's actors influence each other. This mechanism is characterized by three basic settings [17]: the definition of the information type, the definition of the participants required to the interaction and the definition of the influence process.

Regarding the information type, in most works, the message content is the attitude itself [17], [20] or parts of the attitude [15], [27]. While it is true that daily communication is heavily based on attitudinal information (*e.g.* assessment without arguments, commercials *etc.*), conversational narratives (reporting facts) also represent a significant part of communication, maybe up to 40% according to Eggins [28]. Moreover, to our knowledge, there is no psychological theory describing in detail the impact of a communication about attitude itself. For this reason, we propose to base our attitude dynamics and communication mechanism on beliefs exchange and updates, rather than direct attitudinal influence.

Little work seem to have been done in this view in the domain of attitude dynamics. However, research in the domain of innovation diffusion, such as the COBAN system [29], propose models for beliefs exchange. In the model proposed by Thiriot and Kant [29], knowledge representation relies on associative networks and the communication protocol is based on social objects. More precisely, communications consist in exchanging part of the emitter's belief network to his addressee. Then, the receiver of the message may revise his own network depending on some criteria such as the source's credibility or the compatibility of the new information with his/her own knowledge. This model was proposed for innovation diffusion and evaluated on a word-to-mouth problem. However, since the whole knowledge network is an evaluation of a social object, it is very similar to an attitude, hence, we can assume this model can be used to compute attitude diffusion (and dynamics). For this reason, we propose to reuse this communication mechanism in our model, by replacing the knowledge network by agent's beliefs about actions proceeded by the Forces.

C. Attitude Dynamics Based on Beliefs Dynamic

In the next sections we will present our model of attitude dynamics implementing Fazio's concept of attitude, with a belief diffusion model based on Thiriot's model. Basically, the idea of a simulation's proceeding consists in execution of actions (patrol, medical support, bombing) by the Forces (UN, terrorist or others) over time that are perceived by the individuals. Those individuals' perceptions, once evaluated respectively to their subjectivity characterized by their former attitudes and affiliations, will bring them information on Forces' benefits which will be memorized into their beliefs. Based on these personal beliefs' evaluations, people will adapt their attitudes and may communicate their knowledge to spread information into their social network. Every agent will compute attitudes toward the Forces based on the evaluation of their belief base.

We will first present the static model (section III) which describes the key concepts needed to construct the simulation: the different actors (the population represented by individuals grouped into different factions, and the Forces), the actions, their corresponding beliefs, the attitudes and finally the messages. We will show, in section IV, how the model manipulates these concepts by exchanging beliefs and dynamically computing attitudes.

III. Static Model

This section defines the representation of the key concepts in our multi-agent model of attitude dynamics. In our model, we consider a set of *Forces*, representing the belligerents as abstract entities (the UN, the terrorists, *etc*) and a set of agents, representing the members of the population, each one building and updating an attitude toward the Forces.

A. Individuals

The individuals of the population are represented by computational agents and are characterized by a unique social group defined as "a set of individuals sharing similar characteristics or goals" (in our application case, these social groups are ethnic groups). Let us denote $SG = \{SG_1, SG_2, ..., SG_n\}$

the set of social groups and Ind the set of all individuals. Each individual $i \in Ind$ is defined by a tuple

$$i = \langle socialGroup(i), Blf(i), Cnt(i) \rangle$$

with:

- $socialGroup(i) \in SG$ the social group of the individual
- $Blf(i)$ the set of all the beliefs on actions present in the individual's memory (belief description is detailed in section III-F)
- $Cnt(i) \subset Ind - \{i\}$ the set of all the contacts of the individual in the interaction network (see section IV)

B. Forces

The Forces represent objects that can act in the simulation and for which we want to analyse the attitudes evolution among the population. Each of them correspond to an computational automaton executing its actions list given by the user (for instance, in the context of military interventions, the UN can secure a zone, the terrorists can perform a bombing attack ...). For each Force $f \in F$, we denote $actionList(f)$ the ordered list of actions (defined in III-D) to be executed during the simulation.

C. Social Objects

We call social object an abstract or concrete, human or artificial entity on which people (at least two) exert a social behaviour (attitude formation, opinion exchange, formation of social representation, *etc.*). Here, the social objects are the objects that are the focus of the attitudes: the Forces and social groups. We denote ***SO*** $\in SG \cup F$ the set of all social objects.

D. Actions

An action represents an accomplished task by a *Force* that affects *SO* through *impacts*. We denote *Act* the set of all actions. An action $a \in Act$ is defined by:

$$a = \langle name(a), force(a), date(a), impactList(a) \rangle$$

with:

- $name(a)$ the unique name of the action
- $force(a) \in F$ the *Force* which performed the action
- $date(a)$ the occurrence date of the action
- $impactList(a) = \{impact(a)_1, \cdots, impact(a)_k\}$ a list of impacts' information due to the action (defined in the section below).

In the following sections, i and j will always be used to denote an individuals (*i.e.* agents) and a will always represent an action.

E. Impact

An *impact* defines the objective effect's payoff of an action on a specific *social object*. Impacts are always defined w.r.t. a specific actions. Besides this information is associated to a certain *credibility* accorded to its source. Thus, we define an impact $ip(a)$ as a tuple:

$$ip(a) = \langle subject(ip(a)), payoff(ip(a)), credibility(ip(a)) \rangle$$

with:

- $subject(ip(a)) \in SO$ the social object associated to the subject impacted by the action
- $payoff(ip(a)) \in [-1, 1]$ the payoff acquired by the subject which is negative when harmful and positive when beneficial
- $credibility(ip(a))$ noted also $\sigma(ip(a))$, the credibility of this impact's information's source with $\sigma(ip(a)) \in \Sigma = \{\sigma_1, \sigma_2, ..., \sigma_s\}, s \in \mathcal{N}, \sigma_1 \succ \sigma_2 \succ ... \succ \sigma_s$

It is important to note that we have a finite ordered set of possible credibility values, with a minimum (σ_1) and a maximum (σ_s). They will be used in the action perception mechanism in section IV.

F. Beliefs

The computation of attitudes by the individuals of the population is done by manipulating a set of *beliefs* about *actions* that they have either directly witnessed or indirectly heard of. The set of all the *beliefs* of an *individual i* is defined as a set of actions:

$$Blf(i) = \{action_1^{(i)} \dots action_n^{(i)}\}$$

with: $action_k^{(i)} \in Act$ the action concerned by the belief stored in the agent's memory.

Actually, actions will only exist in our model as beliefs, should they be witnessed actions, believed actions or communicated actions. For this reason, we shall always indicate the point of view of an action. We denote $a(i)$ the action as it is believed and interpreted by agent i and, by extension, we denote $impactList(a, i)$ the impact list of action a interpreted by i and for each $ip(a, i) \in impactList(a, i)$:

- $subject(ip(a, i))$ the impacted social object;
- $payoff(ip(a, i))$ the payoff estimated by i for the social object;
- $\sigma(ip(a, i))$ the credibility of this impact's for i.

G. Attitudes

For a given individual, each *social object* is associated to an *attitude*. We build a function $att : Ind \times SO \rightarrow [-1, 1]$ a function that computes the attitude $att(i, o)$ value of the individual i toward the social object so, negative when bad and positive when favourable (see IV-G).

We must distinguish between two sorts of social objects:

a) Attitudes on Social Groups: People have attitudes toward the different social groups that emanate from social tensions present within the population. We define a table $aTable_{|SG|,|SG|}$ with values in $[-1, 1]$, parameter of the simulation, which contains the inter social groups attitudes, that are considered fixed in our model. The attitude of an agent toward an social group follows this table:

$$\forall i \in Ind, \forall sg(j) \in SG, att(i, sg(j)) = aTable(sg(i), sg(j))$$

Below, an example of attitudes configuration:

By extension, we will define $att(i, j)$ the attitude of agent i toward agent j as:

$$\forall (i, j) \in I^2, att(i, j) = att(i, sg(j))$$

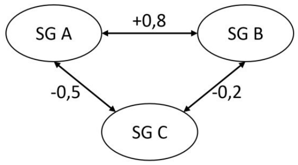

Fig. 1. Example of inter-social group attitudes configuration

b) Attitudes on Forces: The heart of this model consists to simulate the dynamics of the attitudes of the population toward the Forces. We conceptualize this dynamic as the result of individual's perceptions of the Forces' actions. The dynamic model of attitudes' revision is described in section IV. The value of $att(i, f)$ will be defined in this section.

H. Messages

During the simulation, Forces communicate on their actions to the population in which the information is propagated. These communications are done through messages defined by:

$$m = \langle emitter(m), date(m), act(m), Adr(m) \rangle$$

where:

- $emitter(m) \in SO$ the social object associated to the emitter of the message
- $date(m) \in \mathcal{N}$ the emission/reception date of the message
- $act(m) \in Blf_{emitter(m)}$ the action belief reported by the message
- $Adr(m) \subset Agt$ the addresses of the message

IV. Model Dynamics

This section describes the different cognitive mechanisms that will allow the agents to revise their beliefs and compute attitudes. In the course of the simulation, Forces proceed to actions that impacts the population. Individuals that perceive these actions acquire new information and revise the associated impacts. This modification of their beliefs will allow them to compute new values for the attitudes toward the Forces.

A. Action perception

In our model, action perception can be done in three ways:

1) **Direct perception**: the agent either is subject to the action or directly witnesses it (*e.g.* the UN Force brings food to the village and the agent is a member of the village or was around when the action was done);
2) **Force communication**: the Force communicates about an action toward the population and the agent is one of the addressees;
3) **Intra-population communication**: the agent is given information about a previously perceived action by another agent, through a *message*.

Cases 1 and 2 are scripted in our model: they are defined in each $actionList(f), \forall f \in F$. In that case, the credibility value of the impact for this action is fixed: all direct perceptions have a credibility value set to the maximum (σ_1) and all Force communication actions have a credibility value set to the minimum (σ_min). For the intra-population communication (case 3), the value of the impact credibility of the communicated information ($action(m)$) is exactly the value in the sender's belief base ($action(emitter(m))$): the agent communicates the action as it is in its belief base. As will be shown in subsection IV-C, it is the addressee that might modify this value when adding this new information to its own impact list.

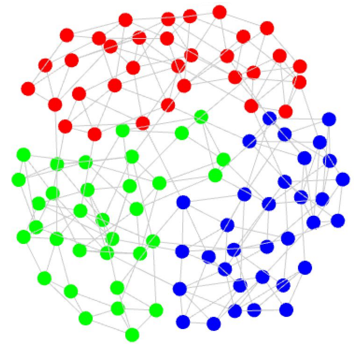

Fig. 2. Small-world network for 3 social groups used in our simulation model

B. Intra-population communication

The intra-population communication relies on the list of individual contacts ($Cnt(i)$): agent can communicate information from their belief base (*i.e.* actions) to their contacts. We will first explain how this contact list is built in our model. We will then show how agents select which belief they want to communicate and when.

1) Network topology: The contact list of agents is defined by the network topology of the social environment in which the information spread through interactions. In most work on attitude dynamics, research use a network to define the interaction between agents, their frequency and intensity (*e.g.* based on affinity between individuals). In our model, we simply consider the links as possible communications between two individuals, regardless of their social group or any other possible affinity. However, unlike what is done in some work [18], [30] where the agent do not really consider any network topology, it seems important in our model to have a network topology that captures in some sense the context of the simulation with different social groups: agents communicate more inside their social group. The recent trend in this domain is to explore the model dynamics in the context of complex social networks such as small-world [31] or scale free networks [32]. Some rare works use advanced networks build with synthetic population generators which take into account qualitative and/or quantitative social demographic data (*i.e.* social statistics, social structure, economic data *etc.*) [33], [34]. In our case, due to the lack of data on the human environment of our interest (crisis zones), we build our social environment based on small-world networks. Figure 2 gives an example of such a small-world network for 3 social groups. For simplicity purpose, the topology of the network is given as a parameter and remains static during the whole simulation.

2) Belief communication : The purpose of intra-population messages is to report actions made by the Forces to let people know their impacts. Whenever an agent receives a message (knowledge acquisition), it will not only update its belief base (as presented in subsection IV-C): it will also evaluate its level of interest for re-transmission to the agents in its contacts $Cnt(i)$.

The value of re-transmission interest is based on two criterion from the simplicity theory by Dessalles [35]:

- The credibility of information: credible information is more likely to be communicated.
- The recency of the information: recent information is more interesting to communicate.

Given an action a that an agent i has just received and interpreted (see section IV-C below), the interest for the agent i to re-transmit a toward all the agents $j \in Cnt(i)$ using a message is given by the linear combination of the average credibility of a and its recency, defined as:

$$\overline{cred}(a,i) = \frac{\sum\limits_{ip \in impactList(a,i)} \sigma(ip)}{|impactList(a,i)|} \tag{1}$$

and:

$$recency(a,i) = 1 + max\left(0, \frac{date(a,i) - cdate}{m}\right) \tag{2}$$

where $cdate$ is the current date and m is a fixed parameter, equal to the size of the working memory. We define two parameters α and β that balance the importance of recency and credibility. Let $interest(a)$ be the re-transmission interest value of a:

$$interest(a,i) = \alpha \times \overline{cred}(a,i) + \beta \times recency(a,i) \tag{3}$$

The action a will be re-transmitted if and only if $interest(a,i) > T_{com}$, with T_{com} being a fixed threshold in the simulation.

When the belief a has to be re-transmitted, the agent does not retransmit it to all its contacts in $Cnt(i)$: the selection of contacts is based on a uniform random basis, depending on the action's interest. The agent builds a list of recipients R for the message $m = \{i, cdate, a(i), R(m)\}$. Let $j \in Cnt(i)$ be a contact agent: the probability that $j \in R(m)$ is defined by choosing a random value $r \in [0, interest(a,i).T_{com}]$.

Note that the transmitted action only contains the impacts of the initial communication. For instance, if a Force does an action with given impacts several times, agents will only communicate about the impacts of the last occurrence. Also, as it will be presented in the next subsection, agent interprets action a prior to computing its interest and re-transmitting it. Hence, the credibility value of the impacts related to the transmitted action might differ from those of the initial information. The idea is that an information coming from the uncle of the wife of a friend is less credible than if it came directly from the friend. Thus, the reach of messages' dissemination is limited by this decreasing credibility process.

C. Belief revision

Whenever an agent i receives a new information $a(j)$, either as a direct observation, through Force communication or via intra-population message exchange, it updates its beliefs $Blf(i)$ as follows:

1) If the action comes from a Force communication or intra-population communication, each credibility $\sigma(ip(a,i))$ associated to the impact $ip \in impactList(a,i)$ is decremented of one unit with respect to its initial value $\sigma(ip(a,j))$. For instance, if a friend tells us that he saw an action, we won't believe it at the same level as he would.
2) If the action a does not already exists in $Blf(i)$ (*i.e.* there is no action with the same $name(a)$ and $force(a)$), the agent adds this action as a new belief. The date of the newly added action is the current date and the impacts is set to $impactList(a,j)$.
3) If the action already exists, its date and impact list is updated depending on the impacts list of the received information. $date(a,i)$ is set to $date(a,j)$. For each impact $ip \in impactList(a,j)$, three situations can occur:
    a) If ip does not appear in the impacts list of $a(i)$, *i.e.* if there is no $ip' \in impactList(a,i)$ such that $subject(ip') = subject(ip)$, then ip is added to the impact list $impactList(a,i)$. This corresponds to the acquisition of new information: in this action that the agent already heard of, someone was rewarded/punished and he did not know this.
    b) If ip appears in the impacts list of $a(i)$ and is compatible in terms of impact value, *i.e.* if there exists $ip' \in impactList(a,i)$ such that $subject(ip') = subject(ip)$, and $|payoff(ip') - payoff(ip)| \leq \varepsilon$, with ε a fixed threshold, then ip is not added to the belief base but instead, $\sigma(ip')$ has a probability to be modified to the immediate next value in Σ if and only if $\sigma(ip') < \sigma(ip)$. This corresponds to the situation in which the agent already knows about someone being rewarded or punished through an action, but it learns this information again from a higher-confidence source.
    c) If ip appears in the impacts list of $a(i)$ and is not compatible in terms of impact value, the agent has to revise both the impact and credibility value. There is a probability that the new impact ip replaces the impact ip' in $impactList(a,i)$.

For impact revision in case of compatible or incompatible informations (case 3.b and 3.c above), we implement a process derived from the probabilistic revision proposed by Thiriot and Kant [29]. Their mechanisms are based on a probability table that compares the credibility of the new information's source to the belief's one stored in memory. The information supported by the highest credibility gets a higher probability to be retained. This method offers several descriptive properties compliant with real-world observation : the temporality of information (*i.e.* more information is old, more it risks being replaced), the impact of multiple sources (*i.e.* more it has sources, more it increases the likelihood of revision) and information inertia (*i.e.* recent information is unlikely to be replaced). In our precise case, the information is the impacts of actions related by beliefs. The revision probability value for $|\Sigma| = 3$ is given by Figure 3. If a low credibility is given to an impact and a new information accounts for an impact with high credibility, the impact value and corresponding credibility will very probably be updated. On the contrary, if a high credibility impact is in contradiction with a low credibility one, there is only a 10% chance that the agent revises this impact.

$\sigma_{mem}/\sigma_{new}$	σ_1	σ_2	σ_3
σ_1	0.5	0.25	0.1
σ_2	0.75	0.5	0.25
σ_3	1	0.75	0.5

Fig. 3. Example of revision probability table depending on credibility confrontation

D. *Attitude construction: general principle*

Whenever the reception of a new information about an action a done by a Force f resulted in a belief revision in $Blf(i)$, individual i will adapt its attitude toward f based on its new mental state.

As presented in the previous sections, our model for attitude construction is based on action beliefs' evaluations associated to the object, as proposed by Fazio [1]. Figure 4 illustrates the representation of an attitude according to the model proposed by Fazio.

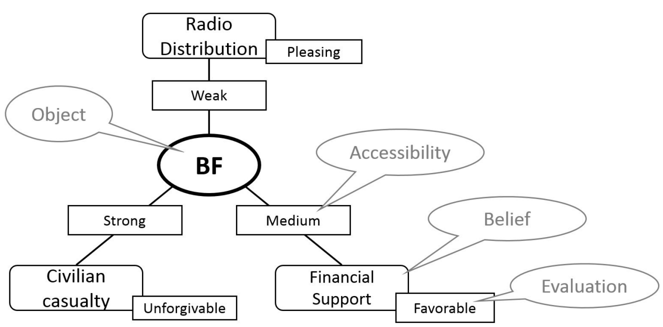

Fig. 4. Example of attitude in Fazio, 2007.

Our implementation first evaluates a subjective benefit of the actions' impacts (see section IV-E). Second, we determine the accessibility of these different impacts. This accessibility value allows us to select a subset of impacts (the most accessible ones) for the building of the attitude. This selection corresponds to the notion of limited rationality of human being [**?**]: one does not use its entire knowledge when evaluating a fact, but only a subset. In our model, the selection of impacts follows the peak-end theory [36] which stipulates that people recalls facts that are either the most impressive (peak) or the most recent (end). This will be detailed in subsection IV-F. The final computation of attitudes based on the selected impacts is a simple aggregation of the selected evaluations weighted by their accessibilities, as will be presented in section IV-G.

E. *Interest and benefit evaluation*

The benefit of an action $a(i)$ are determined subjectively, *i.e.* in respect to agent i's attitude and beliefs, using the evaluation model proposed by Fishbein and Ajzen [37]. This model combines the impact of the action for a subject with the attitude of the individual toward this impacted subject. In this way, an individual judging an action which is beneficial for him or for some of his "friends" (positive attitude), the overall benefit would be positive. Conversely, if the action is beneficial for his "enemy" (negative attitude), the action would have be evaluated with a negative value.

The *benefit* of the action is defined as the aggregation of the impacts weighted by the attitude. We use a classical multi-criteria aggregation operator OWA [38] instead of the mean value:

$$evaluation(a,i) = OWA_{ip \in impactList(a,i)}(payoff(ip) \times att(i, subject(ip))) \quad (4)$$

F. *Accessibility estimation*

The selection of the "most accessible" impacts in memory, which will serve to compute the attitude, we rely on the peak-end theory [36]. To implement this model, we need to determine some selection criterion for "peaks" information and "ends" one.

a) Peaks: The evaluation of peaks is similar to the interest value that was defined for the intra-population communication in section IV-B2, except that we consider three criteria instead of one: the source credibility, the sum of impacts and the unexpectedness. This choice is supported by some elements of Dessalles' simplicity theory [35]: 1) the higher the credibility, the more is the information interesting; 2) very positive or very negative impacting actions are more compelling; 3) unexpected event are more easily retained.

The source credibility follows formula 1 defined previously:

$$\overline{cred}(a,i) = \frac{\sum\limits_{ip \in impactList(a,i)} \sigma(ip)}{|impactList(a,i)|} \quad (5)$$

The sum of the impacts' intensity of a function is weighted by the attitude toward each subject (both as absolute values): the more consequences an action has on each individual it concerns, and the more the individual is important (positively or negatively) for the agent, the higher the interest of this action:

$$sumImpact(a,i) = \frac{\sum\limits_{ip \in impactList(a,i)} |payoff(ip) \times att(i, subject(ip))|}{|impactList(a,i)|} \quad (6)$$

The unexpectedness is computed as the difference between the previous evaluation of the action and the new one (once the new information has been integrated in the belief base):

$$evalDiff(a,i) = \frac{|evaluation_{old}(a,i) - evaluation_{new}(a,i)|}{evaluation_{old}(a,i)} \quad (7)$$

b) Ends: Since the end criteria corresponds to the most recent information selection, we will simply use the recency of the information as described in section IV-B2 and its corresponding function 2:

$$recency(a,i) = 1 + max\left(0, \frac{date(a,i) - cdate}{m}\right) \quad (8)$$

c) Accessibility: Based on the previous values, the accessibility of an action belief is obtained by:

$$\begin{aligned} acc(a,i) \;=\; & \alpha \times \overline{cred}(a,i) + \beta \times recency(a,i) \\ & + \delta \times sumImpact(a,i) + \delta \times evalDiff(a,i) \end{aligned} \quad (9)$$

with α, β, γ and δ that represent the weights for each criteria, taking their values in $[0, 1]$

G. Attitude construction

Once each actions' benefits and accessibilities were computed, the individual can finally compute his attitudes. To account for subjects' bounded rationality we assume that this computation could not occur on all the actions he/she observed. There is a limitation – we denote $maxMemory$ – to the size of the working memory used by the subject to store the list of actions – denoted $aList(i)$ – that will impact the current attitude. Following Fazio's theory, each action a in $aList(i)$ will impact this attitude with a factor $evaluation(a,i) \times acc(a)$. Then, the global attitude impact will be an aggregation of these factors using a classical multi-criteria aggregation operator OWA [38]: $OWA_{a(i) \in aList(i)}(evaluation(a,i) \times acc(a,i))$. Finally, we add a non-linear response factor to this aggregated impact using a sigmoid-like function. Hence the final attitude $a(i,f) \in [-1, 1]$ of agent i toward a Force f is given by:

$$\begin{aligned} & att(i,f) = \\ & tanh\left(\rho . OWA_{a(i) \in aList(i)}\left(evaluation(a,i) \times acc(a,i)\right)\right) \end{aligned} \quad (10)$$

Observations

This overall process of cognition revision is compliant with some real-world/psychological observations:

- Attitude inertia: the intrinsic nature of the attitude makes it fluctuate very little. By conserving the last evaluations for computing the new attitude that derives from a new information acquisition, the model transcribes this feature.
- Consistency between attitudes and beliefs: being directly based on beliefs, attitudes preserve an harmony amid the cognition as proposed by Heider [39].
- Compatibility with other attitudinal theories: while not being fully exploited, the structure of attitude formation is compatible with other models of attitudes like the tripartite view [40].
- A limited memory: by implementing the peak-end rule based on the evaluations accessibility, the agent is able to limit the amount of used information for revising attitudes.
- Subjective perception: impacts are evaluated by considering the individual's attitude toward the subject of the action which makes the information subjective to his point of view.

V. Model Evaluation

This section presents several preliminary experiments results of our model and analyses the impact of some key parameters on the attitude dynamics. We first describe the shared basic settings of the simulations such as their initialization and other cognitive parameters (V-A) before presenting the actual simulation runs. Then, we show some experiments to understand the basic behaviour of the model mechanisms through a simple scenario in which the Force affects a specific social group with beneficial and harmful actions (V-B). This allow us to study the resulting attitudes dynamics of the different social groups based on their relationships. In a second stage, we analyze the evolution of attitudes in a more complex scenario that involves Force's communication (*e.g.* radio broadcasting) to show the effect of a messages which are discordant with the actual perception of the population (V-C).

A. Shared settings

All the experiments are based on a set of shared parameters settings:

- Initialization: The population is split into three social groups (A, B and C) each composed of 33 individuals connected by an interaction network described in IV-B1. The inter-social group attitudes are defined as shown in Figure 1, social groups A and B are allied against a third group C. People are confronted to a series of actions performed by one Force determined by a scenario. Since the population have no information on the Force at the beginning of a simulation, their corresponding attitude is "set" to zero.
- Belief related parameters: We map the highest credibility σ_1 to the subject itself, σ_2 to an individual in the subject's direct contact and the lowest credibility σ_3 to the Force and others. Accordingly, we use the revision probability table described in Figure 3.
- Attitude related parameters: α, β, γ and δ used in the computation of the accessibility (IV-F) are fixed to be equal: 0.25. Also, for these preliminary experimentations, the parameter for the OWA function is set to $\frac{1}{n}$, thus, corresponding to a simple mean.

B. Basic behaviour

In order to understand the basic behaviour of the model, we propose to run simulations through a simple scenario in which the Force targets the social group A and proceeds to actions in three phases:

- Phase 1: six repetitions of beneficial (+0.2) actions visible by 15% of the group
- Phase 2: six repetitions of harmful actions (-0.8) visible by 5% of the group
- Phase 3: six repetitions of beneficial actions (+0.3) by 30% of the group

Actions are separated by an interval of 5 time steps.

Inter-individuals communication's impact on social groups' attitude means dynamics: We propose to vary the communication interest threshold T_{com} to study its impact on the attitude dynamics. Note that decreasing the value of T_{com} increases the communication activity within the population. In the first experiments presented below, we show the general evolution of attitudes means per social group by setting $T_{com} = 1$ (*i.e* no communication) through the simple scenario that impacts the social group A. The curves as coloured as follows: A-red ; B-blue ; C-green.

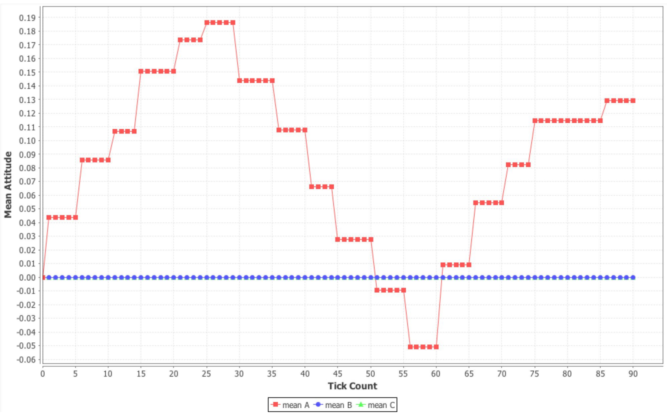

Fig. 5. Attitude means per social group with $T_{com} = 1$ (no communication)

Figure 5: Since there is no communication between the agents, only the witnesses are able to acquire information. Thus, only a part of the group A is informed of the action as we can see, therefore only A's mean is altered. At each action, the number of informed individuals increases. This is confirmed by the shape of A's curve evolving every 5 time steps that corresponds to action interval.

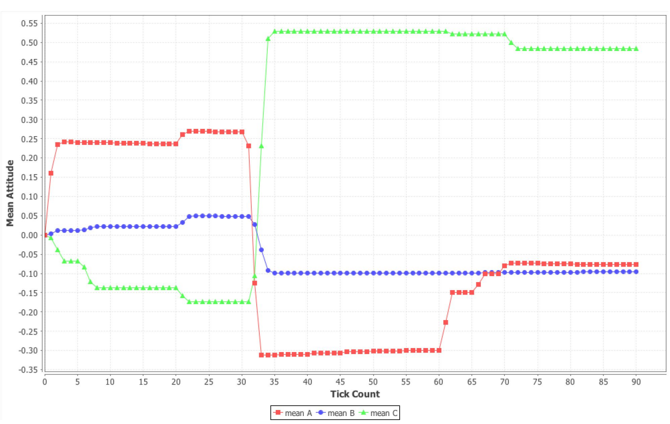

Fig. 6. Attitude means per social group with $T_{com} = 0.22$

Figure 6: Adding communication enables other individuals, including other group's, to get informed of the action. We found that there is an interesting bifurcation effect depending on a certain T_{com} threshold value that affect the inter-individual communication impact. With $T_{com} < 0.22$ there is almost no communication effect on the overall attitude dynamics. Here, with $T_{com} = 0.22$, we can notice that the evolution of the social group B (in blue) is following the curve of the social group A (in red). Since these two social groups are tied with a positive attitude, these groups evaluate the actions in the same way. However, the communicated information's impacts intensity on B's curve is weaker than A's variation. This is due to the fact that the actions do not concern directly B, their accessibility in the memory of B's individuals is lower than in A's memories. Conversely, the curve of the social group C (in green) is virtually symmetrical to A's with which it is connected by a very negative attitude. Also, some information are not well relayed in the network. For instance, we can see that group B is not aware of the third phase's actions since its mean is not evolving after $t = 60$. This is due to the low amount of communications. In the next simulation, we decrease the threshold to $T_{com} = 0.1$ in order to increase the amount of exchanges.

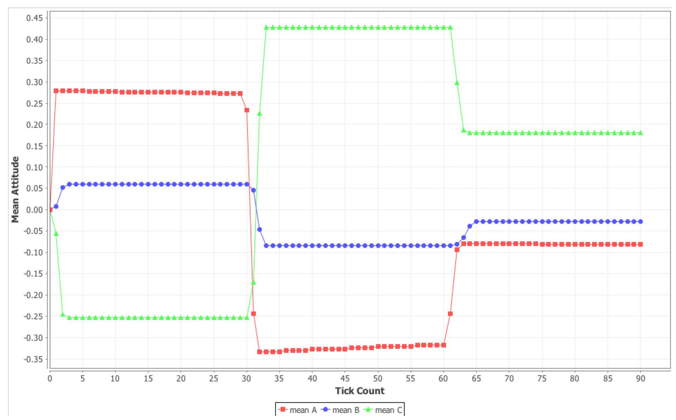

Fig. 7. Attitude means per social group with $T_{com} = 0$

Figure 7: By removing the boundary for messages' interests we let the agents communicate each beliefs they acquire, therefore the amplitude of groups' reactions is increased compared to the previous simulation. Here, a very large proportion of the individuals are aware of Force's actions, but some individuals remains unaffected due to the probability of revision or to the network topology. We can also notice that the mean of the social group A is almost instantly raised to its stabilized value in each phase. This phenomenon is due the quick spreading of information: individuals are informed of the first occurrence of the phase's action before it is repeated, whether by directly witnessing it or during a communication with his neighbours.

C. Discordant communication broadcast

One of the role of military communications consists in providing information in favor of them, as well as done by civilian's (e.g. publicity), in order to facilitate their operations in the area. For instance, they can relate embellished impacts of their actions in messages broadcast through radio. In the next simulation, we show the reaction of the population to a series of actions along with messages broadcast from the Force relating their proceeded actions with embellished impacts. The scenario is based on the latter simple scenario except each action is followed by a message broadcast reaching 30% of total population that relates the action with a doubled impact. First, we run the simulation without inter-individual communication:

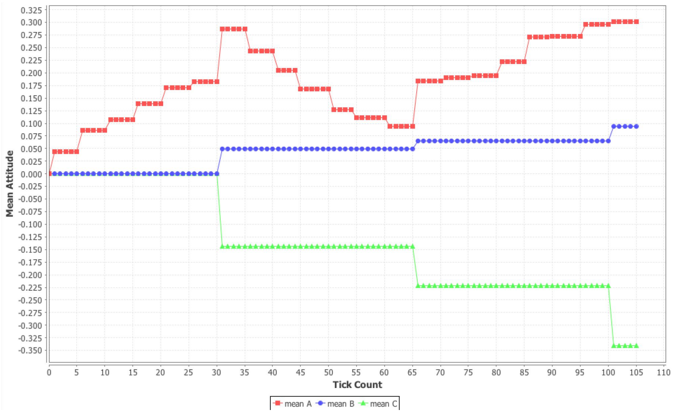

Fig. 8. Discordant message: Attitude means per social group with $T_{com} = 1$

Figure 8: As in the previous simulation 5, only the impacted social group A is aware of the action since we can notice that B and C's means remain steady during the first phase. They are informed of the action after the Force's message broadcast at $t = 30$. All the broadcasts impact the attitude means, this is due to the fact that the majority of the receivers are not direct witnesses of the actions, therefore they believe the message as it is and integrate the related information into their belief base. However, if the receiver has previously witnessed the action by his own-self, the probability that he will trust the message is very low (10% as shown in Figure 3) since the credibility of the Force is very low (σ_3) toward subject's own credibility (highest credibility σ_1). Thus, it would be interesting to see the effect of inter-individual communication on the acceptance of the broadcast message. In the next simulation, we let the agents interact so that the witnesses can inform the action's true impact.

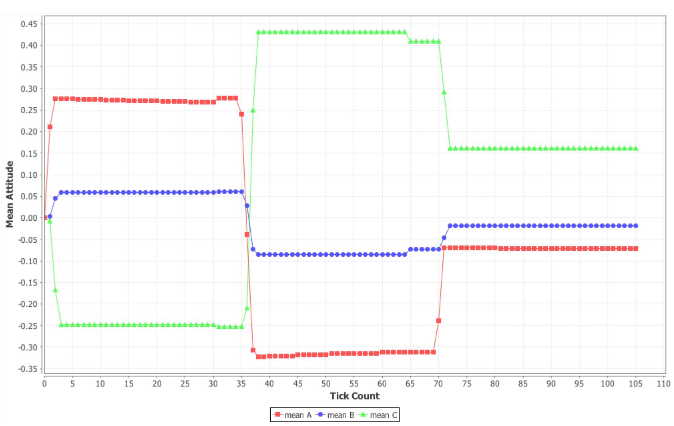

Fig. 9. Discordant message: Attitude means per social group with $T_{com} = 0.1$

Figure 9: The graph shows that the communications broadcast have a very weak impact on the attitude means. This situation demonstrates that the majority of the individuals do not take into account the Force's messages. With a high communication activity within the population, each time an action is witnessed by an individual, its information is diffused within the population. Since the credibility of a message coming from a neighbour is higher than the Force's credibility – *i.e* the neighbour directly witnessed the action – or at least equal – *i.e* the neighbour relayed a message from another source –, the probability to revise their knowledge base using the broadcast message is very low.

D. Dispersion of individuals attitudes

Finally, we study the dispersion of individual attitudes. To do so, we analyze the aggregated standard variation value $agStdDev$ as the mean of the three averages standard variation within each social group. This value corresponds to the average dispersion within each group and is different from the overall standard deviation. We show below, the graph for the simple scenario with $t_{com} = 0.22$:

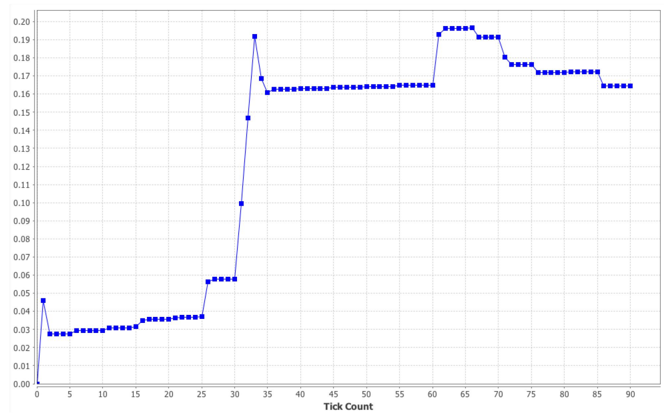

Fig. 10. Aggregated standard deviations of social groups with $T_{com} = 0.22$

Figure 10: We can see that each phase correspond to a plateau with a tendency of an increasing $agStdDev$ over time. This increase is due to the fact that at each new injection of new information, we raise the probability that an individual is aware of the information, thus widening the dispersion with the others who are not informed. Moreover, we can see some transient boosts in these increases that can be explain by the inter-individual communication: at the beginning of a phase, an action is perceived by some agents. This situation creates a disparity within groups between the individuals who are aware and those who are not. But the corresponding information is then diffused into the network via interactions between agents. Thus, this process reduces the disparity by allowing more individuals acquiring the fact. Besides this, the second transient boost in the figure is larger than the others. As we can see in Figure 7, this phase reverses the attitude means for all the groups, as a result it generates a big gap between agents attitudes which explains this peak. Moreover, we found again that the communication intensity has an impact on this $agStdDev$ variation. We show below the variation of $agStdDev$ along with t_{com}:

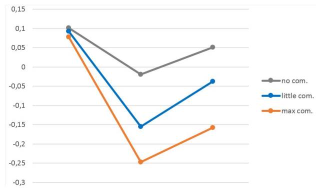

Fig. 11. Aggregated standard deviations at each phase with $T_{com} = \{1, 0.22, 0\}$

Figure 11: We can notice that increasing the communication activity within the population decreases the standard deviations within groups. This is due to a form of agreement within groups catalyzed by the exchange of information.

VI. Conclusion

We proposed a simulation model of attitude dynamics based on socio-psychological theories. This model relies on belief revision for attitude construction, based on communication information. Our communication mechanism considers intra-population relations and influence. The credibility of the information and its importance impacts the computation of the attitude over time. We studied the dynamics of this model on several simple examples that illustrate the impact of the communication on the attitudes.

One goal of our model is to help western countries to rely on communication strategy in stabilization operation and to reduce the use of conventional kinetic actions *i.e.* based on the use of military force. However, this model is not limited to military applications and can be easily adapted to civilian usage: the Forces can represent any kind of active social object such as political parties, institutions, companies, brands *etc.*

The model presented here can be extended in several ways. Our first perspective is to further analyse the sensibility of our model to the various parameters used in the dynamics and also to the simulation initialization. Besides this, it will be interesting to calibrate the model using real-life data collected on the terrain to study both its expressiveness and simulation power. Our second perspectives aim at extending the population model. We want to include the notion of population behaviour (actions) influenced by their attitudes, so that our model can be used for anticipating the actual actions of the studied individuals.

April 15, 2014

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Towards metadata standards for sharing simulation outputs

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***Abstract*—This extended abstract outlines a prototype metadata standard for recording outputs of social simulations, to be refined as part of a project funded through the third round of the Digging into Data challenge. This is with a view to gathering community feedback on the proposals.**

I. Introduction

AGENT-BASED models, perhaps more than other kinds of simulation modelling tool, are capable of producing large quantities of simulation data. This is not just because, through representing individuals and their interactions explicitly, there will be data in each time step of the model for each agent and each interaction, but also because a typical use-pattern for agent-based models is to run them multiple times to test the behaviour of the model under different parameter settings and seeds for pseudo-random number generators.

As a consequence, there are challenges associated with interpreting, analysing and visualising results from agent-based models that are akin to those of the 'big data' community with social datasets collected from the real world. Traditional methods for mapping relationships among input, parameter and output variables, such as regression models, are generally designed for independent variables that are additively linear (even when interaction terms are included), generally assume continuous and monotonic dependent variables, and are developed under the assumption that dependent and independent variables have Gaussian distributions. However, data outputs from simulations of complex systems are often nonlinear with discontinuities, discrete and leptokurtic.

The MIRACLE project (Mining Relationships Among Variables in Large Datasets from Complex Systems) will be investigating and developing tools for analysing and visualising outputs from social simulations. We propose to build tools on the CoMSES Net web platform allowing users to upload their model output and associated metadata, visualise and analyse results, and conduct comparative meta-analyses. As part of this exercise, we wish to engage with the social simulation community to gather requirements.

Model output metadata is information describing outputs from simulations. These outputs could take various forms and be stored in different file formats, including screenshots or videos of the model running, data from time-series graphs, networks or spaces, and detailed data describing the states of individual agents. Model output metadata provides more information about the files than may be captured in the file formats themselves, which could include how the files were generated (version of model implementation software, input parameters), why (e.g. as part of an experiment, or for a presentation or publication), or even simply that two files were generated by the same run of the model.

The main purpose of the MIRACLE project is to make data analysis and visualisation tools available and easy to use to practitioners in agent-based modelling. However, since some of the metadata we might record about simulation outputs pertains to its provenance (i.e. the parameter settings, model versions, etc. that generated it), the project should have the added bonus of facilitating replicability and increasing transparency about how the results were generated for stakeholders in the model [1].

II. Earlier work

Early work on using metadata to record simulation outputs includes [2], which used an OWL ontology [3] to record the outputs of experiments with FEARLUS [4]. The ontology is shown in Fig 1; specific subclasses of the ontology were used to describe FEARLUS models, simulation outputs, experiments and results. The ontology provides the ca-

≥ This work was sponsored by the third round of the Digging into Data challenge. http://www.diggingintodata.org/

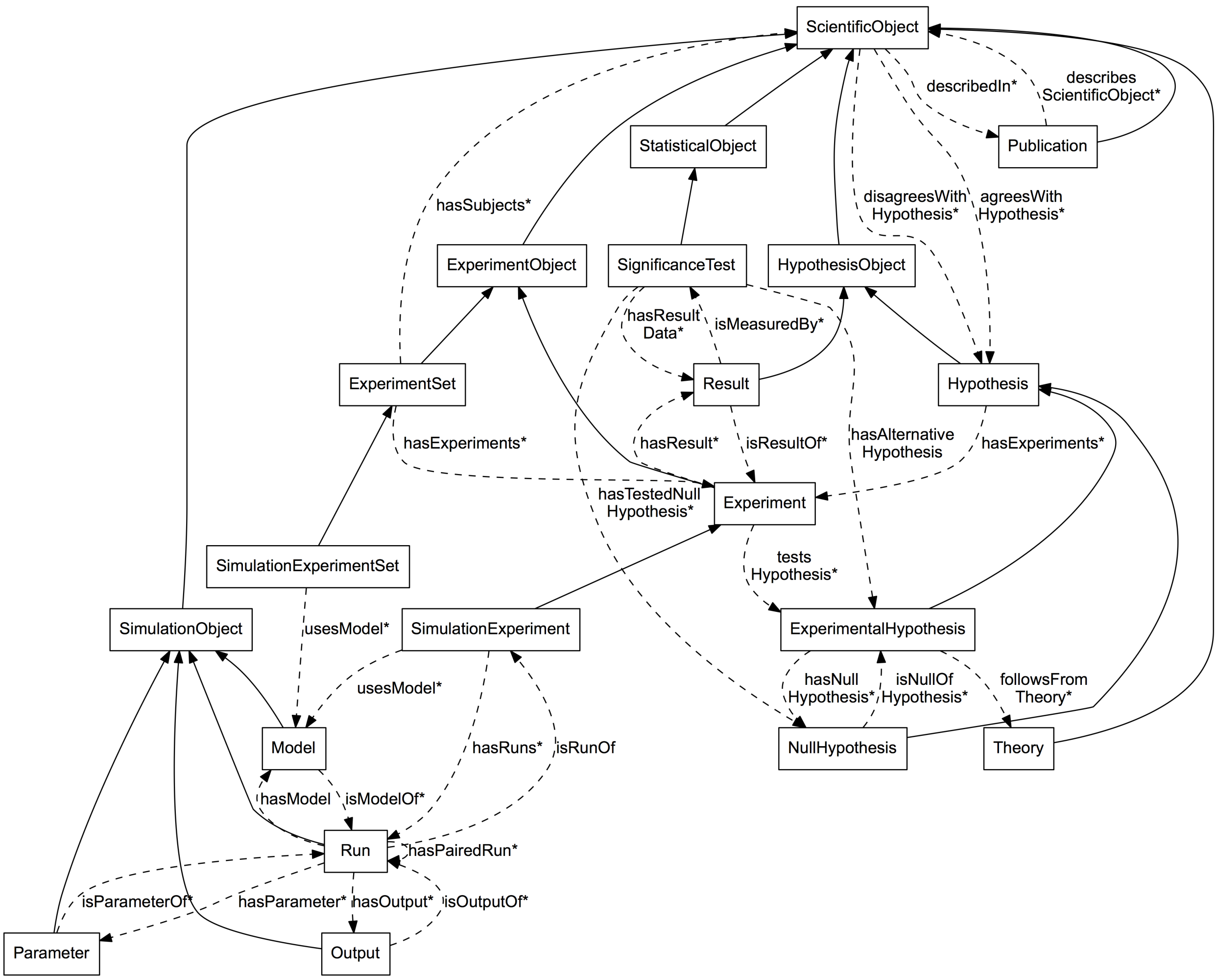

Fig 1: The FEARLUS-G ontology used for recording outputs of simulation experiments. Solid lines connect subclasses to their superclasses; dashed lines are relationships among classes, and are accompanied by a label that ends with an asterisk if the relationship is many-one.

pability to record rich metadata about how and why simulation `Outputs` were generated, and was used as part of a system in which some of the metadata (in particular, instances of `Result`, `Run` and `Output` and relationships among them) were generated automatically.

The ontology was designed with hypothesis-driven research using simulation experiments in mind, and applying conventional statistical tests. This kind of approach has been the subject of some criticism [5], as (i) modifying the input or algorithm of a simulation for the purposes of testing a null hypothesis arguably means the tests are not being conducted on the same 'world'; (ii) there is now sufficient computational power that significant results can be obtained just by performing more runs. Thus, although the ontology could be reused, there are good reasons to consider more general metadata about the *provenance* of simulation output data.

More recent work [6] has explored the use of the PROV ontology [7] as a foundation for recording metadata about how simulation outputs are generated, distinguishing three types of provenance, of which (2) is the most relevant here: (1) the social process of constructing the model; (2) running the model; (3) 'history' within a simulation run. The PROV ontology has entities, activities and agents as the main classes, and according to [6], entities for type (2) provenance are the data and parameters used to initialise or as input to the model (including where they have come from), software used to run it, and output files generated by it; activities are running the model; and agents the hardware and users.

III. Towards a metadata standard

A specialisation of the PROV ontology drawing on the FEARLUS-G ontology seems an appealing starting point for recording metadata about simulation outputs. Our prototype is shown in Fig 2. The FEARLUS-G `hasModel` and `hasParameter` properties are subproperties of the PROV `used` property, and `hasOutput` is a subproperty of `generated`. Properties can also be defined to show the relationship between the `Hardware` and `User`

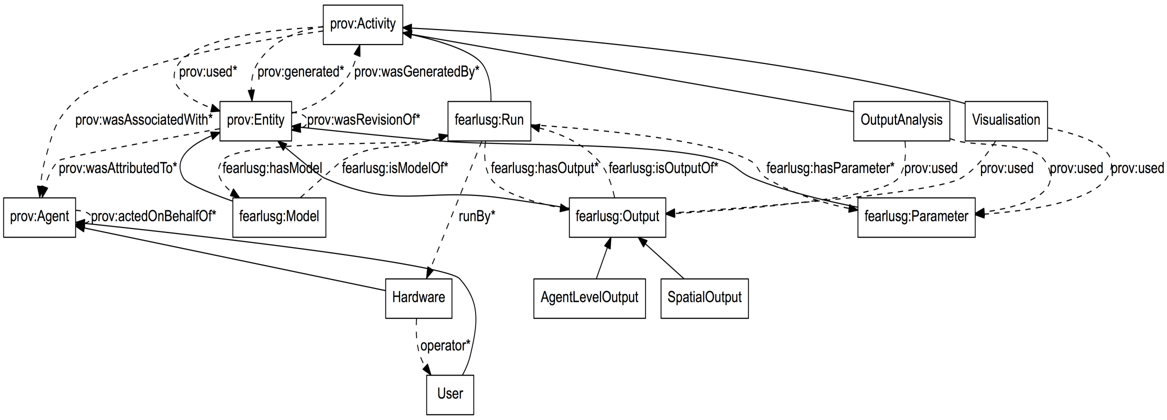

Fig 2: Specialisation of the PROV ontology using FEARLUS-G as a starting point for a simulation output metadata standard. Specialisations of PROV drawing on FEARLUS-G have a fearlusg `namespace`, PROV entities have a `prov` namespace; additional proposed entities have no specified namespace.

`prov:Agents`, with the `operator` property a subproperty of `actedOnBehalfOf`. Similarly, the `runBy` property is a subproperty of `wasAssociatedWith`, used to record the `Hardware` on which the `Run` was conducted.

The PROV ontology provides further vocabulary that might be useful, such as `wasRevisionOf`, which could be used to record versions of `Models`, and `wasAttributedTo`, which could record authorship of `Models`.

In the MIRACLE project, however, there will be a need to record further metadata associated with other possible subclasses of `Activity`, as reflected in the classes `OutputAnalysis` and `Visualisation`. It will also be important to record different kinds of output – in Fig 2 we have shown two for illustration: `SpatialOutput` and `AgentLevelOutput`. Though not shown in the diagram, certain subclasses of `OutputAnalysis` and `Visualisation` are associated with specific subclasses of `Output`. For example, `SpatialOutput` would be suitable for geostatistical subclasses of `OutputAnalysis`. At a workshop at iEMSs 2014 in San Diego, participants identified space-time visualisation tools as a particularly high priority, and clearly such tools would only operate on `SpatialOutput` variables.

An ontology such as the proposed would enable the user to understand whether their output is suitable for analysis or visualisation using a particular technique, and to use standard provenance reasoning techniques to gain some understanding of the processes by which the output was generated.

Workflow tools can prove useful in capturing the processes by which simulation outputs were generated and analysed, and provide a metadata basis for recording scientists' *intent*: goals and constraints of the research [8].

IV. Discussion

A common problem with recording metadata, is that manual entry can be a barrier to its adoption [9]. There is a gap between what would ideally be recorded, and what can feasibly be recorded, either through software facilitation (where constraints might pertain to computational cost or disk space associated with computing and storing relevant metadata) or through manual form entry during upload (where constraints might pertain simply to the amount of metadata users are willing to enter at any one time).

Work with the virtual research environment reported in [9] also noted resistance of users to a static metadata framework, and the authors developed a hybrid semantic/social web approach allowing interoperation between community-driven metadata (e.g. tags) and formal assertions in OWL that are amendable to automated reasoning. It is reasonable to anticipate that flexibility of this kind will be necessary in developing the kind of tools that will enable researchers to use simulation output analysis and results visualisation methods for their models: different output analysis and visualisation techniques may have different requirements for metadata that cannot be comprehensively anticipated at the time simulation output metadata standards are developed.

One of the advantages of social simulation, however, is that there are significant user communities around commonly-used tools such as NetLogo [10] and RePast [11], and that much of the workflow is done using these tools. This creates opportunities to capture metadata manually not only at the time of uploading simulation outputs to a repository, but also during use of the model with appropriate software support, reducing the amount of metadata entered at any one time. Indeed, since activities such as running a simulation model are conducted on a computer, the tools could record associated provenance metadata automatically.

An important question in recording metadata about social simulation outputs is the degree to which the model itself needs to form part of that description. If so, metamodels, such as MAIA [12], may provide useful vocabularies that can be drawn on in developing simulation output metadata. Bearing in mind the foregoing discussion about the potential for demanding too much from users in the way of manual metadata entry, the benefits of including metadata about the model itself needs to be weighed against the cost in terms of metadata about the outputs that may as a consequence not get recorded.

There is normative pressure for researchers to record metadata about the use of simulation models [e.g. 13, 14], even if only in text form. Much of the information proposed standards or protocols such as these request are amenable to software-facilitated if not automatic capture.

One of the challenges for MIRACLE is to develop a metadata standard for recording simulation output, that allows users (both internal and external to the original project) to explore outputs from agent-based models and build useful queries. The use of tags and keywords could be instrumental in complementing the more formal ontology-based approach to describing these outputs, a prototype of which we have outlined above.

The next steps for MIRACLE involve obtaining requirements for output metadata recording to facilitate development of a standard, and to deploy commonly-used output analysis and visualisation techniques in a web-based platform.

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Computing Job Satisfaction with Social Comparison Process : an Agent-Based Approach

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***Abstract*—In this article we propose a brief overview of *Happywork*, a multi-agent based model of job satisfaction inspired by well established psychosocial theories. We focus here on the cognitive dimension of job satisfaction that will be built from work features. The model is intended to model and simulate the core mechanisms that underlie individual evaluation of the job. We present here the model and some preliminary results that show significant consequences of job enhancement policy in term of comparison outcome.**

I. Introduction

Work is the activity in which people spend most of their daylight time. According to opinion survey regarding life domains, job often comes at the top ranking in terms of subjective importance [4] and job satisfaction is one of the strongest predictor of overall happiness [7]. Moreover, the interest in job satisfaction has recently increased when more firms and governments realize the importance of work-related illnesses. Many reports (e.g. [41]) point out the increasing number of psychosocial risks at work, including musculoskeletal disorders, depression or burn-out. These clinical consequences are usually associated with typical behavioural patterns - e.g. absenteeism, withdrawal behaviour, quitting or job dissatisfaction [14] - that non only affect the firm but also send a warning sign about employees' psychophysical condition.

In this article we focus on mechanisms that lead someone to judge his/her work more or less satisfying. By contrast with many normative approaches, our methodology relies on *psychomimetism* [21] : we want our model to derive from well-established (mainly from human experiments) theories in social psychology, taking therefore a rather descriptive approach.

A. Defining Job Satisfaction

Job satisfaction is roughly about "how people feel about their jobs and different aspects of their jobs [...] the extent to which they like (satisfaction) or dislike (dissatisfaction) their jobs." [35]. The seminal work of Locke [26] goes further to explain the content of this *feeling*, that is: "the pleasurable emotional state [i.e. job satisfaction] resulting from the appraisal of one's job achieving or facilitating one's values." As the new direction initiated by Easterlin [8], job satisfaction field of study lies on the subjective experience, either "feelings" about or "appraisal" of the job. Although there is a relative consensus about the nature of job satisfaction, there are many controversies regarding the content and area of influence of this subjective reactions to job conditions. In this work we followed an attitudinal approach.

B. The attitudinal approach of job satisfaction

In this approach, job satisfaction is mostly conceptualized as an *attitude* toward the job [35]. Here, attitude refers to Allport's view of a "mental state of readiness" that will influence the individual's response to a social object and all related objects and situations [2]. Following Hulin & Judges [17] this job attitude have three main components : cognitive (evaluative), affective (or emotional), and behavioural.

1) Cognitive dimension: It focuses on information processing based on job features [10]. Among many of these cognitive approaches, we find Social Information Processing [31], Value-Based Evaluation [26], input/output based judgment (e.g. the Cornell Model [18]) and Needs Based Judgment (e.g. the Job Characteristics Model [12]). The job attitude is computed through a comparative evaluation of job features, i.e. an aggregation of perceived discrepancies between job features and a set of standards (referents) [5]. These referents could be alternative situations (lived in the past or by others or even mentally experienced ones [23]) or abstract standards (values, needs, etc.).

2) Affective dimension: It includes affective response at work [20], emotional responses to job events [43], personality bias and interaction between affective and cognitive evaluation while at work [42]. However, several authors warn about the speculative content of mechanisms involved in emotion at work and their links with cognitive reaction to job events and features. Emotion and cognition are intimately related to one another, but no consensus emerges on their respective roles in job satisfaction formation [19].

3) Behavioural dimension: It is about how job attitude influence the subject's behaviour and actions. Therefore, it is of great interest since a good understanding of the relation between attitude and behaviour can provide insights to improve organization outcomes [1]. Note that this component is mostly studied as a consequence rather than as an antecedent of job satisfaction: for instance, one will study if a very unsatisfied employee will under-perform or be ill more frequently [14].

C. Related Works in agent-based Simulation (ABS)

While many models of opinion dynamics have been proposed in the ABS, only few of them deal with attitudes in the psychosocial sense we defined above. Most of these attitudes are unidimensional (modelled with one vector x, each component x_i denotes the opinion of agent i), and treated as an opinion like in the bounded confidence framework [6] [15]. This is problematic for job satisfaction, as our attitudinal approach makes the distinction – well established in social psychology – between an opinion (verbal, external) and an attitude (three dimensional, internal). Moreover, as recalled above, an attitude is strongly multi-dimensional, based on several components and several features.

Some models are inspired by psychosociological theories [22] and some of them incorporate multi-dimensionality [40]. However, though they model the resulting changes in attitude (usually through communication and diffusion), they do not consider the inner mechanism that builds the attitude. In other words, the attitude formation is black-boxed, while here we aim to open the box in order to understand and study the determinants of job satisfaction. Hence, our model is not only to be inspired by psychosociological theories: we want to *implement* them (in the sense of [21]). As for agent interactions, we go beyond diffusion or communication by modelling a complete social comparison process, as it as been shown by the literature to be a crucial component of job attitude [9].

Finally, our mid-term / long-term goal is to provide a decision-aid tool for managers that aim to improve job satisfaction within their firms. Therefore, we need a rich and realistic enough model. In particular we must incorporate the elements (e.g. job conditions,...) we find in actual firm organization and that manager will seek to adjust.

D. Our approach to job satisfaction : the HappyWork framework

As stated before, we follow here an attitudinal approach. Moreover, we will focus only on the cognitive dimension of job attitude, for two main reasons. First, most of the surveys and data available on job satisfaction only capture the cognitive dimension [42]. The affective one is difficult to measure and to model at the moment [10]. Second, even if behavioural dimension is a mid-term/long-term goal of our project, it implies to include a work-at-the-firm dynamics and a firm organizational model that are out of scope for this paper.

Our approach for job satisfaction, we call the *HappyWork framework*, is based on subjective feature evaluation and comparison process with standards. If we take the point of view of organizational psychology and econometrics, the features will be the characteristics of the job, and concern the job at different levels like work load, demand for creativity, autonomy, salary, etc. They are subjective perceptions of the job and could be accessible through surveys.

Defining standards is a difficult task, as there is no accepted consensus on their type and content: in Locke's value-percept model [25], standards are personal values; in Adam's equity based model, standards are others' job content; in Cornell's model [34] standards are past experiences and social values. Michalos [27] tried to synthesize these approaches in his multi-discrepancy theory (MDT) and proposed several comparison couples like self/wants, self/others, self/past best, etc. From our review of this literature, we have selected two types of standards and hence *two types of comparison* :

- a *social comparison* where a subject compare his/her job situation with some other individuals (denoted as *social referents*)
- an *historical comparison* where a subject compare his/her job situation with the ones he/she had in the past (denoted as *past referents*).

To these comparison processes, we add a *third component*: the *direct effect* that represents a direct evaluation of job features. This component is intended to capture individuals and environment differences, like the interaction between work and family/private life and job features' impacts on health or on the fulfilment of one's needs.

The Happywork framework is summarized in the Figure 1 below.

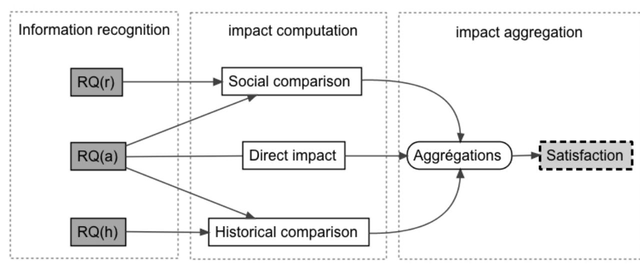


Fig. 1: The HappyWork Framework : cognitive process of job evaluation resulting in job satisfaction

At first, agent a acquires information about the job and comparison standards: a job feature perceptions vector $RQ(a)$, the job features for referent r $RQ(r)$ and past job features $RQ(h)$. Once the three cognitive sub-processes (social, historical and direct) have been performed, a final aggregation can be done to obtain the overall job satisfaction (corresponding to the answer to a question like :"overall, are you satisfied with your job"). This is the general modelling framework we propose to get a cognitive model of job satisfaction that will be well-grounded on social psychology. However, in this paper, we will describe and study the *social comparison* component only.

Finally, in HappyWork, we promote a *data-driven approach*, in order to account for real data deriving from field surveys. Thanks to our partner Technologia, we were able to use some of their questionnaires and surveys to feed our agents at initialization, and study their job satisfaction dynamics (see section III-A below on data collection).

II. Agent-based model of job satisfaction through social comparison

A. Model inputs and initialization

Let A be the set of agents in the simulation. Let $Q = \{q_1, \ldots q_n\}$ be the set of *job characteristics*, these characteristics being sorted out in a set of *job dimensions* $d \in D = \{d_1, \ldots d_m\}$. Q and D will be provided by the questionnaire we aim to study. Hence every agent $a \in A$ is initialized with values $RQ(a) = [q_{1a}, \ldots q_{na}]$ that encode his/her subjective job feature perception – namely their response to the questionnaire on each feature q_i. For instance, subjects were asked to evaluate their agreement in a scale from 1 to 4 to statements like : "Your job demand to work fast", "In my job, I have to learn new things" or "My colleagues are professionally competent". $RQ(a)$ could be continuous or an integer for ordinal data (like in Likert scales [24]).

Note that there is a *direct and monotonous link between satisfaction and questionnaire response values*. Whether ordinal (Likert) or continuous, Q is designed so that the highest the value of q_{ia}, the highest the (subjective) satisfaction of a is on characteristic q_i.

B. Discrepancy evaluation

The social comparison implies a computation of the discrepancies $\Delta(a, r)$ between an agent and his referents where r denotes one particular referent chosen by a. We have:

$$\Delta(a\,, r) = [\delta(a,\, r,\, q_1), \ldots,\, \delta(a,\, r,\, q_n)]$$

where, $\delta(a, r, q) \in [-1; 1]$ computes the discrepancy between a and r on feature q. $\delta(a, r, q) > 0$ means that a feels to be better than r on characteristic q ; when $\delta(a, r, q) < 0$ we have the opposite, that is, a feels to be worse than r on q; and if $\delta(a, r, q) = 0$, a feels similar to r on q.

Let $min(q_i)$ and $max(q_i)$ be respectively the minimal and maximal values of question q_i in the input data set. Then :

$$\delta(a, r, q_i) = \frac{q_{ia} - q_{ir}}{max(q_i) - min(q_i)} \qquad (1)$$

As one can notice in equation 1, δ is not a distance function; in particular it is not symmetrical.

C. Social comparison

For social comparison specification we take our inspiration from well established psychological field of social comparison (see [38] for a review). In direct line with Festinger's seminal work, social comparison is conceptualized as a mean to achieve a self-evaluation in a particular social environment [37]. Our social comparison mechanism is inspired by *Selective Accessibilty Model (SAM)* from Mussweiler [28][29][30].

According to Mussweiler, people compare with each other using three main processes :

1) the subject a uses a set $RS(a)$ of referents as a basis for the comparison ;
2) for each referent $r \in RS(a)$, if a feels similar enough with r, then he/she engages the comparison process
3) at this stage two different sub-processes might occur: *assimilation*, when a feels very close to the referent r and seeks similar features with him, or *contrast*, the opposite case when a feels different and will focus then on contrasting features with r.

Hence, our process of social comparison can be modelled as a sequence of *three distinct steps*: referent and information selection, similarity hypothesis testing, and assimilative / contrastive interpretation of comparison content. Let us now detail these three steps.

1) Referent selection: Classical definition of social referent encompass closeness and similarity, e.g. [9] [37]. While these concepts have no clear definitions, referents in work organization are basically the people we interact with [16][33], colleagues [32] and generally people in close environment [11]. In absence of data regarding the real social network, we decide as a preliminary step to randomly assign for each subject a a set $RS(a)$ of referents, with cardinality RN:

$$\forall a \in A \quad RS(a) = \{r_1, \ldots, r_{RN}\}$$
$$\forall k \in \{1, \ldots, RN\}\; r_k = RandomAgent(A, RS(a)) \qquad (2)$$

where $RandomAgent(A, RS(a))$ returns a randomly picked agent from A that is not already in $RS(a)$. We denote $RefSort$ the sorting probability for this random process.

2) Similarity hypothesis: In this step, agent a must decides whether it is close enough to referent r. To do so, a computes $modeInit(a, r) \in [0; 1]$ as the number of features on which a and r have different values (i.e. do not share the same feeling on this job characteristic). Hence, 0 means a complete similarity, and 1 a complete dissimilarity. However, following Mussweiler [29], $modeInit(a, r)$ is not computed on the entire job feature set. In fact, people typically select few salient information about their referents to engage in a basic, spontaneous and preliminary comparison process. Because these salient information are priming stimulus, they should be defined by their accessibility [29]. We denote this salient feature set $SF(Q)$, typically the employment conditions, like wage, working hours, status, years of service, etc. Then $modeInit(a, r)$ would be the proportion of features in $SF(Q)$ where a and r differ.

If $modeInit(a, r)$ exceeds a given *deflection threshold* $\sigma^{deflect}$, the comparison target is too dissimilar. In that case, the referent is deflected [36] and no comparison occurs. Otherwise, the similarity hypothesis is supported and a moves to the third step.

3) Assimilation and contrast outcomes: According to SAM theory, comparison outcome depends on comparison content and "on what information is cognitively accessible" [38]. Content is defined by the *direction of comparison*, namely *downward* when a compares his/her self with someone he/she feels to be worse off or *upward* comparison for the opposite. SAM conceived accessible information as priming stimulus focusing on similarity or dissimilarity. The model posits that if someone is *primed* to insist on similarities with the comparison target, then assimilation effect is likely to occur. On the contrary, if someone is *primed* to insist on dissimilarities with the comparison target, then contrast effect is likely to occur [36][29].

Moreover, assimilation tends to increase/decrease a's evaluation on feature q as a result of comparing with someone better/worst on this feature q [44]. Contrast typically render opposite consequences, that is a decrease/increase of self-evaluation when comparing with someone better/worst off. This could be summarized in Table I below, where $IC(a, r, q) \in [-1; 1]$ is the outcome of a's comparison with referent r on feature q. $IC(a, r, q) > 0$ means that a's comparison with r will tend to increase a's satisfaction on feature q. $IC(a, r, q) < 0$ means that a's comparison with r will tend to decrease a's satisfaction on feature q.

TABLE I: Assimilation and contrast outcomes

	r is better ; $\delta(a, r, q) < 0$	r is worse ; $\delta(a, r, q) > 0$
Assimilation	$IC > 0$	$IC < 0$
Contrast	$IC < 0$	$IC > 0$

The comparison process is conducted as below :

- If subject a feels similar enough to r, that is if $modeInit(a, r) < \sigma^{assimil}$, then a performs an assimilation comparison. $\sigma^{assimil}$ is called the *assimilation threshold*, it represents the minimum proportion of similar features – taken from the set $SF(Q)$ of salient features – between a and its referent r to trigger an assimilation process. In that case, following Table I, we compute the impact $IC(a, r, q)$ as $IC(a, r, q) = -\delta(a, r, q)$. However, several sociopscychologists [44][29] have found that comparison often exhibits mixed - assimilation *and* contrast - effect even though someone feels very close to comparison target. Therefore the final impact during assimilation becomes:

$$IC(a, r, q) = \delta(a, r, q_i) \times \big(1 - \frac{simil(a, r)}{\alpha^{transfer}}\big) \tag{3}$$

  where $simil(a, r)$ computes the overall similarity between a and r as the proportion of features on which a and r feel similar, here taken on the entire feature set Q. $\alpha^{transfer}$ defines the minimum required similarity to ensure the assimilation effect will occur : at the contrary, if $simil(a, r) < \alpha^{transfer}$ then $1 - \frac{simil(a,r)}{\alpha^{transfer}} > 0$ and so IC and δ will have the same signs, denoting a contrast process (see Table I).
- Otherwise, if $modeInit(a, r) \geq \sigma^{assimil}$, the contrast comparison occurs and, following again Table I, we have $IC(a, r, q) = \delta(a, r, q) \cdot dissim(a, r)$ where $dissim(a, r) = 1 - simil(a, r)$ computes the overall similarity between a and r.

The complete impact comparison is summarized in the algorithm below :

Algorithm 1 *Comparison impact* computation

for all $r \in RS(a)$ **do**
  if $modeInit(a, r) > \sigma^{deflect}$ **then**
    bypass r and **continue**
  else
    if $modeInit(a, r) < \sigma^{assimil}$ **then**
      for all $q \in RQ(a) \cup RQ(r)$ **do** {Assimilation}
        $IC(a, r, q) = \delta(a, r, q_i) \times \big(1 - \frac{simil(a,r)}{\alpha^{transfer}}\big)$
      end for
    else
      for all $q \in RQ(a) \cup RQ(r)$ **do** {Contrast}
        $IC(a, r, q) = \delta(a, r, q) \cdot dissim(a, r)$
      end for
    end if
  end if
end for

Figure 2 displays the different comparison processes, according to σ values.

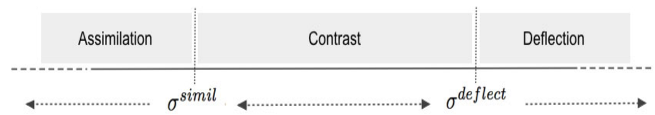


Fig. 2: Assimilation, contrast and deflection according to σ values

D. Social comparison aggregation

We must now compute the final social comparison outcome for agent a from its $IC(a, q, r)$ values. This is done through a sequence of multicriteria aggregations:

At first, because dimensions are the main facets of job satisfaction, we aggregate along the features of each dimension to obtain the aggregated comparison impact $ICD(a, r, d)$ on each dimension $d \in D$:

$$ICD(a, r, d) = WOWA_{q_j \in d}(IC(a, r, q_j)) \tag{4}$$

where $WOWA$ denotes the weighted ordered weighted average multi-criteria aggregation operator [39]. Then, all the referents $r \in RS(a)$ will be aggregated to get the overall comparison impact on dimension d, $ICA(a, d)$:

$$ICA(a, d) = OWA_{r \in RS(a)}(IC(a, r, d)) \tag{5}$$

where OWA denotes the ordered weighted average multi-criteria aggregation operator [45]. We do not need a WOWA here, as we have no information on the subject preference relations concerning his/her referents.

People are not equally sensitive to social comparison, they could react more or less to comparison impacts depending on their social comparison orientation (SCO) [3] or their emotional arousal. Thus, we add a non-linear sigmoid transformation of the comparison impact aggregation (ICA):

$$CompSoc(a, d_i) = \tanh\Big(\rho_a \cdot ICA(a, d_i)\Big) \qquad (6)$$

Hyperbolic tangent is used to saturate comparison impacts, while parameter ρ_a stands for the sensitivity to comparison for a. $CompSoc(a, d_i)$ is the job satisfaction for dimension d_i.

Finally, we compute the *final social comparison outcome* $SocSat(a) \in [-1; 1]$ with a WOWA aggregation of the job dimension satisfactions 6) :

$$SocSat(a) = \underset{i=1}{\overset{|D|}{WOWA}}\big(CompSoc(a,\, d_i)\big) \qquad (7)$$

III. Agent based simulation exploration of job satisfaction social component

Multi-agents based simulations are very tricky to explore and even more with a global descriptive perspective. Given that our model is particularly detailed, the mechanisms underlying agent behaviour are not simplistic to explain. In this paper, we decided to restrict our analysis to a key element : the effects of the assimilative / contrastive mechanism.

A. Data collection and initialization process

The set A of agents is initialized from real word data coming from a manager's satisfaction survey conducted by our partner Technologia, within a big French company. There are 178 agents in this dataset, and all the questionnaires Q is made of Likert scales. There are 4 dimensions in D : the 3 Karasek dimensions – i.e. job control (JC), job demand (JD), and social support (SS) – and employment conditions (EC). Referent sorting probability function $RefSort$ is set to an uniform distribution within the agent set A.

B. Simulation protocol

The idea that leads the exploration of the model relies on understanding the impact of assimilation and contrast on final social comparison outcome (eq. 7). To do so, we aim to study three typical $psychosociological$ profiles, that will be set through a combination of σ^{simil} and $\alpha^{transfer}$ values :

1) *High Assimilation (PHA)* : a conjunction of highly permissive "priming on similarity" (high threshold σ^{simil}) and a high orientation toward assimilation outcome (low $\alpha^{transfer}$). This profile represents a very high propensity to assimilate with someone else, and therefore will serve at gauging typical outcomes of quasi-systematic assimilation.
2) *Moderate Assimilation (PMA)* : the "priming on similarity" threshold remains high ($\sigma^{simil} = 0.6$) but the predisposition to assimilation outcome is lowered (higher $\alpha^{transfer} = 0.6$ so a contrasting counter-effect is more plausible).
3) *High Contrast (PHC)* : it represents a social comparison based on contrast, that is a low threshold of dissimilarity (priming on similarity is very restrictive) and keeping a high $\alpha^{transfer}$ to trigger contrast.

Table II displays the values that implement these 3 profiles in our simulations :

TABLE II: Profile parameters

	σ^{simil}	$\alpha^{transfer}$
High assimilation (PHA)	0.6	0.2
Moderate assimilation (PMA)	0.6	0.6
High contrast (PHC)	0.2	0.6

For each simulation, all agents are initialized with the same profile. All other parameters remain constant over simulations: namely, the initial set of referents is set to 10% of agent population, $\sigma^{deflect} = 0.8$, individual comparison orientation given by : $\forall a \in A\ \ \rho_a = 2$. For sake of simplicity, the OWA and WOWA operators are set to mean operators, and the weights for WOWAs are derived from feature and dimension weights available in the data set. For the Salient Features $SF(Q)$, we have the employment conditions, the seniority within the firm, and the employee qualification.

C. Analysis of static simulation

First of all, a static analysis has been carried out in order to evaluate the basic impact of parameters. We use a quartile representation of agent job satisfaction, where we computed the average of final social comparison outcomes within 4 groups, each of one corresponding to each quartile (from the $Q1$ quartile of 25% most satisfied to the $Q4$ of 25% least satisfied agents). We conducted 50 runs for each profile of the defined profile parameter and average the values over these runs to get the outputs shown below.

1) Assimilation vs contrast: The results are displayed in Table III, showing the proportion of contrast and assimilation in the comparison. For instance, a contrast value of 0.3 means that on average the agents feel to be in a contrasting position with 30% of their (non deflected) referents. We compute the assimilation proportion likewise. The deflection score is computed as the proportion of deflected referents. As expected, we observe clear tendencies depending on the profile we defined above. High and moderate assimilation (PHA & PMA) display assimilation to be more than twice often as contrast, when high contrast has a very high proportion (PHC) of contrast and almost no assimilation.

TABLE III: Proportion of assimilation and contrast

	Contrast	Assimilation
PHA & PMA	0.30	0.70
PHC	0.95	0.05

2) Link with declared satisfaction: For each profile, we get a different quartile distribution and we can compare it with the average declared (in the survey) job feature value on each quartile. The average is based on a Likert scale value transposition. The initial value of response statement is transposed in $[-1; 1]$. For example, on a Likert of 4 scales values are transposed as follow $\{1, 2, 3, 4\} \Rightarrow \{-1, -0.33, 0.33, 1\}$. As displayed in Table IV, we identified a correlation between these declared feature values and propensity to assimilation or contrast. In fact, it appears that for PHA social comparison impact is inversely correlated to declared job feature values.

TABLE IV: Mean of job feature declared evaluations per quartile and profile

	Q1 & Q2 (Highest)	Q3 & Q4 (lowest)
PHA	0.17 (±0.4)	0.34 (±0.37)
PMA & PHC	0.37 (±0.34)	0.15 (±0.42)

This could be explained by the fact that, as we already mentioned in our model description, assimilation tends to reverse the sign of the comparison content – upward or downward (cf. Table I). Therefore, people with a high (low) job feature value tend to decrease (increase) their job attitude when they compare and assimilate with worse (better) subjects on this feature.

D. Simulation exploration based on scenarii

We present here an empirical exploration of simulation according to a simple scenario, based on organizational policies regarding job enhancement and design [13][35]. These policies are targeted at employees that suffer deprivation in work motivation within an organization. In our scenario, this can be improved by raising some job feature values in agent job representation $RQ(a)$, like task identity and variety, autonomy, or relation with others (job enrichment, see e.g. [12]).

In our simulation, the improvement occurs as follows: at each tick, after agents have compared themselves with their referents, the organization takes a set of NI agents and increases a number FI of their lowest feature values, and repeats this process at each tick until all agents have a job satisfaction level $SocSat$ above a threshold λ. In our experiments we set $\lambda = 0$.

First of all, we display in Table V the average of agents' job feature values along the 4 dimensions (EC, JC, JD and SS). We use the same transposition than in Table IV, but compute average feature values taken from dimension rather than from the entire set of feature. These values are calculated at the start of the simulation for line 1 while the lines 2 to 4 show average feature values at the end of the scenario for population of agent with profile PHA, PMA and PHC respectively. From start to end, dimension value indicators have actually been significantly raised as the result of job enhancement, but relatively less for PHA than for PMA and PHC. More over, the standard deviations are quit high for PHA compared with the other two profiles, suggesting that for many agents the satisfaction is much lower that this average and therefore these agents will not see much improvement. Pure assimilation seems to be a profile more difficult to improve.

Now, we show typical graphics of satisfaction dynamics in figures 3 below. These ones depicted information about final social comparison outcome, from lowest (red) to highest quartile (purple), that is the average of job satisfaction for each quartile including standard deviation. y axis depicted job satisfaction average level, and x axis displayed simulation ticks.

TABLE V: Policy impact on global job feature values per dimension for scenario with $NI = 0.04$ and $FI = 1$.

EC = employment conditions; JC = job control;
JD = job demand; SS = social support.

	EC	JC	JD	SS
Start (t=0)	−0.05 (±0.44)	0.18 (±0.14)	0.19 (±0.24)	0.74 (±0.1)
PHA end	0.52 (±0.50)	0.56 (±0.39)	0.58 (±0.39)	0.85 (±0.14)
PMA end	0.85 (±0.13)	0.90 (±0.10)	0.87 (±0.16)	0.87 (±14)
PHC end	0.73 (±0.08)	0.96 (±0.08)	0.96 (±0.08)	0.96 (±0.10)

In Figure 3a (PHA profile), high assimilation process shows a persistent dispersion of satisfaction values, the gap between the four quartiles remains constant along the simulation. That means there is no real improvement on average and therefore the policy failed.

By contrast, in Figure 3c (PHC) corresponding to high contrast agents, we have a very different result : the gap between job satisfaction quartile is significantly reduced and at the end the attitudes increase for all the four quartiles, meaning a success in the policy. This was at the cost of the Q1 quartile (most satisfied) that have their satisfactions slightly reduced, thanks to the social comparison process.

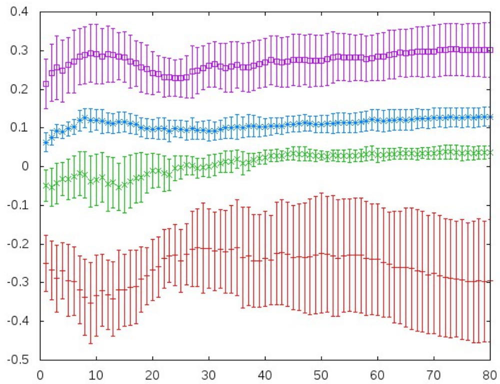
As expected the moderate assimilation depicted in Figure 3b lies in between the other two cases. The gap is actually reduced (a sort of consensus on job satisfaction among the population) but there is no significant collective improvement : the most satisfied display a satisfaction decrease, and the worse off show a little improvement. In that case, it is difficult to assess if the policy succeeds or not.

We now investigate on transition flows over the λ parameter. Results in Table VI show that improvement is almost total in the high contrast context, while high and moderate assimilation show more mixed flows. Thus, in our high contrast, 100% of unsatisfied subjects become satisfied (move above λ) at the end of the scenario, and only 5% of the initially satisfied ones become unsatisfied (95% keep their positive job attitude). In assimilation profile agents show a greater resistance against job improvement : more of them remain in a negative satisfaction, less of them shift to a positive one. The resistance is slightly reduced when assimilation is only moderate.

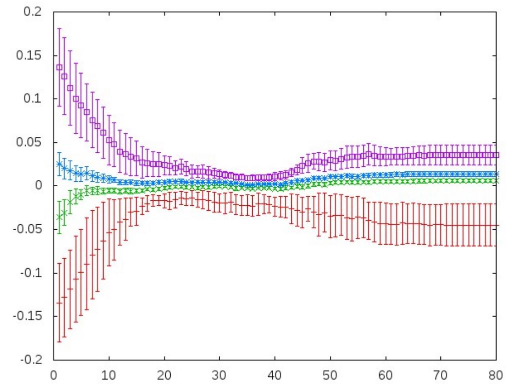
TABLE VI: Transition flows for scenario 1

	Stay neg	Stay pos	pos → neg	neg → pos
PHA	0.38	0.9	0.1	0.62
PMA	0.22	0.8	0.2	0.78
PHC	0.0	0.95	0.05	1.0

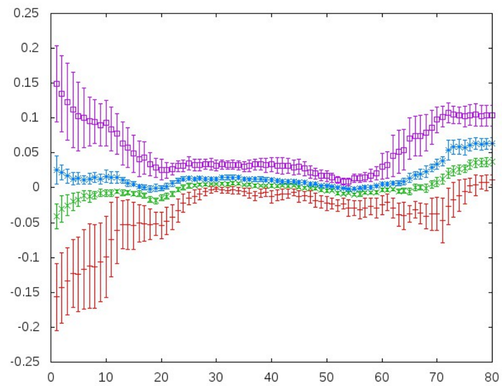
To sum up, the more contrast you have, the better the improvement you will get, but the more organization has to invest on job enhancement policy. Whatever the profile is, aeast 80% of agents remain satisfied and at least 62%



(a) High assimilation



(b) Moderate assimilation



(c) High contrast

Fig. 3: Simulation results from scenario 1

become satisfied. In High assimilation, we found the lowest improvements. As we shown in Table IV, the lowest quartile in PHA have initially the highest job feature values, so maybe there was not much to improve. More convincing, because of the sign reversal at the core of assimilation (remember Table I again), if a PHA agent's situation is improved so that he feels even better than his referent, that will have a negative impact on his social comparison outcome ($IC < 0$), thanks to assimilation.

IV. Conclusion

In summary, we explored consequences of social comparison on job evaluation. We showed that assimilation and contrast lead to very different outcomes in term of response to job content policy improvement. From an organizational point of view, job improvement could lead to unintended consequences. Nevertheless, these results needs further analysis to be confirmed. Along with a deeper sensitivity analysis of the parameters, we could improve the scenario by mixing job feature raises and diminutions, or changing referents over time (mimic a local re-organization of work processes). We also plan to explore more the cognitive profiles. For instance, we will study the behaviour of mixed agent population, made of different cognitive profiles (PHA, PMA and PMC). Nonetheless, we have shown in this preliminary paper how our agent-based model could be used to assess a particular job improvement policy.

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On Fragmentation and Scientific Progress

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1 Introduction

Why are the social sciences so fragmented as compared to the natural sciences, for example physics or biology? What consequences has fragmentation for the overall progress of a field?

The focus of this work is the question why disciplinary fragmentation and scientific progress are correlated. Potential explanations are abound. First, there might be a direct causal relationship between fragmentation and scientific progress. For instance, it could be that the natural sciences are less fragmented into opposing schools because they have developed a scientific consensus very early in their history (Cole, 2001, Chap. 6). Likewise, a high degree of fragmentation might slow down scientific progress, because it hampers the diffusion of ideas and insights (Cole, 2001, Chap. 6). Second, fragmentation and progress might not influence each other, but there might be third variables that affect both outcomes. These factors might be rooted in the nature of the disciplines. For instance, many concepts of social scientific theories are difficult to define, leading to disagreement about their appropriate interpretation and measurement (Cole, 2001, Chap. 1). Unclear definitions of concepts also slow down the process of scientific discovery. Furthermore, institutional factors might affect the degree of fragmentation and progress in the different disciplines (Cole, 2001, Chap. 14). For instance, scarcity in public funding does not only slow down progress but might also further increase competition between scientist and hamper the willingness to interact with competing research teams, which in turn fosters the formation of distinct clusters.

2 Model Specification

We assume a population of $N = 100$ scientists exploring a continuous epistemic space under the effect of social influence of related opinions. The position $\vec{x}_i(t)$ that scientist i occupies in the epistemic space at time t represents his or her current *view*. At time $t+1$, scientist i can either update or not his position. Such a movement in space then represents the *theoretical approach* that the agent follows in his or her investigation. We specify the exploration of the epistemic landscape by the scientist in search for the correct theory as follows:

$$\frac{d\vec{x}_i}{dt} = \underbrace{\vec{v}_i(t)}_{Exploration\ velocity} + \underbrace{\vec{C}_h(t)}_{Convergence} + \underbrace{\vec{\xi}_i(t)}_{Noise} . \quad (1)$$

The *exploration velocity* term is specified as in Vicsek et al. (1995) model for collective motion of self-propelled particles:

$$\vec{v}_i(t+1) = \alpha\vec{v}_i(t) + (1-\alpha)\langle\vec{v}_j(t)\rangle_R \,, \quad (2)$$

where $0 < \alpha \leq 1$ and $\langle . \rangle_R$ means an averaging over all scientists within the radius R. This specification of the exploration speed reflects the desire to produce scientific progress along with one's peers, but also some persistence in the research path taken.

However, unlike the original Vicsek's model, the velocity is not a constant, but varies over time. In fact, each scientist is initially assigned a velocity $\vec{v}_i(t_0)$ drawn from a uniform random distribution. The averaging over neighbors eventually produces an alignment of the velocities vectors of both components of Eq. 2, e.g. the direction and the strength of the vector. Given that agents that meets at a certain position can follow completely antithetical approaches, the size of the velocity vector is usually reduced by the averaging procedure. This represents frictional effects in social interactions.

The *convergence term* $\vec{C}_h(t)$ reflects the attraction to the ground truth. As mentioned also by Hegselmann and Krause (2006), it is not to be interpreted literally, but rather as the feedback that individuals receive from the results of their experiments and continued investigation. The force is suppose to give a weak hint regarding the research direction to follow, but never the exact answer, because otherwise every individual could jump directly to the true value, and this is simply not how scientific research typically develops. Formally $\vec{C}_h(t)$ is modeled as:

$$\vec{C}_h(t) = \frac{\vec{x}_h - \vec{x}_i(t)}{\tau_h}, \tag{3}$$

where $\vec{x}_h - \vec{x}_i(t)$ is the distance between the agent's position and the location of the ground truth, and τ_h is a parameter representing the strength of the attractive force. It implies that initially, when still far away from the ground truth, scientists receive a clear signal of the research direction they should take to approach the truth. However, the closer they get to the true value, the harder it gets to actually make progress.

The noise term $\vec{\xi}_i(t)$ plays a crucial role in our model in a twofold manner. On the one side, we assume (i) Gaussian position noise on the approach hold by a scientist at time t, and on the other (ii) we assume Gaussian angular noise on the research direction followed by each individual scientist at time $t+1$. The position noise, whose standard deviation is denoted by ϵ, acts as white noise, while the angular noise, whose standard deviation is denoted by σ, introduces stocasticity and path dependence in the trajectory followed by the scientist. The former can be interpreted as an measurement error, which can be reduced but never completely eliminated. The latter can instead be interpreted as the inevitable difference between planned and actual research path, or as well as the degree to which a scientist is voluntarily ready deviate from the approach of his or her peers, if he or she is making research in a group.

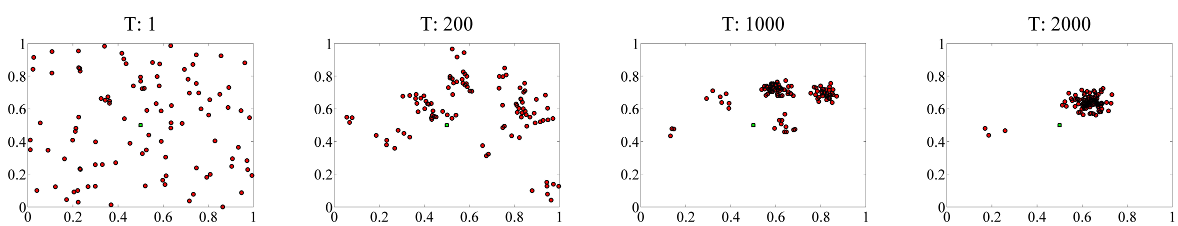

Figure 1: Ideal typical run showing different patterns of consensus and level of scientific progress at four time steps: 1, 200, 1000, 2000. The figure shows the emergence of different schools of thought, that gradually merge together in proximity of the truth.

3 Preliminary Results

We devised the following computational experiment. At the beginning of each simulation we have randomly preassigned agents to $n = (1, \ldots, 30)$ clusters. Each group of agents was then placed on a radius of 0.4 units away from truth, and equidistant from neighboring groups. Afterward, we have then measured the time necessary to achieve a stable *consensus* on truth, defined as 75% of the agents within a radius of 0.05 units from truth. The results are shown in Fig. 2 A. Unequivocally, we observe two different consensus regimes, determined by the value of the interaction radius R. In the case of small R, there is a significant positive relationship between the number of clusters and the time necessary for reaching consensus. In the case of large R, the number of cluster has a very limited effect. Surprisingly, however, the coefficient even takes the opposite sign: the more clusters the faster the consensus is built up. The results from the linear regression of time to consensus over initial number of clusters are shown in Table 1.

We then investigated, the effect of the other social influence variable of our model, i.e. the strength of social influence α. In case of a large radius R, as expected, manipulating α played no major role. However, in case of a small radius R, the results are striking. When social influence is very strong ($\alpha = 0.01$), the R^2 value of the regression is 0.51. On the contrary, if social influence is very weak ($\alpha = 0.99$), no simulation reached consensus within 20.000 iterations!

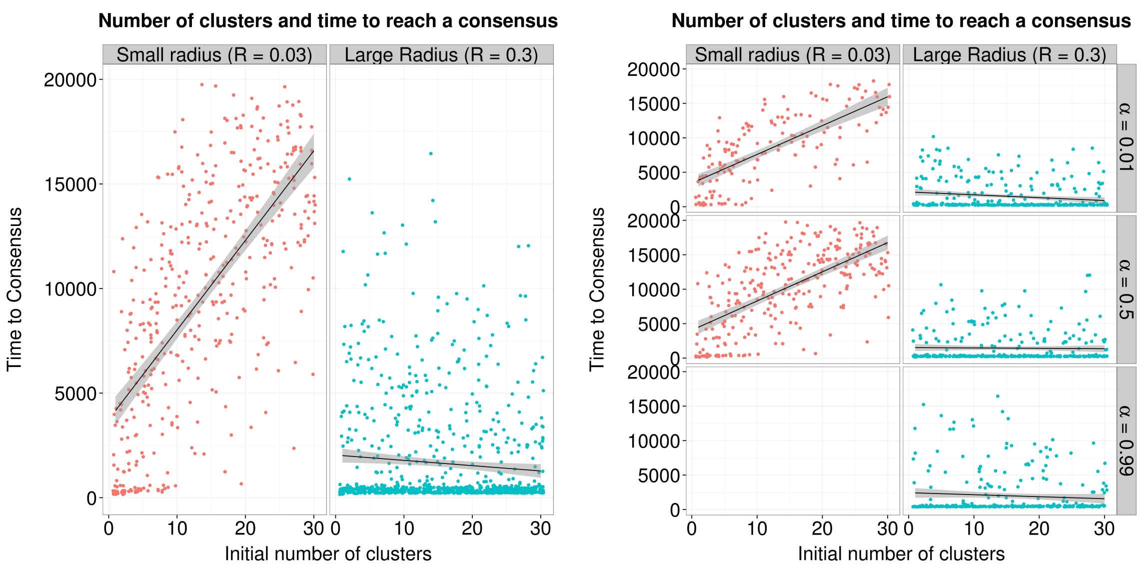

Figure 2: At the beginning of the simulation agents were randomly preassigned to $n = (1, \ldots, 30)$ clusters. Each group of agent was then placed on a radius of 0.4 units away from truth, and equidistant from their neighboring groups. The graph shows the time necessary to 75% of the agents to end up in a radius of 0.05 units from truth. Clusters are a hurdle to consensus if and only if the interaction radius is small. On top of this, if also social influence is also weak, e.g. $\alpha = 0.99$, reaching the truth can be extremely unlikely.

Clustering per se is not a factor that slows down scientific progress. It is rather the nature of social interactions that completely determines how consensus is built up and how long it takes to reach the ground truth. A small interaction radius, and highly individualistic agents represent the worst environmental conditions to form a consensus, but also to find the truth.

Even if clustering does not directly retard scientific progress, it is in fact a proxy for identifying the real cause: the small radius of influence used by the agents in the field. Large radius, even in connection

	Model 1	Model 2	Model 3	Model 4
(Intercept)	3735.33^{***}	2037.75^{***}	3406.91^{***}	2142.94^{***}
	(364.17)	(176.41)	(482.20)	(250.77)
Clusters	428.33^{***}	-25.31^{*}	418.27^{***}	-41.39^{**}
	(22.37)	(9.94)	(32.95)	(14.13)
R^2	0.46	0.01	0.51	0.03
Num. obs.	435	900	155	300

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 1: Model **1**: $alpha = [0.01; 0.5; 0.99]$, and $R = 0.03$. Model **2**: $alpha = [0.01; 0.5; 0.99]$, and $R = 0.3$. Model **3**: $alpha = 0.01$, and $R = 0.03$; Model **4**: $alpha = 0.01$, and $R = 0.3$;

with low social influence, do not generally lead to a clustered field. The confounding nature of clustering and social influence has is such that fragmentation has often been erroneously seen as the primary cause of the slow rate of progress of disciplines like sociology. Our simulation results clearly show that clustered fields can make quick progress if agents are open to social influence, and use a large enough radius to combine the results of investigations of others with their own.

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Generic bottom-up building-energy models for developing regional energy transition scenarios

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***Abstract*—Energy demand from buildings has the largest single share of the global final energy demand, but offers massive energy saving potentials through state-of-the-art technologies and behavioural changes. However, the required speed of technology adoption and behavioural changes to achieve such savings are largely uncertain and embedded in complex socio-technical system. Successful examples of achieving such systemic transition in the energy system are mostly found on the regional scale. Therefore a transition from the existing conventional centralized and mainly fossil fuel-based energy infrastructure towards a decentralized and renewable-based energy infrastructure is required. This research presents a generic bottom-up building-energy model for developing regional energy scenarios. Besides the development of regional scenarios, this model allows for analysing various detailed aspects of buildings' energy demand, such as retrofitting behaviour, technology adoption, and occupancy behaviour with agent-based modelling extensions.**

I. Introduction

ENERGY demand from buildings and activities in buildings account for 34% of global final energy demand, of which three-quarters are for thermal purposes [1]. State-of-the-art technologies as well as non-technological options present a major opportunity to reduce energy demand from buildings drastically in the next couple of decades. According to the Global Energy Assessment Report energy demand for heating and cooling could be reduced by about 46% by 2050 compared to the 2005 levels by applying today's best practices while still more than doubling the usable floor space. The long lifetimes of buildings and building technologies require immediate action to reduce energy demand, but also present a significant risk of lock-in. If less than state-of-the-art technologies are promoted global energy demand from buildings will increase by up to 33% [1].

A wide range of policy instruments has been successfully applied to reduce buildings energy demand including control and regulatory mechanism, regulatory informative instruments, economic and market based and fiscal instruments, and support and information programs. However, no one-fits-all solution has previously been found. In addition, the importance of addressing the broad range of co-benefits (i.e. non-energy benefits such as health, ecological, economic, service provision, and social effects) from reduced energy demand in buildings have been highlighted [1].

Energy demand from buildings therefore not only accounts for a significant amount of the final energy use, offers massive savings including a range of co-benefits, but also restricts the speed of change through the long lifetime of our build environment. In addition, buildings are strongly interlinked with the energy supply infrastructure such as electricity and gas distribution networks, or in some cases district heating networks. Changes in either, the buildings' energy demand or the supplying infrastructure, affect and are constrained by the state of the other. Therefore, a transition from the existing conventional centralized and mainly fossil fuel-based energy infrastructure towards a decentralized and renewable-based energy infrastructure is required. Examples for such transitions are so called energy regions, which show possible transition pathways towards a functional sustainable energy infrastructure at regional scale. Energy regions are regional initiatives which usually envision energy self-sufficiency by using regional energy sources and building a decentralized energy infrastructure [2].

Reducing energy demand in buildings is not just a matter of having the right technological kit in place. End-use technologies hold the greatest potential for climate mitigation [3, 4], but there are challenges in terms of sufficient research and development, widespread adoption, as well as appropriate maintenance and usage of these technologies. The total energy consumption of buildings is determined by demand levels, the efficiency of the

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conversion technologies, their operation and maintenance, and the efficiency of supply and distribution networks [5]. All of these require more or less active involvement of supply network actors, home owners, and occupiers; offer a variety of efficiency options over different lifetimes; and are heavily interlinked and influenced by a variety of policies [6].

Agent-based modelling (ABM) is able to capture such complex interactions between policy interventions, social and technical structure, and individual behaviour [7, 8]. Whilst agent-based models of social systems abound, only recently, work has emerged to simulate the long-term development of energy infrastructure and other socio-technical systems [9-14].

This research presents a generic bottom-up building-energy model for developing regional energy transition scenarios, accounting for the complex socio-technical interrelations typically found in contemporary energy systems. We further present a range of potential behavioural extensions to the model addressing individual aspects of the energy demand from buildings, and discuss further research.

II. Case Study Regions

We analysed energy transitions in two Austrian energy regions: oekoEnergieland in the district Güssing, and Energieregion Weiz-Gleisdorf. These were selected because they show significant differences in their initial conditions, applied strategies and transition processes. Furthermore, in both regions efforts to foster a transition towards a sustainable energy region started in the 90s, providing a wealth of data as well as committed stakeholders for collaboration. For both regions detailed data about the regional energy resources, energy infrastructure and energy demand, in particular the building stock, its' size, technical standard, and development were collected.

III. Methods

1. *The need for generic building models*

Put simply, the energy demand from an individual building depends on its size, the installed building envelope insulation, the efficiency of the heating system, and the behaviours of occupants (i.e. room temperature, hot water and electricity demand). On a regional scale those already numerous aspects are multiplied by the number of building, and the heterogeneity of their attributes. Any individual aspect of energy demand from buildings (e.g. heating technology adoption or end-user energy saving behaviour) is therefore embedded and co-evolves in the broader context of the build environment and its interrelation with the energy infrastructure. Consequently any research addressing these aspects relies on some kind of energy demand model from buildings. In this research we present a generic bottom-up building-energy model, which can be applied to different regions. It is intended to present the backbone for a range of behavioural models addressing individual aspects of buildings' energy demand.

2. *Model overview*

In the following we present an overview of the model structure and background data used following the (ODD) protocol to describe agent and individual-based models [7, 8].

Purpose: The model aims to portray the building stock's energy demand and heating systems transition in the energy regions. Furthermore, it is designed to test the effectiveness of different policy measures on overall energy demand, cumulative energy savings and energy source used. It is based on data from the statistical office in Austria and a literature review of buildings' and heating systems' efficiencies, renovation rates and cycles, and stock change.

Entities, state variables and scales: Buildings and a system level policy entity are the two entities modelled. Buildings are categorized by type of building (i.e. single family house (SFH), multifamily house (MFH), non-residential building (NRB)), construction period and type of heating system. Buildings' end-use energy demand is the sum of their heating, hot water and electricity demand [kWh/m^2] multiplied by the energy reference area (ERA) (i.e. useful dwelling floor area (UFA) times a reference factor for residential buildings). Heating demand is determined by the building's envelope standard, which itself depends on type, age and renovation of the building. For hot water and electricity fixed reference values from literature were used. End-use energy is provided through main heating systems and, in about 50% of the buildings, through additional secondary or supporting heating systems, primarily for water heating. Main heating systems are differentiated by type of centrality (i.e. district heating, central building heating, or room or flat heating systems) and energy source used (i.e. oil, wood, wood-chips, coal, power, gas, solar or heat pump, others, waste-heat), defining their conversion efficiency. In addition to main and secondary heating systems some of the buildings are equipped with photovoltaic systems (PV), generating a certain amount of the locally demanded electricity or feeding in any surplus.

The system level policy entity sets measures to influence the general building stock fluctuation (i.e. new construction and demolition rates), buildings' envelope renovation rates and standards, and renovation rates, standards and types of heating systems.

The model has a one-to-one scale for the two energy regions meaning each building is represented. An artificial space representation, based on housing density distributions, is used for demonstrative purposes. Each time step represents one year and the model is run for 50 years (i.e. 2000-2050).

Potential behavioural extensions, such as an analysis of occupancy behaviour, or retrofitting would then include appropriate agents (i.e. occupants, owners, contractors, advisors, etc.).

Process overview: In the following we elaborate on the main execution routine represented in the model. For each year the following six key processes are modelled:

(i) Setting the political (i.e. regulation or incentives) framework conditions according to the scenario modelled, which are based on literature and expert interviews in the regions.

(ii) Stock fluctuation including two sub-procedures; demolitions and new buildings. Only buildings of a certain age and which haven't been recently retrofitted are worth demolishing. The number of buildings demolished is determined based on a demolition rate. New buildings are constructed based on a construction rate. Both rates can be fixed throughout the simulation run or dynamically changing depending on the scenario. Empirical data from the regions are used to run the reference scenario. The attributes of the new buildings (except the heating system which is set new) are inherited from a randomly selected building from the stock in the generic model.

(iii) Envelop renovations are either determined through a fixed rate or by the time past since the last renovation and the performance of the building. In both cases only buildings above the energy demand standard (i.e. buildings with higher energy demand) are refurbished. They get a new heating demand, which is drawn from a distribution below the regulatory standard. Renovation rate is set to currently observed values (i.e. 0.8%) in the reference scenario.

(iv) Heating systems are replaced once they reach their end of life. The type of new heating system is determined from a frequency table according to regional scenarios. The efficiencies of the installed systems increase with the expected technology trajectories, which are derived from literature.

(v) New photovoltaic systems are installed or old once are replaced based on the regional adoption projections based on empirical data.

(vi) Finally, buildings' main attributes such as energy demand per area and overall energy demand per year are updated.

3. Details

Initialisation: The model is initialized with buildings stock and technology data from 2002. Since this data is only partially available on the regional scale several buildings' and technologies' attributes have been calculated referring to data sources on national or district level. Four chunks of data have been collected to initialize the model: (i) building stock data including number of buildings of a certain type, construction period, and energy carrier in the two study regions, (ii) average energy reference area per building type and construction period, (iii) heating, hot water, and electricity demand data, and (iv) heating technology specific data such as current efficiencies and expected efficiency increases.

(i) Building stock data (i.e. number of buildings) of the two energy regions was collected regarding the following four parameters; construction period, type of building, type of heating system, and the corresponding energy carrier.

(ii) Using the Usable Floor Area (UFA) to calculate the heating demand for each building would neglect large parts of buildings, which are usually heated but not accounted for in the UFA. Therefore, the energy reference area (ERA) is calculated as suggested in the Austrian building standards [15], by multiplying the UFA by a reference factor. Data on UFA was derived from the apartment and flat census 2001 [16] on the district level. The reference factor depends on the type of building. A value of 70% for SFH, 60% for MFH, and 65% for residential community houses was derived [17]. For non-residential building average energy reference areas were derived from the ZEUS database [18].

(iii) Heating, hot water and electricity demand values per square meter of ERA were derived from literature. The heating demand was derived for each building type by investigating a broad range of literature. Depending on the scope of the studies heating demand values for different building categories vary quite drastically (Figure 1). Based on these literature values heating demands distributions could be estimated per building type and construction period. This basically indicated the buildings envelope insulation rate. For hot water and power reference values per square meter and year from literature were used. The hot water demand is based on reference values from institute for housing & environment (IWU) [19] and Energy Saving Regulation of Germany (EnEV) [20] for residential buildings, and on the ZEUS database [18] for non-residential buildings. Power demand for residential buildings were based on provincial data from the statistical office in Austria [21], and again on the ZEUS database [18] for non-residential buildings.

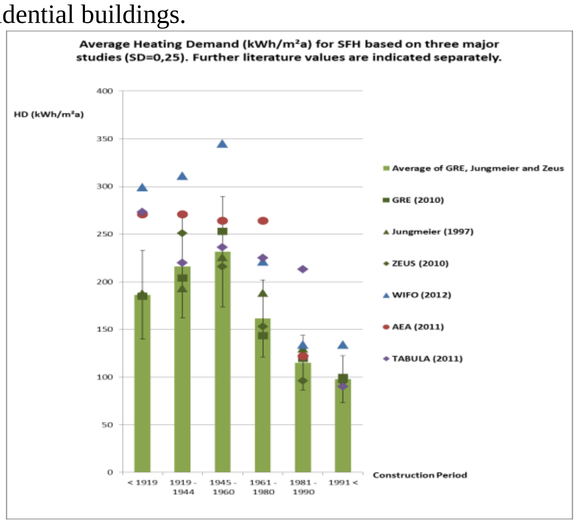

Figure 1: Comparison of heating demand per construction period for SFH

(vi) Based on a broad literature review data for the energy efficiencies of different heating system technologies was collected [22-28]. Heating system technology efficiency indicates how efficient the respective energy carrier is converted into heat, for room heating and hot water. Based on average heating system age of about 15 years in the 2000 stock average heating efficiencies from 1990 were used to initialize the model. State-of-the-art heating efficiencies for 2000 as well as expected efficiency improvements, and the resulting efficiencies, for 2020 and 2050 were derived form a range of studies looking at different heating technology development pathways (Figure 1).

In addition data for secondary hot water systems and photovoltaic (PV) systems have been collected. *Secondary hot water systems* can provide a significant amount of the total energy consumption of a building especially if the building has already a high energy efficiency standard (i.e. low heating energy demand). In the study regions more than 50% of all residential buildings have secondary hot water systems [24, 25, 29]. In most of the cases these are electric or gas based systems, with a minority of solar thermic and hot water heat pumps. *Secondary power systems* on a domestic scale are mainly linked to photovoltaic systems (PV), micro wind and micro-CHP systems might be potential future technologies, but are not considered in this model. Annual PV installation in Austria showed a step change between 2008 and 2012, as installation doubled in each of these years [30]. At the same time the mean module installation price dropped by almost 50% [30]. The provinces where the two case studies regions are located show particularly different pictures regarding installed PV capacity. The province of Styria (Weiz-Gleisdorf) is the leading province in Austria for PV installation, with a total of almost 54 MWpeak installed. On the other end of the scale, the province of Burgenland (Oekoenergieland) has the smallest installed capacity with 3.5 MWpeak [30]. The most installed systems in Austria have a size of 5 kWpeak [30] which is equal to about 40 m^2 of installed panels [31], and provides about 950 kWh per year and kWpeak installed [30]. For the base model (i.e. without behavioural extensions) logistic growth rates are assumed mirroring the two regions different PV adoption patterns.

IV. Preliminary Results

In the following, we present a selection of preliminary results from the generic model without behavioural extensions.

1. Renovation rates vs. legislation standards

In a first analysis a *reference scenario* with current legislation standards (i.e. 100 for renovation and 80 for new builds [kWh/m^2*a]) and a current renovation rate (i.e. 0.8%) was compared to a *legislation scenario* with tightened standards (i.e. decreasing to 50 and 25 [kWh/m^2*a]), a *renovation scenario* with doubled renovation rate (i.e. 1.6%), and a *combination* of the two. In all cases a static stock (i.e. fixed demolition and construction rates of 1%) was assumed.

On the final energy demand in 2050, tightened legislation clearly has the highest impact reducing the annual regional energy demand between 50% and 60% depending on the renovation rate. However, considering the cumulative savings over 50 years an increased renovation rate is almost three times more effective than the tightened standards. This of course depends on the scope of analysis, running the model for 100 years instead of 50 evens out the difference in cumulative savings.

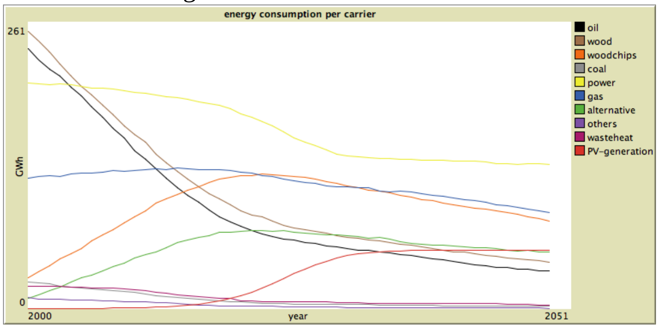

Figure 2: Development of energy consumption per carrier in the energy region Weiz-Gleisdorf

2. Changing energy carrier mix

The model allows for tracking the change of energy carriers under different scenarios. In the reference scenarios the frequencies of the installed heating systems observed in the first decade of this century were expected to be static. In such a business-as-usual scenario the initially dominant energy carriers (i.e. oil and wood) quickly drop and are among the least important in 2050. Heating systems based on woodchips, gas, and alternative systems such as heat pumps or solar thermic systems initially see increasing demand. However, the overall energy consumption of these carriers starts to decrease in about 2025 when energy heating demand decreases as more and more buildings are retrofitted. Although no electric main heating systems are installed anymore, electricity consumption only decreases slightly throughout the simulation, as power demand in buildings stays the same. This trend is only mitigated through the increased power generation from PV systems after 2030. Nevertheless electricity demand will become the most important energy carrier in the regions in the future (Figure 2).

V. Discussion

Building stock fluctuations, envelope renovations, heating system replacement and PV installation, are all represented as drastic simplifications of the actual actor interactions and decisions determining these processes. However, this simplification allows for sensitivity analysis of the individual processes and zooming into individual energy demand aspects without overly complex models. In the following we briefly discuss some of these potential extensions.

Building stock fluctuations could be made more elaborate by including population dynamics and service demand per capita (i.e. increasing floor area and room temperature). This route could be particularly interesting if large population fluctuations are expected or changes in the service demand (e.g. rebound effects) are the focus of analysis.

Homeowners' decisions to renovate are influenced by a range of project specific and personal factors and often done in collaboration with construction experts and consultants [32]. Extending the model in this direction would allow addressing the two key parameters discussed above (i.e. renovation rate and building standard). Doing so, the most effective policy levers as well as potential trade-offs (e.g. too tight standards could lead to a reduced renovation rate) could be identified.

Environmental impacts or benefits in the case of a reduction from buildings' energy demand largely depend on the type of heating system installed. Further analysing what determines actors heating replacement and new installation decisions would shed light on what policy instruments could be most effective in reducing environmental impacts caused by buildings' energy demand. Furthermore heating systems are the link to regional energy management as regional energy resources are limited. A sustainable energy management strategy therefore needs to address resource potentials and heating systems altogether.

VI. Conclusion

This research introduces a generic bottom-up building model to analyse different regional transition pathways. Input data are gathered from two regions and can be extended to other regions. Besides developing basic scenarios this model can be extended in various directions as exemplified above, which is really the central purpose of the model. The main advantage of such modular setting lies in the possibility of analysing single aspects of buildings' energy demand within their full complexity (i.e. actor interaction, learning, adaptation, etc) without the need for modelling every aspect of the problem, as these are covered by the generic model at first. If individual aspects overlap (e.g. envelope and heating renovations) they can be incrementally included with a clear idea about the impact of each of those aspects.

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The Efficiency of Organizational Withdrawal vs Commitment

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Abstract—**Actors within an organization usually do not behave as expected at design-time. There are diverse reasons for this, notably the actors' motivation and organizational commitment. In this paper, we explore the efficiency of a concrete public organization in the context of the Latin-American culture, to the light of the *organizational commitment* of its members. In order to evaluate how much each member of the organization is committed, we associate to each one a parameter that quantifies its commitment and we evaluate by simulation the impact of this parameter on its behavior an the organization performance. With a model of the organization as it was intended to operate at its foundation, we proceed to a number of simulations to find the parameter values that yield the actual observed working of the organization. By the way, we found that withdrawn behaviors have much more impact than committed ones.**

I. Introduction

Let us define an *organizational setting*, or an *organization,* as a set of *goals* to be achieved, or more generally some purpose, a set of *members* who contribute to their achievement, a set of *resources* (material or cognitive such as information, procedural knowledge, expectations, etc.), and a set of *rules* about the handling of resources by the members intended to enable the goals achievement, all these elements being more or less precisely defined and recognized depending on the nature of the organization.

The organization's rules are intended to shape and so to regulate the participants' behaviors in order to ensure, or at least to allow the achievement of the organization's goals. However, in most organizational settings, the participants do not behave as they are expected to do. This fact may be due to the quality of the rules, which are more or less easy to apply and demanding for participants, and also are more or less effective for the achievement of the organization's goals.

But rules are abstract in nature so that the participants need to interpret them in every concrete situation where their application might be considered. Anyway, in many particular cases, the letter of a rule can't be applied and it must be adapted to the specificity of the current case while keeping the spirit of the rule as much as possible. Moreover, a strict interpretation of rules does not suffice to ensure the proper operating of an organization and, insofar participants are interested in its success, they do collaborate and they work to rule only in exceptional circumstances.

In his interpretation of rules, each participant considers the organization's goals but also his own individual goals. Indeed, the membership of a participant to an organization is never completely motivated by the achievement of organization's goals and any member expects to obtain some individual rewards from his participation. Whatever the applicability of the rules of an organization, the behavior of each participant is driven by a mix of his own goals with the organization's goals, and this causes some deviation between his actual behavior and the intended implementation of the rules.

Let us call the *aim* of a participant the mix of his own goals and, according to its role(s) in the organization, the goals of the organization that drives his behavior with regard to other participants and the whole organization. The relative weight of these two components is mainly determined by his *in-group identification* that characterizes the strength of his membership to the organization and includes both a motivational component (his attachment to group goals) and a cognitive component (sharing of the group culture) (Simon, 1998). There are several models of this concept, see for instance (Kelly, 1993), (Tropp &Wright, 2001), (Cameron, 2004). According to (Leach et al., 2008), the in-group identification of an individual may be assessed by his self-definition – the self-stereotyping as being similar to others and the group homogeneity – and his self-investment – the satisfaction of being a member, the solidarity with others and the subjective importance of membership.

The in-group identification of a participant is a psychological trait tightly related to his *organizational commitment* attitude (Kanter 1968). This concept is the matter of a wide literature in management studies since the organizational commitment of employees is an essential factor of the proper working of firms and any organization, see for instances (Meyer & Allen, 1991), (Soligen et al. 2008) and (Subhashini et al. 20014). It determines behavioral attitudes such as lateness, absenteeism, turnover or organizational citizenship behavior to defend the group against threats. Notably, the organizational commitment determines the participant's willingness to make efforts to support the organization to achieve its objectives and so his propensity to collaborate with others. On the opposite, a withdrawal behavior gives rise to a weak, or even negative involvement in the running of the organization; it may come from job dissatisfaction, retaliation against unfairness, job stress, lack of empowerment or a strong identification in another organization (Beehr et al. 1978).

SocLab is a theoretical framework for the study of cooperation between the actors within an organization, based on power relationships (Sibertin-Blanc et al., 2013a). It is implemented in a platform that allows (1) to describe the structure of an organization as an instance of a generic meta-model; (2) to study structural properties of the model of the organization in an analytical way and to explore the space of its possible configurations (and so to discover Pareto optima, Nash equilibria, structural conflicts and so on); (3) to compute by simulation how it is plausible that each actor behaves with regard to others within this organizational context. The SocLab simulation algorithm makes each actors to adopt the behavior that provides him with the means to achieve his goals, so that in most organizational settings, actors reciprocally cooperate with one another (Sibertin-Blanc et al., 2013b). This algorithm does not cope with the relative organizational commitment or withdrawal of the actors, so that it falls short for the modeling of organizational settings where this factor plays a significant role.

Considering the importance of the actors' involvement for the performance of some organizations, the aim of the paper is to show how to deal with the actors' commitment in order to enhance the SocLab simulation algorithm, and to illustrate the application of this new model of actors' behaviors to a concrete organization. The paper is organized as follows. We first give an overview of the SocLab modeling framework and how, according to the current simulation algorithm, every actor selects his behavior with regard to others. In the third section, we will present the case of a real organization which functioning cannot be understand without considering the organizational commitment and the withdrawal of the actors. In the forth section, we present how to assess the withdrawal or commitment of each actor. Section five presents the SocLab model of the case while section six supplies and analyzes the outcomes of the simulation experiments before to conclude.

II. The SocLab Framework

To enable the modelling of social relationships between the actors of an organization, SocLab proposes a meta-model of organizations that catches the common concepts and properties of social organizations. This meta-model is grounded upon the Sociology of Organised Action (Crozier and Friedberg, 1980) and it is intended to be instantiated on specific cases as models of concrete or virtual organizations. Accordingly, the model of the structure of an organization is composed of instances of *Actors* and *Relations* that are linked by the *Control* and *Depend* associations.

Fig. 1 shows the meta-model of organizations' structures as a UML class diagram. A relation is founded on an organization's resource, or a set of resources to be jointly used, and it is controlled by a single actor. Resources are material or cognitive (factual, procedural or principled believes or expectations) elements required to achieve some wished actions, so that their availability is necessary for some actors. The *state* attribute of a relation represents the behavior of the controller actor with regard to the availability of the resource for the ones who need it. Its range of value SB (Space of Behavior) goes from the least cooperative behavior, -1, of the controller preventing the access to the resource, to the most cooperative behaviors, 1, favoring this access, while the zero value stands for neutral behaviors.

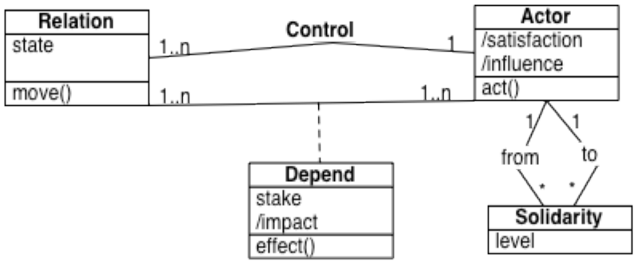


Fig. 1. The core of the SocLab meta-model of the structure of organizations

The *stake* attribute of the dependence of an actor on a relation corresponds to the actor's need of the relation, that is the usefulness of the underlying resources for the achievement of its goals and the relative importance of these goals. Stakes are defined on a scale:

null = 0, negligible = 1,… , significant = 5,… , critical = 10.

The *effect function* evaluates how much the state of the relation makes the resource available to the actor and so provides him with an amount of *capability* to reach his goals. A function $effect_r : A \times SB_r \dashrightarrow [-10, 10]$ has values in:

worst access = -10, ..., neutral = 0, ..., optimal access =10.

The shape of an effect function is designed according to the potential contribution of the resources underpinning the relation to the actor goals.

In addition, actors may have solidarities the ones with regard to others, defined by as a function *solidarity(a, b) ---> [-1, 1],* where negative values correspond to hostilities and positive values to effective friendships.

Defining the state, or configuration, of an organization as the vector of all relation states, each state $\mathbf{s} = (s_{r1}, \ldots, s_{rn})$ determines on the one hand how much each actor has the means he needs to achieve his goals, defined as:

$$satisfaction(a, s) = \sum_{c \in A} \sum_{r \in R} solidarity(a, c) * stake(c, r) * effect_r(c, s_r)$$

and, on the other hand how much it contributes to the satisfactions of each other actor:

$$influence(a, b, s) = \sum_{r \in R;\ a\ controls\ r} \sum_{c \in A} solidarity(b, c) * stake(c, r) * effect_r(c, s_r)$$

and $influence(a, s) = \sum_{b \in A} influence(a, b, s)$.

The aggregation of the actors' satisfaction determines how much they have the means to achieve their goals. As these goals include the goals of the organization, it determines how well the organization operates. The simplest way to aggregate the satisfactions is obviously to sum them, and we do so in the study of the case, but any other operator may be used according to the specificity of the case under consideration.

This interaction context defines a *social actor game*, where each actor seeks, as a meta-objective, to obtain from others enough satisfaction to reach its goals and, to this end, adjusts the state of the relations he controls. At each step of the game, every actor has the possibility to move the values of the states of the relations he controls, and this change of the game's state modifies the satisfaction of actors who depend on these relations. Let (s_{r1}, … , s_{rm}) be a state of the organization and (c_{r1}, …, c_{rm}) be moves such that ($c_r + s_r$) ∈ SB_r and c_r is chosen by the actor who controls r. Once each actor has chosen such an action, the game goes to a new state defined as

$$\textit{Transition: } [-10;\,10]^m \times [-10;\,10]^m \rightarrow [-10;\,10]^m$$
$$(s_{r1}, \ldots, s_{rm}), (c_{r1}, \ldots, c_{rm}) \mapsto (s_{r1}+c_{r1}, \ldots, s_{rm}+c_{rm})$$

Unlike games considered in economics, the end of a social game is to reach a stationary state: there, actors do no longer change the state of the relations they control, because every one agrees with the level of satisfaction provided to him by the current state of the game. A *regularized* configuration has been reached and the organization can lasting operate in this way.

The simulation module of SocLab makes the actors to jointly play the social game. We just give an overview of the principles, the simulation algorithm is detailed in (Sibertin-Blanc et al, 2013b). The actors are assumed to follow a bounded rationality (Simon 1982) that is implemented as a self-learning process of trial and error based on a system of rules of the kind (*situation, action, quality*). Each actor manages a variable that corresponds to his *ambition*, and the game reaches a stationary terminal state when every actor gets a satisfaction that exceeds his ambition. The length of simulations is a good measure of the difficulty of actors to find how to cooperate and in some cases they do not succeed (for instance in a circular organization where a depends on b, which depends on c, which in turn …). This ambition is initiated at the highest possible value of the satisfaction for that actor and it progressively comes closer to its current level of satisfaction, according to a reality principle. Each actor also manages a dynamic rate between exploration and exploitation that determines the strength of its search for a higher level of satisfaction. An essential property of this algorithm is to assume that actors have no information about the structure of the game, very few about its current state and bring into play limited cognitive capabilities, see (Sibertin-Blanc et al, 2013b) for details.

To sum up, each simulation run yields a regularized configuration characterized by the state of each relation, i.e. the level of cooperation of the actor who controls this relation, and the resulting levels of satisfaction and influence for each actor.

III. The Modelled Case: A Team in a Latin-American Public Foundation

The study of a concrete organization is introduced to illustrate how taking into account of group identification can help in auditing organizations or designing policies likely to promote collaboration. *TDPM* is a team inside a Public Foundation that is an agency of the Ministry for Science and Technology of a Latin-American country. This Public Foundation (or *the Foundation*) is entrusted with the investigation, development and spreading of socially pertinent free technologies and conducts various projects. TDPM (Team for Designing a Planning Methodology) is in charge of designing a methodology for Institutional Planning in the Public Sector and its functioning evidences in-group identification issues.

A. The origin of the agency: The historical/cultural context of the organization

The motivation for the design and creation of the Foundation was the lack of pertinence of technology, due to certain cultural problems. Consequently, to understand why this Foundation (of which the TDPM is part) has been instituted, and which is its aim, a short description of his historical/cultural context is necessary (following (Fuenmayor, 2006)).

A culture is in a good state if people looks for and *cultivates/cares* common good, and if it is auto-generative. On the other hand, a culture is ill if it is not autonomous, for instance, when it is highly imitative and oriented by external influence, actors and interests, creating some processes of change that disturbs its auto-generative capacities.

Until the first decades of 1900, the Latin-American culture was in a good state. It was mainly of a rural character and auto-generative. Common good (including the culture) was cultivated. After these decades, a high percentage of people from the country side moved to the cities (the rate: "people in the cities / people in country side" changed from 20/80 to 80/20 in many countries). Along this, imitation of other cultures promoted by, for instance, communication media like radio, TV, CINEMA, etc., increased the demand for material instruments, things, and technology that were poorly pertinent for the Latin-American society. Over time, also the quality of education and caring of common good in general decreased. Finally, the culture became ill (at different degrees, in almost all countries) in the sense described above as it lost its auto-generative capacity. As a result, socially negative attitudes appear in organizations, e.g., workers distract their effort towards activities different from their duties, creating an institutional problem in the public sector.

B. The Foundation: activities and work process

In one of the Latin-American countries facing the strongest cultural difficulties, a group of researchers and public servants have promoted the creation of the Foundation (of which the TDPM is part), aiming at dealing with and changing this cultural and institutional situation. The aim of the Foundation is to create free pertinent technologies. In this sense, there should be promoted: i) a critical/reflexive attitude (*reflective/Critical Action*), in order to be able to discern about pertinent/appropriate technologies; and, ii) spreading of the products in the society, in order to increase their impact. The Foundation is then designed as having four departmental units for its basic activities, supervised by a Management Unit. The basic units are:

- Pertinence Unit: advises other units about the relevance of technologies. Its main concern is to reflect on the nature of the society, its problems and needs.
- Research Unit: designs free-technology methodologies, organizational patterns and tools.
- Development Unit: produces the tools for the methodologies.
- Technological Spreading Unit: spreads the use of the methodologies and tools in the society.

The Foundation is involved in projects of software, hardware and telecommunications, including organizational forms, in collaboration with other public institutions and enterprises. TDPM is a team gathering Foundation's employees in charge of one of these projects: developing a planning methodology. The work process of TDPM follows the path shown in Fig. 2. The meeting/dialogue activity (in the middle of Fig. 2) allows to coordinate actions of the members of the team and to increase their common understanding/view of the project.

C. *The TDPM*

The analysis of TDPM organization regarding group identification issues leads to identify seven actors: two actors from the Research Unit, two actors from the Development Unit, and one actor from each of the three other units. Their work process is schematized in Fig. 2 and we summarize the duties of each actor as follows:

Director: It manages the work of others and allocates the means they need. It is also responsible for delivering the products of the Foundation to the society and the Ministry for Science and Technology.

- Researcher_C: It designs the planning methodology, and specifies the requirements of the tools. It is responsible for the quality of the methodology and its effective pertinence.
- Researcher_W: It operatively helps the Researcher_C in elaborating detailed requirements of the methodology.
- Developer_C: It designs and develops software tools for the implementation of the methodology and is responsible for the quality of the tools.
- Developer_W: It helps the developer_C actor operatively, developing particular functionalities of the software.
- PertAdviser_C: It investigates the state of the art and is responsible for advising the rest of the team, notably the researcher about the social pertinence of methodologies.
- TechSpreader_W: It is responsible for spreading the product, i.e., for promoting the use and social impact of the methodology.

D. *The members' expected and actual behaviors*

At the time of its creation, the Foundation was design assuming workers being highly identified and committed with the Foundation and strongly collaborative with their partners. The workers are expected to show a critic and autonomous attitude, cultivating themselves in this way, in order to find out the sense and pertinence of the technology in the country. As in any organization, the more the collaboration of actors and the coordination of their activities, the better the suitability and quality of the products provided by the team.

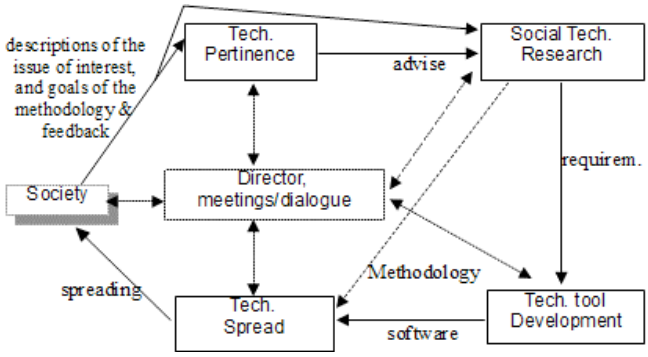


Fig. 2. Main interactions within TDPM for developing the planning methodology. It completes a loop from identifying requirements of the society to spreading the methodology into the society.

However, the Foundation suffers from the above mentioned cultural problems and from negative attitudes that prevail in the considered country. A common withdrawal attitude pays little attention to organizational duties and gives preference to personal activities such as the membership to a political party or involvement in the academic milieu. Fortunately, not all actors have this kind of behaviour and there are also actors highly involved with the organization. Some actors of TDPM are highly engaged and creative, identified with the organization and hardworking, while other actors are weakly identified with the organization, and thus their work is of poor quality and they are little creative.

In the TDPM, the actors pertAdviser_C, researcher_C and developer_C reveal to be highly Committed while the other four actors are Withdrawn at different degrees.

IV. Evaluation of the Commitment and Withdrawal of Actors

There are obvious differences in the commitment of the actors of TDPM, so the question arises to evaluate their respective levels of commitment in order to evaluate the magnitude of the management actions that could improve the involvement of the withdrawn actors. This evaluation can be done using a GI (Group Identification) parameter associated to each actor, where GI = 1 corresponds to a fully committed actor, GI = -1 corresponds to a fully withdrawn actor while GI = 0 corresponds to a neutral attitude which is not particularly committed or withdrawn.

What about the impact of the GI parameter on the actors' behavior-selecting process? In the SocLab simulation algorithm, actors are mainly utilitarist as they just search to obtain a good level of *satisfaction*, i.e. the capability got from others to reach their own goals by having a good access to the resources they need. To account for the commitment of an actor, we may assume that it is also interested in exerting a high level of *influence*, i.e. in the capability it distributes to others. As for a withdrawn actor who devotes its energy to another matter than its job, it searches on the contrary to reduce its influence. This leads to consider that the behavior-selecting process of an actor will no longer be driven by just its satisfaction but by its *aim,* defined for an actor *a* in a state ***s*** = (s_{r1}, …, s_{rn}) of the organization as:

*aim(a, s) = (1 - abs(GI(a)))*satisfaction(a, s) + GI(a)*influence(a, s)*

where the *abs()* function returns the absolute value of a number. A neutral actor will search just for a high satisfaction, a committed actor will also search for a high influence while a withdrawn actor will also search for a low influence.

In the capabilities exchanged among actors, there is a specific amount that appears both in the satisfaction and the influence of an actor, that is its auto-satisfaction *influence(a, a, s)*. For committed actors, this term is not affected by the value of GI, and for withdrawn actors it means that the actor searches to disfavor itself. To avoid these inconsistencies, we take off the auto-satisfaction of an actor from its influence and so define the aim as:

*aim(a, s) = (1-abs(GI(a)))*satisfaction(a, s) + GI(a)*(influence(a, s) - influence(a, a, s)).*

For the modeling of TDPM, we could design a model describing the actual observed configuration with a neutral GI for all actors, and then search for a distribution of GI that makes TDPM to operate properly as wished by its promoters. Proceeding in this way would provide the deficit of commitment of actors; for instance, for a withdrawn actor, we will find a positive GI that indicates how much it should increase its (negative) investment for the organization to recover a better working. This way would assume that the effect of a change in the Group Identification of an actor is quite linear and that withdrawal is just the opposite of commitment. This is a very strong hypothesis that is not always verified in psychological matter, as shown by the well-known case of risk-aversion (this is why SocLab use bipolar scales for behaviors (i.e. the state of relations) and capabilities).

So we will process in another way. We will model TPDM as it was expected to operate by its designers (see A and B above) with actors featuring a neutral GI, and then search for a distribution of GI whose outcomes correspond to the actual observed behavior.

V. The SocLab model of TDPM

We will now apply this approach to the TDPM case study. The SocLab model includes the seven actors previously introduced and each actor controls a single relation that synthesizes its means to influence others. This model has been developed in interaction with persons who are or have been involved in TDPM, with whom also the simulation results have been shared and discussed. A more extensive description of TDPM and its model are given in (Terán et al., 2013) and indications about the designing of SocLab models are given in (Sibertin-Blanc et al. 2013a).

Table I shows the actors' stakes and Table II the effect functions. We cannot discusses these tables in detail and just give some comments. The distribution of stakes shows how much each actor depends on the behavior of each other for the achievement of its goals, assuming that these goals are just determined by its role in the organization. Resercher_C depends only for 2 points on itself (while others depend on 3 or 3.5) because it is the responsible for the project. The shape of the effect functions is very standard: each one benefices of the work done by others and is fully satisfied by a moderate effort.

Table III show the solidarities of each actor toward its colleagues that reveal to be reciprocal. It is due to actors common interests and activities related with: (i) academicism, i.e., accumulation of academic curriculum that are beyond the benefice of TDPM and result from a personal interest, in the case of actors TechSpreader_W and Researcher_W; (ii) politicism, related with their participation in a political party that favours the involved actors, in the case of the actors Director and PertAdviser_W. Due to the solidarity between the Director and PertAdvis_C, the former will get a lower satisfaction than the other withdrawn actors, and PertAdvis_C a higher one than the others committed actors.

VI. Results of experiments

All the simulations are run 100 times and we just present the average values. We first give the simulation results with a null GI for all actors, i.e. as intended by the promoters of the Foundation. In this case, TDPM operates well and simulations are short: actors do not have difficulties to cooperate and they do collaborate. Then we calibrate the actors' GI parameters to find the values that provide simulation results close to the operating of TDPM that is actually observed.

A. The expected operating of TDPM

Table IV shows the distribution of capability of actors one another at the mean configuration resulting from simulations; the standard deviations are between 0.3 and 1.4, quite small with regard to the range of values (around 190). Table V shows the same results in percentage, i.e. as *(value – min_value) / (max_value – min_value)*. The differences in value do not produce the same differences in percentage because the actors do not have the same range of capabilities. As the actors of the TDPM model are strongly dependent on one another, each one cooperates to the best of its possibilities so that results are very close to the ones at the "optimal" configuration where each actor gives 100% of its influence and the maximum of the total actors' satisfaction is reached. However, due to the shape of the effect functions, satisfactions at the mean configuration are higher (6 or 7 points) than the mean satisfactions (respectively: Director 83.69, Researcher_C 83.03, Researcher_W 85.54, Developer_C 83.93, Developer_W 83.73, PertAdviser_C 83.17, TechSpreader_W 84.35).

TABLE I. DISTRIBUTION OF THE ACTORS' STAKES (IN COLUMN) ON THE RELATION; VALUES ON THE DIAGONAL SHOW THE WEIGHT OF AUTO-SATISFACTIONS.

	director	**research_C**	**research_W**	**develop_C**	**develop_W**	**pertAdvis_C**	**techSpread_W**
projectSupport	**3.5**	2.0	1.5	1.0	1.0	1.0	1.5
researchMeth_C	1.5	**2.0**	2.5	1.5	1.5	1.5	1.0
researchMeth_W	1.0	1.5	**3.5**	1.5	1.5	1.0	0.5
develTools_C	1.0	1.0	0.5	**3.0**	2.0	1.0	1.0
develTools_W	1.0	1.0	0.5	2.0	**3.0**	1.0	1.0
pertinence	1.0	1.5	1.0	0.5	0.5	**3.0**	1.5
techSpread	1.0	1.0	0.5	0.5	0.5	1.5	**3.5**

TABLE II. THE SHAPE OF THE EFFECT FUNCTIONS OF EACH RELATION (IN ROW) ON EACH ACTOR; THE X-AXIS CORRESPONDS TO THE STATE OF THE RELATION AND THE Y-AXIS TO THE RESULTING CAPABILITY FOR THE ACTOR. THE TABLE SHOWS ONLY THE FIRST TWO ROWS, THE EFFECTS OF THE RELATIONS PROJECTSUPPORT AND RESEARCHMETH_C. THE EFFECT FUNCTIONS OF OTHER RELATIONS ARE SIMILAR REGARDING THE SHAPE OF THE FUNCTION FOR THE ACTOR CONTROLLING THE RELATION AND THE SHAPES OF THE FUNCTIONS FOR OTHER ACTORS.

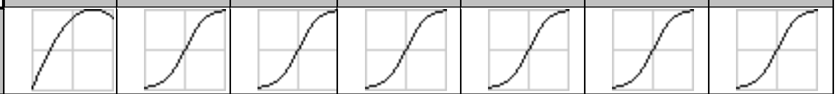
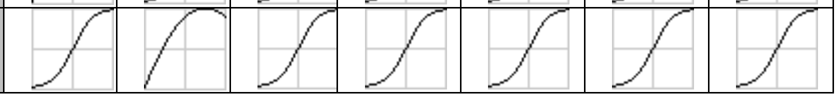
	director	**research_C**	**research_W**	**develop_C**	**develop_W**	**pertAdvis_C**	**techSpread_W**
projectSupport							
researchMeth_C							

TABLE III. THE SOLIDARITY OF ACTORS (IN ROW) TOWARD ITS COLLEAGUES

	director	**research_C**	**research_W**	**develop_C**	**develop_W**	**pertAdvis_C**	**techSpread_W**
director	0.8	0.0	0.0	0.0	0.0	0.2	0.0
researcher_C	0.0	1.0	0.0	0.0	0.0	0.0	0.0
researcher_W	0.0	0.0	0.9	0.0	0.0	0.0	0.1
developer_C	0.0	0.0	0.0	1.0	0.0	0.0	0.0
developer_W	0.0	0.0	0.0	0.0	1.0	0.0	0.0
pertAdviser_C	0.2	0.0	0.0	0.0	0.0	0.8	0.0
techSpreader_W	0.0	0.0	0.1	0.0	0.0	0.0	0.9

TABLE IV. THE DISTRIBUTION (IN VALUE) OF CAPABILITY OF EACH ACTOR (IN COLUMN) TOWARD OTHERS AT THE MEAN CONFIGURATION RESULTING FROM 100 SIMULATION RUNS WHEN GI IS NULL FOR ALL ACTORS. THE LAST ROW SHOWS THE INFLUENCE OF EACH ACTOR AND THE LAST COLUMN ITS RESULTING SATISFACTION. THE BOTTOM-RIGHT CELL GIVES THE MEAN SATISFACTION (AND INFLUENCE) OF ACTORS.

	director	research_C	research_W	develop_C	develop_W	pertAdvis_C	techSpread_W	Satisfaction
director	28.6	13.3	8.7	8.6	8.7	12.9	9.6	90.5
researcher_C	17.9	19.2	13.1	8.6	8.7	13.5	8.8	89.7
researcher_W	13.4	20.9	31.1	4.7	4.8	9.4	7.3	91.7
developer_C	8.9	13.3	13.1	29.4	17.4	4.5	4.4	91.0
developer_W	8.9	13.3	13.1	17.2	29.2	4.5	4.4	90.7
pertAdviser_C	13.9	13.3	8.7	8.6	8.7	24.7	12.3	90.2
techSpreader_W	13.4	10.2	7.3	8.2	8.3	13.0	31.0	91.5
Influence	105.0	103.7	95.1	85.4	85.9	82.5	77.8	90.8

TABLE V. THE DISTRIBUTION (IN PERCENTAGE) OF CAPABILITY OF EACH ACTOR (IN COLUMNS) TOWARDS OTHERS AT THE MEAN CONFIGURATION RESULTING FROM 100 SIMULATION RUNS WHEN GI IS NULL FOR ALL ACTORS.

	director	research_C	research_W	develop_C	develop_W	pertAdvis_C	techSpread_W	Satisfaction
director	98.4 %	96.1 %	95.2 %	94.7 %	95.2 %	100.0 %	95.5 %	97.0 %
researcher_C	96.4 %	98.0 %	95.2 %	94.7 %	95.2 %	96.6 %	95.5 %	96.2 %
researcher_W	96.4 %	96.1 %	98.8 %	94.7 %	95.2 %	96.6 %	99.8 %	97.2 %
developer_C	96.4 %	96.1 %	95.2 %	99.0 %	95.2 %	96.6 %	95.5 %	96.7 %
developer_W	96.4 %	96.1 %	95.2 %	94.7 %	98.7 %	96.6 %	95.5 %	96.5 %
pertAdviser_C	100 %	96.1 %	95.2 %	94.7 %	95.2 %	98.3 %	95.5 %	96.9 %
techSpreader_W	96.4 %	96.1 %	99.7 %	94.7 %	95.2 %	96.6 %	98.7 %	97.1 %
Influence	99.6 %	98.4 %	99.2 %	98.8 %	99.1 %	99.7 %	99.7 %	

B. Variation of the distribution of actors' GI

Tables VI to IX show simulation results according to the decreasing GI of the withdrawn actors (director, researcher_W, developer_W and techSpreader_W) and increasing GI of the committed actors (researcher_C, developer_C and pertAdviser_C).

Table VI shows that simulations runs are short when GI of all actors is null (the top-left cell); the structure of the game is simple and the seven actors have no difficulty to find a (good) compromise. A glance at each column shows that the decrease of the GI of withdrawn actors makes simulation runs systematically longer, meaning that it becomes more difficult for the actors to find a consensual configuration. On the opposite, the increase of committed actors' GI makes simulation runs systematically shorter, but with a smaller effect: values on the diagonal are increasing.

Table VII shows that the decrease of the GI of withdrawn actors diminishes the global satisfaction of actors more and more from 0 to -0.4, whatever the GI of committed actors. For the (0, 0) distribution, the 83.81 satisfaction corresponds to 95% of the optimal operating of TDPM, while for the (-0.5, 0) distribution the 10.9 satisfaction corresponds to 57% of the optimal operating (the minimum and maximum global satisfactions are respectively -96.5 and 92 respectively). Except in the absence of withdrawal (the first row), the increase of committed actors' GI also decreases the global satisfaction, while slightly.

Table IX shows that withdrawn and committed actors have similar satisfactions when all GI are null (the slight difference 0.81 comes from the responsibility of the project for the Researcher_C committed actor), and that the formers take advantage of whatever departure from this situation. The higher involvement of committed actors increases the gap between the withdrawn and committed actors and this explain why it also decreases the global satisfaction seen in Table VII: a systematic cooperation of committed actors ensures withdrawn actors a high level of satisfaction and by the way exempt them to cooperate, so that its impact on the whole organization is negative. In average, the increase of commitment from 0 to 0.5 increases the gap by 4.3 while the increase of withdrawal from 0 to -0.5 increases the gap by 5.1.

To sum up, in all tables the main variations occur between rows and not between columns: the effect of withdrawal is much more important than the one of commitment. Withdrawal and commitment are not at all opposite phenomena since, if one except the first and the last rows of Table VII, the increase of both decreases the global satisfaction (Table VII) and benefits to withdrawn actors (Table IX). Moreover these effects are quite independent: all rows exhibit the same variation pattern (up to translation) and the same holds for columns. The effect of commitment (examine each row) is quite linear while the effect of withdrawal (seen on each column) is not: e.g. in Table VII, the effect is increasingly important from 0 to -0.4, while the change from -0.4 to -0.5 requires specific explanations. As mentioned at the end of section V, the solidarity between Director and PertAdvis_C lessens the effect of GI variation, increasingly with the gap between withdrawn and committed actors.

TABLE VI. MEAN NUMBER OF STEPS TO REACH A REGULATED CONFIGURATION DEPENDING ON THE GI LEVEL OF WITHDRAWN (IN ROW) AND COMMITTED (IN COLUMN) ACTORS.

	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0	1673	1082	653	455	388	344
-0.1	2697	2128	1649	1303	1034	910
-0.2	4292	4154	3906	3564	3231	3172
-0.3	6680	6536	6569	6266	5910	5501
-0.4	9638	9649	9713	9410	8922	8321
-0.5	11033	11236	11239	11099	10659	9994

TABLE VII. THE AVERAGE SATISFACTION OF ALL ACTORS DEPENDING ON THE GI LEVEL OF WITHDRAWN (IN ROW) AND COMMITTED (IN COLUMN) ACTORS.

	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0	83.81	84.41	85.25	85.65	86.13	86.71
-0.1	83.01	83.09	83.01	83.11	82.92	82.99
-0.2	77.36	76.44	76.14	76.95	77.88	75.60
-0.3	60.18	59.93	58.39	59.10	57.45	53.68
-0.4	32.15	32.55	31.75	31.08	31.30	28.64
-0.5	10.93	12.20	13.27	13.40	13.25	13.63

TABLE IIX. THE AVERAGE SATISFACTION OF WITHDRAWN ACTORS DEPENDING ON THE GI LEVEL OF WITHDRAWN (IN ROW) AND COMMITTED (IN COLUMN) ACTORS.

	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0	84.15	85.56	86.79	87.56	88.30	89.16
-0.1	83.94	84.49	84.94	85.16	85.34	85.68
-0.2	79.37	79.21	79.18	80.29	81.16	79.27
-0.3	64.04	64.25	63.21	64.22	63.09	59.43
-0.4	36.87	37.85	37.50	37.01	37.58	34.89
-0.5	13.42	15.40	17.12	17.55	17.63	18.38

TABLE IX. THE GAP BETWEEN THE MEAN SATISFACTIONS OF WITHDRAWN AND COMMITTED ACTORS DEPENDING ON THE GI LEVEL OF WITHDRAWN (IN ROW) AND COMMITTED (IN COLUMN) ACTORS.

	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0	0.81	2.69	3.59	4.44	5.05	5.73
-0.1	2.19	3.27	4.50	4.78	5.66	6.28
-0.2	4.70	6.47	7.10	7.79	7.64	8.57
-0.3	9.02	10.08	11.25	11.95	13.16	13.43
-0.4	11.02	12.37	13.42	13.83	14.66	14.60
-0.5	5.82	7.47	8.98	9.69	10.21	11.08

The GI distribution -0.3 for withdrawn actors and 0.2 or 0.3 for committed actors is quite close to the observed configuration, even if more precise distributions distinguishing the GI among the withdrawn and among the committed actors should be considered (see (Terán et al., 2013)).

VII. CONCLUSION

Organizations seldom operate as intended and expected. It can be caused by the very structure of the organization that render the necessary cooperation among the actors difficult to establish, by the presence of structural conflicts that force actors either to opposition or to fragile compromises, or by lack of fairness or empowerment. The SocLab simulation algorithm studies how each actor is likely to cooperate within an organization, assuming that it is interested in the duration of the organization, and thus its proper functioning, and thus cooperates to the extent this is beneficial for him, according to the reciprocity principle (Sibertin-Blanc et al. 2013a; 2013b). The deviation from the intended working of an organization can also be caused by the lack or even the excess of commitment of actors who do not cooperate in an appropriate way with others.

In this paper, we have shown how to account for the withdrawal or the commitment of actors by the introduction of a parameter associated to each actor, its Group Identification (GI), that indicates to what extent it deviates from the standard level of cooperation, in excess or in default. Applying this model to a very concrete organization that features troubles due to a dysfunctional GI of some of its members, we have found values likely to approximate the level of GI of actors of the organization. By the way, we have found that withdrawal is much more effective than commitment. Withdrawal is not just the opposite of commitment, since the later does not compensate the former, and a change in withdrawal has much more effect than the same change in commitment. Surprisingly, it seems that high commitment of some actors' is not always beneficial to an organization.

Even if this quantification of withdrawal is approximate, it allows making comparisons between different cases, what is the basis of any engineering practice. It is also likely to indicate the order of magnitude of actions to be undertaken in order to modify the GI of the members of an organization.

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High Skilled Emigration and Wealth Distribution

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***Abstract*— Emigration is a social movement associated to the demand of better life conditions in different countries from those where one was born. In the specific case of skilled workers, this phenomenon is typically characterised in a negative way, due to the country's loss of highly skilled resources, in whose education significant investment was done. While the impact of immigration on labour markets is widely studied and developed, the same is not true in what respects the impact of emigration at emigrant´s home countries. This article aims to analyse the effects of high skilled emigration from developed countries on wealth distribution at origin countries. For such purpose, an agent model was developed, and simulations are proposed to depict this phenomenon and discuss the inherent impacts.**

I. Introduction

The recent flows of emigration occurred in Europe affected by the sovereign debt crisis have sparked debates in origin countries about the inability of these to offer employment to its citizens. This fundamentally happens when labour force is young and highly qualified and where the dominant discourse is the impoverishment of the country. The questions that arise are: is this social movement positive or negative to the origin countries, in terms of wealth distribution? What is the role of the employee's wealth expectations during labour activity? The rising of the phenomenon of emigration always has an impact on the demographic structure of a country as well as in family relationships. However, and although the phenomenon carries a negative connotation in people's common sense and removes qualified work force from labour market, the reality is that there may be other factors that transform emigration in a positive issue for the labour markets at origin countries.

Migratory movements are an important mechanism because they give people access to better income levels comparing with what they have in their home countries [1]. This empirical evidence is found when emigrants increase their earned wages in host countries. Currently, there is considerable literature about the effects of immigration on wages in host countries. This literature is striking to note that negative impacts are small and statistically irrelevant. However, the literature is limited in what concerns highly qualified young people. This is surprising, because overall migration causes more impact on origin countries than in the host countries, taking into account the massive exodus over several countries. In this sense, we will study the effect of highly skilled emigration on origin countries regarding the distribution of wealth concept. For this, we opted to use a multi-agents methodology to develop a model that replicates this reality, allowing us to make some remarks about this subject.

This article is organised as follows: in the next section, we review the scanty literature about the effects of emigration on wealth distribution. On section 3, we present and describe our multi-agent model. Section 4 outputs the obtained results in what concerns the scope of this research. Finally, on section 5, we establish our conclusions and introduce future steps to this research.

II. Reviewing Relevant Literature About Emigration

The return of intensive international migration in the last 5 years is one of the main reasons for the growing interest about the relations among emigration, labour market and wealth distribution. In 1962, [2] had already alerted to the question: "how effective is the inter-regional migration in the income fairness of comparable work?" Since then, migration has been linked to the economic development.

In 1993, [3] launched a theoretical basis, with some empirical evidence, where migration serves as an important driver for economic convergence between rich and poor countries. This impact is rarely mentioned and where wages act as a convergence mechanism. The debate over highly skilled brain drain and emigration, for example, derives indirectly from this argument that was covered extensively in the literature. However, the impact on the labour market as well as on the wealth distribution of the origin country is rarely mentioned.

The relation between supply and demand of labour establishes that a decline in labour supply in the origin country should raise wages, because immigration determines the return into equilibrium of labour markets. Migration is also attractive to move out people from poverty, providing economic alternatives to families outside the local market. Its influence extends to the labour at the household level [4], often in addition to

□This work was not supported by any organization

other families [5]. The simplified neoclassical model motivates us to verify if it makes sense not increase wages after a migration flow. Given the above argument, the law of supply and demand have clear implications, where the effect can theoretically range from zero to very large. For example, [6] remarked that the free movement of workers helped relieve the pressure on the domestic labour market, reducing unemployment and boosting growth in wages, although this has caused great labour shortages, in certain sectors. In 2007, [7] found that in fast-growing economies, the incompatibility of simultaneous exit of workers in the middle of a growing demand requires a country to resort immigration in order to offset the gap.

In Europe, research shows that emigration has contributed to the convergence of real wages by reducing the growth of the labour force [3]. Borjas inspired another branch of research focusing on the impact of national migration, instead of smaller geographical segments [8]. As such, the major determinant of immigration impact on wages is the range of skills distribution within groups, over time. In addition to identifying replaceable workers, two additional factors influence whether and how a change in the workforce will change the labour market. The first is a direct change in the composition of skills of the labour force, an effect through the labour supply. In this sense, an impact on the labour market should be migrant’s skills, which is composed differently from the native labour force. A second factor is an indirect effect affecting the demand for labour. The production mix of tradable goods and the degree of international openness of a country economy will determine whether and how quickly the labour market of this country adjusts to its long-run equilibrium. For instance, the labour market in a relatively closed economy, with little variety in the merchandise exported will likely experience long-term changes in its own equilibrium, when it faces a change in its workforce. A relatively open economy, with a mixture of high power will return to the original equilibrium if the adjustment occurs [9].

There are few studies that have measured empirically, the impact of emigration. The majority explores the variation in skill sets over the time. In 2007, [10] and [11] in Mexico, [12] one year after in Puerto Rico and [13] two years later on Moldova, they all conclude that emigration increases wages with elasticity’s ranging from 2% to 6%. In 2012, [14] have used a stylized growth model to analyze the various channels through which a “brain drain” affects the sending countries. They conclude that high-skilled emigration not deplete a country's human capital stock, generating some positive network externalities.

Although some micro-level studies allowed us to verify that shocks of income on migration choice varies according to the wealth. However, this reduction was not convincingly to establish relations for a theory. Meanwhile, several studies relate macro-level measures of average income inequality and migration using cross-country data, but do not use the income distribution to identify the prevalence of financial constraints in the population for potential migrants [15]. This article fills those gaps by deriving a generalized mapping between wealth distribution, income shocks, and the rate of migration flow. It was identified a constrained choice in migration liquidity based on randomized money transfers to the poorest families in Mexico and Bangladesh.

The remittances are a major economic component on developing countries, reaching 20 % of GDP in many developing countries [16]. The most relevant literature discusses the effects of remittances on poverty and wealth distribution. There are many studies that support poverty reduction [17], [18] and initiate a dynamic development marked by reduced production and constraints to the existing investment in the economy [20]. This happens because it provides opportunities for revenue growth, helping origin countries to create small business [22] or by creating a path for risk diversification [23].

Studies also suggest that remittances can produce a cycle of dependency and stunting the development of origin countries. More specifically if the funds are spent on consumption, rather on savings. Or when these funds generate employment in low-productivity activities, contributing to an unsustainable lifestyle, in the long term [24]. More recently, studies have shown that remittances used for consumption generates strong multiplier effects on the origin countries economy [19]. Literature had also considered the impact of migration and consequent remittances on economic disparities in the origin countries. Many studies have found that the flow of remittances reduce income inequality and wealth [20], while others observed the opposite pattern [18]. Recent studies serve to reconcile these patterns showing how the impact of remittances on inequality depends on the cost or the level of migration [24], [25].

III. Multi-Agents’ Model

The proposed model, named SEWD, Simulates the impact of Emigration on the Wealth Distribution in society. The intent is to reflect the labour market of a society by using a multi-agent methodology. The market is composed by companies and workers. The workers demand for the work supplied by companies in order to generate wealth.

A. SEWD Model Parameters

The multi-agent model is composed by a group of parameters with impact on wealth distribution and controlled by the researcher. The parameter named best companies performers (ϕ) determines the initial quantity of companies (patches) that have the capacity to pay a high level of salaries (ω). As more companies exist is society with capacity to pay high salaries, the greater is the possibility for workers to increase their wealth and avoid the decision to emigrate.

The salary growth interval (φ) determines how often the salaries grow in the market. It represents the output of negotiations among government, labour unions and the employers association, in a context of social agreement. If this cycle is long it means that the labour market may be closed to full employment. This happens because all the agents are satisfied with the conditions they have. This parameter affects the stability of salaries over time and consequently the accumulated wealth. Another parameter is the growth of salaries (g) and it determines how much money is incremented in the salaries practiced in the labour market. The wages growth is established by the decisions occurred in each round of negotiations among agents.

The parameter number of employees (η) determines the initial number of workforce susceptible to do their activities in this market. The age at onset of labour activity (m) represents the shortest age that an employee can start working on this market according to the law against child labour. On the other hand, the maximum expected age activity (M) is the longest age that an employee can work on this market according to the law that establishes the age for retirement. As higher is the gap between both parameters the greater is the possibility of a worker accumulate high wealth at the end of his labour life. The maximum salary (ς) parameter sets the highest amount of income that an employee demands on the labour market. The maximum mobility parameter (π) gives the range of possible companies that an employee could be interested in working on. The justification for this parameter is the fact that some attractive jobs are far from their houses, which is a constraint that affects their expectations about their way of life. Normally, employees are reluctant to change from their region to work. Employees have a consumer pattern defined by consumer percentage parameter, that interferes in savings and consequently on the accumulation of wealth. The "wage capacity" parameter represents the maximum amount of money that employers can offer to employees. For each income level a proportional tax rate is applied. Another parameter is the "maximum wealth expectancy" representing the employee's expectations regarding the wealth that they can accumulate during their working life. Finally, the parameter "salary multiplier" settles the salaries increment that immigrants or emigrants will require to enter or return to this labour market. When there is shortage of highly qualified workers, companies have to increase salary rates in order to attract and recruit them abroad.

B. SEWD Model Description

This model is intended to demonstrate the effect of emigration in wealth distribution. It represents a society with the respective labour market, composed by companies representing employers and where employees demand for a job opportunity. Employees will try to maximise their wealth by looking for better salaries in order to match their wealth expectations. In our simulation, we use NetLogo patches [26] to represent employers who are offering a job. A dark patch represents a company in difficulties, without projects in its portfolio and consequently not recruiting new workers and without attractive salaries. On the contrary, a light yellow patch symbolises a very dynamic and competitive company with many projects in its portfolio and looking for high qualified workers in the market **(see Fig.1)**. This process works dynamically. This means that an excellent company (yellow patch) could become in bad situation (black patch) if paid wages beyond their means. When a patch change from black to yellow means that a new company have replaced the position of a bankrupt company.

So, the colour variation depends of the competitiveness in the market and respective success of companies. If a employee salary is more than company capacity (ς>ω) each patch changes dynamically from yellow to dark and vice versa, revealing the high or low competitive environment among companies.

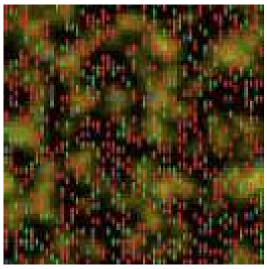

Fig1. Labour market environment

Each healthy company has some projects where can invest in order to create more value to their stockholders and consequently to the market. Through the implementation of these projects, companies have a number of available jobs in order to increment the value (v) of labour market. So, v is the value generated by the business and depends on the company's budgeted investment for each year and it is expressed in net cash flows. This investment is settled randomly and has ω as an upper limit (v < ω). In this sense, the jobs added to the market comes as a function of the number of best companies' performers and the maximum investment capacity (1).

$$p=f(\phi,\omega) \quad (1)$$

$$v_t=v_{i-1}(1+g)^i \quad (2)$$

Additionally, the amount of resources and consequent value creation can grow on each company, which translates into the hypothesis of market value growth (2). Employees receive their salaries from the value they helped to generate in companies. The individual salary (γ) is obtained from companies, where each employee works in each time period generating his/her own wealth. A salary is used by employees to consume where the remaining amount is allocated to savings, in order to increase their wealth. Consumption value is established randomly, lower than consumer parameter (δ) and is less than maximum salary ($\delta < \varsigma$).

The model begins with a randomly-settled, unequal, wealth distribution. Workforce is divided according to their initial wealth, in three classes: rich, medium class and poor. Then, an employee wanders around a good company performer gathering as much salary as he/she can (3). This means that if an employee find another company inside of his/her maximum mobility (π) offering better salary, he/she will resign with his company and moves to the new company.

$$\gamma_t = \max (v_i, \pi_i) \qquad (3)$$

where

$$\pi_i = f(\pi_{i-1}) \qquad (4)$$

Employers attempt to move in the direction where most of the high salary companies (yellow patches) are, and up to where they are available to be reallocated qualifications to go. The maximum reallocation that employees are willing to commit themselves is given by the parameter that rules the maximum mobility that an employee could accept. (4). This means that employees could restrict their job search. In our model, the radius of maximum mobility varies between one company (patch) and fifteen companies (patches). Consequently, depending of their maximum mobility, employees will move in the direction of the company or group of companies offering better salaries.

As described above, in each time period, each employee consumes and saves part of his/her income. Consequently, in every run the wealth (w) is calculated as follows (5):

$$w_i = w_{i-1} + \gamma_i - t_i \gamma_i - \delta_i \gamma_i (1-t_i). \qquad (5)$$

Employees also have an expectation about the period of labour activity, according to the wealth they want to achieve. This expected activity (ea) is given by (6):

$$ea = m + (M-m) \qquad (6)$$

where the difference (M-m) is settled randomly.

When employees decide to retire (i >= M), where i is the employee age, or when they are unemployed because $w_i < 0$, they simple get out of the labour market. The unemployed workers emigrate to other countries looking for a job opportunity. Emigration can also happen if employees don't match their wealth expectations (ϐ). The expected wealth is based on maximum expected wealth (ɰ) and calculated as follows (7):

$$ϐ = ɰ / ea \qquad (7)$$

If emigration happens, a company is forced to recruit a new employee to fill the vacancy left by the employee who emigrated. In Portugal, when high qualified workers emigrate they don't send remittances to its origin country. This is a phenomena occurring nowadays and goes contrary to what is explicit in [14]. High skilled workers don't send remittances to their origin countries only low skilled workers. We use this fact as assumption in our model in order to represent this new emigration profile.

However, companies can opt to offer a salary above the ones that were practiced in the market or to invest in recently graduated students. So, new employees enter the labour market with a salary randomly settled and ranging uniformly from the poorest to the richest agent in activity.

C. SEWD Model Lorenz Curve and Gini Coefficient

To analyse the fairness of the wealth distribution, we have drawn the Lorenz curve, a tool frequently used in these circumstances. We have ranked employees by their wealth and then we have plotted the percentage of them that owns each percentage of the wealth. We ranked the employees based on their wealth, from the greatest to the least: the poorest employee would have the lowest ranking of 1 and so forth. Then we have plotted the proportion of the rank of an employee on the y-axis and the portion of wealth owned by this particular employee and all the workers with lower rankings on the x-axis.

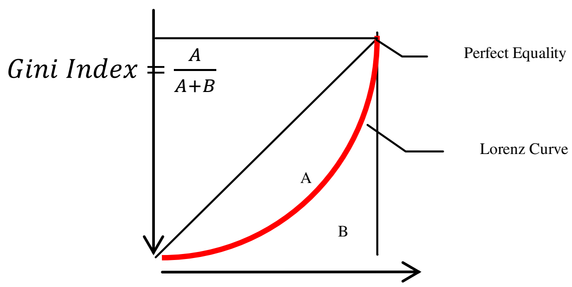

Fig.2 Computing Gini Coefficient Schema

For example, employee alpha with a ranking of 20 (20th poorest in society) would have a percentage ranking of 20% in a society of 100 agents. The corresponding plot on the x-axis is the proportion of the wealth that this employee with ranking 20 owns along with the wealth owned by all workers with lower rankings, from 1 to 19.

A straight line with a 45 degree angle at the origin (or slope of 1) is a Lorenz curve that represents perfect equity meaning that everyone holds an equal share of the available wealth. On the other hand, should only one individual hold all of the wealth in the population (i.e. perfect inequity), and then the Lorenz curve will be a backwards "L" where 100% of the wealth is owned by the least possible percentage proportion of the population.

For a numerical measurement of the fairness of the distribution of wealth, the Gini coefficient is derived from the Lorenz curve. To calculate the Gini coefficient, we first have found the area between the 45-degree line of perfect equality and the Lorenz curve. Secondly, we divided this quantity by the total area under the 45-degree line of perfect equity, which is always 0.5. If the Lorenz curve is the 45-degree line then the Gini coefficient would be 0, meaning that there is no area between the Lorenz curve and the 45 degree line. If, however, the Lorenz curve is a backwards "L", then the Gini coefficient would be 1. Hence, equity in the distribution of wealth is measured on a scale of 0 to 1.

IV. Simulation Results

The results reported in this section were obtained conducting the described experiments using version 5.0.4 of the NetLogo framework [26]. NetLogo is a programmable modelling environment for simulating natural and social phenomena. It is particularly well suited for modelling complex systems developing over time.
At this stage of research, we are still doing more experiences and getting insights on how the several parameters impact the system dynamics. So, in this section we will only analyse the results under the scope of this article.

In terms of parameterization we used as reference indicators from Portuguese labour market in 2012 [Source: Eurostat]. It is an excellent example, according the long tradition of emigration in this country. In this sense, the number settled employees are 1000 and the percentage of best companies' performers with condition to pay high salaries is 6%. The wage growth interval is established in 5 years. When it grows, the incremented value is about 8%. Companies have on average an offer limit of 25 thousand of euro and employees a demand average limit of 15 thousand euro. The minimum and the maximum expected activity are 22 and 66 years old. The maximum mobility parameter we assumed a value of 2 in a scale of 0 to15. Employees reveal a consumer pattern of 65% of their salary. The maximum wealth expected by employees during their labour activity is in average €20,000.We decided to apply the current tax rates in Portugal. Portugal at this moment uses progressive tax rates. Consequently, we used the average rates for the first, second and third levels of income. The main reason to choose these values is to match the current values practiced in the Portuguese labour market **(see table 1)**.

TABLE 1 - Normal and Average Portuguese Tax Rates [Source: Portuguese Tax Authority]

Income Level (in €)	Normal Rates (in %)	Average Rates (in %)
<=7000	14,5	14,5
>7,000 to <= 20,000	28,5	23,60
>20,000 to <= 40,000	37,0	30,3
>40,000 to <= 80,000	45,0	37.5
>80,000	48,0	-

After several runs, we verified that wealth expectations and the capacity of companies in recovering the human resources they have lost, through immigration, are key factors to retrieve some conclusions. So we built four scenarios. The first one was emigration with low value of expected wealth and without immigration. It means that companies didn't succeed in finding new employees to replace the exit ones. If we take a look for simulated results, we verify that emigration does not have impact on wealth distribution, maintaining the Gini-Index relatively constant. **(see Fig.3)**
However, if we put a high expectation on employees' wealth (>€22 thousand), the Gini-Index decreases as the number of employees emigrated, revealing an artificial increase on wealth distribution. We called artificial because in reality there is no improvement on the distribution of wealth.

What we have is an exit of workers with low salaries to other countries and the permanence of employees with good salaries. In other words emigration has an impact on this specific case, not in function of better redistribution of wealth, but due to massive exodus of underpaid and high qualified workers**.** The greater are the expectations to become rich, the greater is the number of emigrants and the lower is Gini-Index. **(see Fig.4)**

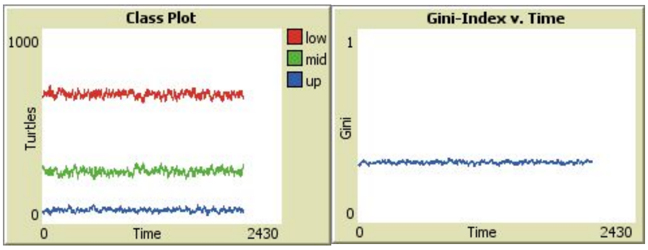

Fig.3 Simulation of emigration effect on wealth distribution with low expected wealth

Logically the society could improve wealth distribution, if emigrated employees transfer remittances to their relatives frequently. But as we saw earlier this is not the case for high skilled workers.

Of course and as it was referenced earlier, companies can recover the lost manpower by recruiting new employees in other countries with better remunerations or wait for students to finish they degree and pay them the same salary. So, if companies recruit outside the Gini-Index remains stable and ranges between 31,5% and 33%. **(see Fig.5)**

Instead, if companies decide by the option of investing in recent graduates, the distribution of wealth decreases slightly into a range between 28,9% and 30,3%**.(sees Fig.6)**

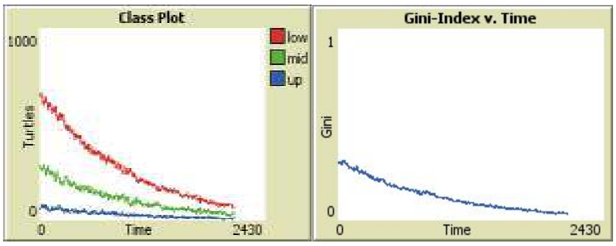

Fig.4 – Simulation of emigration effect on wealth distribution with high expected wealth

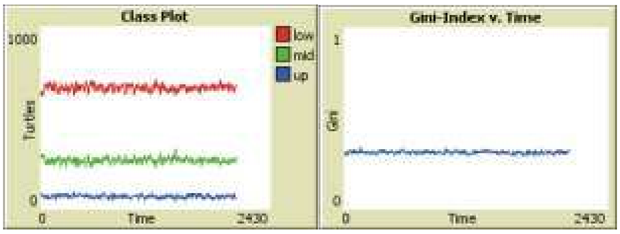

Fig.5 Simulation of emigration effect on wealth distribution with consequent immigration

Now if we compare figures we realize that Fig.5 and Fig.2 have similar patterns in what concerns wealth distribution.

This situation suggest that a market composed by employees with low wealth expectations have the same impact on wealth distribution as it have, if companies decide to invest in new and less experienced graduated

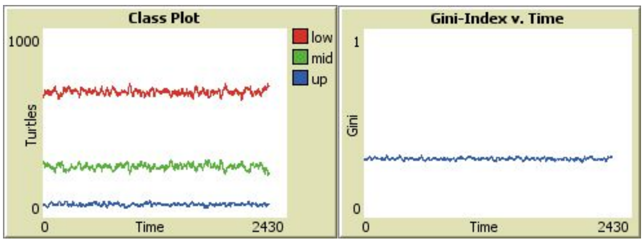

Fig.6 Simulation of emigration effect on wealth distribution with consequent immigration

students. In the case of high skilled workers where remittances transference doesn't happen, a better wealth distribution could be achieved, if companies can recruit high skilled workers in other markets, even if they have to pay more money. This action will improve the price equilibrium in labour market of origin country. In our case, the increase in Gini-Index is not substantial because we have used current parameters of Portuguese Labour Market. For example the consumption rate and the proportion of taxes in salaries influence results. And obviously these parameters differ from country to country. We didn't contemplate the impact of these parameters because it was outside of article scope.

V. Conclusion and Future Work

The main goal of this article was to study the impact of emigration in the distribution of wealth. After multiple runs, results suggest a small contribution of highly qualified emigration to a better wealth distribution. Results also demonstrated that highly skilled emigration could generate a better Gini-index and consequently a better distribution of wealth in origin country. This depends on the role of the employee's expectations. However, this is an artificial impact, because the index has not improved because of greater effectiveness on the allocation of wealth, but rather because of the population reduction. Workers with low salaries get out of country and consequently reduce the active population.

Future steps involve the analysis of other situations that contribute to the oscillation of emigration and consequent effect on wealth distribution. For example, instead of assuming that all workers are highly qualified, we will divide the society in high and low skilled workers. With this procedure we want to include the effect of remittances sent by low skilled workers.

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Intellectual Property Framework and Dynamics of Technology Change under Sequential Innovation

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Abstract

A large number of modern consumer focussed industries are characterised by fast paced technology driven innovations - smart phones and other computing devices, software, home audio and video technologies, automobiles, pharmaceuticals etc. being a few notable examples. Such industries are research driven and are characterised by their unique technological ecosystems. Competition within such industries is not limited to pricing and marketing strategies alone, but is driven by R&D as well, whereby new features, new variants and upgraded technology is constantly being introduced to attract customers (Frambach, 1993). Consequently, firms often tend to use the existing intellectual property (IP) framework within their industries as a standard tool against rivals – both for defensive and offensive purposes (Litchenber, 2002).

This paper focuses on industries engaged in "sequential innovations", where new innovations are possible by investing in R&D to improve existing stock of technology (Bessen, 2009), and examines using agent based models, the impact of alternative IP protection norms and regulations on – first, the evolutionary path of technology development and emerging market structure, and second, the dynamics of technology progress and the nature of competition in technology as a function of the IP protection framework.

We examine three alternative IP protection frameworks – Open Access (OA), Patent Licensing (PL) and Secrecy (S), and compare their impact on the dynamic evolution of both firm and industry level technology and competition using agent based simulations. Firms in the model invest in R&D in every period to improve the existing stock of technology, where the existing stock could be their own or a rival's past technology, and the IP regime determines the strategies available for exchange of technology stock between rival firms (for example, copying, licensing, reverse engineering etc.). Firms use a simple profit based reinforcement learning algorithm to choose the frequency with which they use the available strategies under each regime. How much they invest in improving the stock depends on past profitability, and the outcome of this investment is stochastic in nature. A parameter ϵ controls the stochastic nature of research outcome – with high values of ϵ making bigger jumps in technology more probable for a given level of investment. Budget conscious heterogeneous consumers in the simulations base their purchase decisions every period, on the level of technology in the product they currently use, levels of technology available in the new products and on price. Consumers invest in a new product, only if the available products represent a significant jump in technology compared to the existing product they are using. This is represented through a threshold parameter γ - high value of which indicates that consumers are conservative in their purchases, and would require the new technology to be significantly better than their existing ones for them to consider making a purchase. Apart from γ and ϵ we also test the effects of size of the market (number of consumers) and size of competition (number of firms) on the outcome of the model. The patent and secrecy regimes are characterized by a few additional parameters, such

as probability of successful infringement, royalty fee, penalty of unsuccessful infringement in case of PL and reverse engineering cost in case of S.

Results indicate that both γ and ϵ affect the technology trajectory of the industry. Lower conservativeness in consumers results in higher levels of technology overall, across all IP frameworks. Moreover, lower conservativeness in consumers implies that the technology trajectory is a step function of time, where there are episodes of marginal incremental progress inter-spaced with rare large jumps in technology levels. In terms of market structure, increased conservativeness in consumers result in more egalitarian distribution of market shares, where no single firm is able to dominate the market, and even if one of them does dominate, is not able to maintain its dominance for too long a period. Hence, higher values of γ result a in smoothening of the technology trajectory itself although at the cost of overall technology level achieved in the industry. Along with it, we see higher levels of competition and coexistence of rival firms in the market. As expected, increasing ϵ results in higher levels of technology overall, but contrary to expectation, increases the length of incremental progress episodes in the technology trajectory. In all cases, the presence of a single dominant firm slows down the overall pace of technology progress within an industry, coinciding with episodes of incremental improvement. However, the largest jumps in technology occur when one dominant firm is overtaken by a previously smaller player through introduction of a new technology which is adopted by a large number of consumers. A comparison of the regimes themselves showed that, in general, higher levels of technology are reached and higher levels of investment in R&D are carried out, when the industry is characterised by OA or PL, compared to S.

Additionally, the size of the market has a positive impact on the industry level investment in R&D and technology and the number of firms has a negative overall impact on both. Within the patent regime, weakening the enforcement structure (in terms of increased probability of firms being able to infringe a patent successfully), enhances technological progress and inter firm technology transfer. Within the secrecy regime, increasing reverse engineering costs result in decline in technology progress and R&D investments in the industry.

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A Few Bad Apples Are Enough. An Agent-Based Peer Review Game

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Abstract—**Following previous agent-based research on peer review, this paper presents a game theory-inspired model that looks at peer review as a cooperation dilemma. We tested different scientist behaviours and network topologies in order to understand their implications on the quality, efficiency and type of resource distribution in the science system. We tested random, scale-free and small world networks connecting scientists and three types of referee behaviour: self-interested (providing unreliable opinion), normative referees (providing reliable opinion) and conformist reviewers (conforming to other referees' behaviour). Preliminary results indicate that differences in the combination of referee behaviour have significant impact on the quality of the process and that the percentage of conformists is one of the most crucial model parameters.**

I. Introduction

PEER review is recently under the spotlight. Cases of misconduct [1], [2], proofs of biased referee behaviour [3] and studies about the process quality and scientists' satisfaction [4] called for reconsideration of the quality and sustainability of this important institution, especially in periods of explosion of online journals and publications.

Previous examples of applications of agent-based models have testified to the advantages of looking at the internal mechanisms of peer review, e.g., scientist behaviour at the micro level [5], [6].

This paper proposes a game theory-inspired approach that looks at peer review as a cooperation problem with network externalities, with room for strategic and normative behaviour and reciprocal influence by all scientists involved.

This approach brings a theoretical basis to previous work and a more realistic modelling, in which the efforts and the resources are limited, and so the strategic behaviours make more sense.

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II. The peer review game

We assumed that peer review was a cooperation dilemma where players can take on two different roles, authors and referees. Following [5], each player $i \in \{1,\ldots,n\}$ had a certain amount of resources R_i that could be seen as productivity, available time, funds, human resources, etc. according to academic status, position, experience, and scientific achievement.

They could choose how much to invest in writing articles and reviewing. We assumed that this investment had a cost $c>0$ independently of the player's role, given that both activities (writing and reviewing) have a cost on resources.

In case of publication, authors received a benefit $b>c$, since publishing usually leads to achieve resources in a scientist's career (such as getting grants, funding for attending conferences, developing projects, hiring researchers, etc.).

On the other hand, reviewers do not receive any benefit, since we understand that the reviewing activity does not produce any profit in terms of consumable resources.

The game assumed continuous investment choices, mimicking successive rounds of the publication process.

We defined e^s_i, $e^r_i \in [0, 1]$ as the efforts made for submitting and reviewing respectively. Then, we assumed that the cost of both submitting and reviewing articles was proportional to these efforts. In the simplest form, we had $c^s_i = e^s_i c$ and $c^r_j = e^r_j c$.

The author's submission quality was given by

$$Q^s_i = e^s_i R_i \quad (1)$$

while the quality of the review performed by a reviewer $j \in \{1,\ldots,n\} \mid j \neq i$ was:

$$Q^r_j = e^r_j R_j \quad (2)$$

We assumed the peer review game had a certain publication threshold (T).

A review was considered fair, i.e., reflecting the true value of the paper, if $Q^r_j \geq T$.

If the review was fair, a given submission was accepted if $Q^s_i \geq T$ and the published author received the publication benefit. Otherwise, if the submission was rejected, the author got nothing. Note that the condition $Q^s_i \geq T$ meant that authors with higher resources could meet the publication threshold more easily (i.e., with lower effort).

If the review was unfair, the paper was accepted with probability 0.5, which meant that the expected utility of the submission was $\frac{1}{2}b$.

In each period, costs were subtracted and benefits were added to the authors' and referees' own resources, which lead to the period payoff table shown in Table 1.

TABLE I.
PEER REVIEW GAME FOR AUTHOR I SUBMITTING A PAPER HAVING J AS REFEREE

		Referee	
		$Q^r_j \geq T$	$Q^r_j < T$
Author	$Q^s_i \geq T$	$b - c^s_i, - c^r_j$	$\frac{1}{2}b - c^s_i, - c^r_j$
	$Q^s_i < T$	$- c^s_i, - c^r_j$	$\frac{1}{2}b - c^s_i, - c^r_j$

The equilibrium of the game was as follows: referees had a dominant strategy of putting a zero effort ($e^r_j = 0$) in their review. Knowing this, the best response for authors was to set $e^s_i = 0$ in turn, leading to a unique equilibrium of the game where only low quality were produced and publication was at random.

III. The agent-based model

We built an agent-based model that implemented the peer review game by adding behavioural heterogeneity. We assumed one type of agent, namely scientists.

In each time step, agents played twice, once as author and once as referee. The role order was random and couples changed with roles, meaning that the same two agents were unlikely to play together twice in the same time step.

A fixed global resource R was divided among scientists following an individual resource share that varied at the beginning of each time step. Thus, the resource available for each scientist i was R_i.

The benefit received in case of publication was given by b, where b was a parameter of the model.

The basic cost of both producing a submission and reviewing was the parameter c, which was multiplied by the effort.

The effort for reviewing articles depended on three types of referee behaviour, i.e., self-interest, normativism and conformism:

- Self-interested referees did not contribute to the quality of peer review by putting little effort in reviewing ($e^r_j = 0.5$), trying to save resources for publishing.
- Normative referees were intrinsically motivated by Mertonian norms of scientist conduct [7], e.g., they always put a great effort in reviewing in order to provide pertinent judgment so intentionally contributing to the quality of peer review ($e^r_j = 0.75$).
- Conformists were referees whose effort depended on the behaviour of other scientists which they were connected with. While self-interested and altruists were not influenced by others' behaviour, conformists were sensitive to social influence. They commiserated their effort by looking at the average effort by their connected scientists.

We manipulated the initial combination of self-interested, normative and conformists in order to understand interaction effects among these types of behaviour. As it is known in behavioural game theory, the combination of heterogeneous behaviour over time can have dramatic implications for the aggregate level of cooperation [8].

Furthermore, we assumed that scientists were connected in networks, which defined the neighbourhoods affecting the behaviour of conformists. We tested different network topologies, by initializing the system with random, small-world and scale-free networks [9]. These topologies have been tested by previous studies to reproduce co-authorship networks of scientists.

IV. Results

Preliminary results by implementing the proposed model in NetLogo indicated that different behavioural combinations could dramatically affect the quality of peer review.

While the percentage of self-interested referees in the population could condition cooperative equilibria, we found that also the presence of a significant number of conformists could have negative effects. This is especially evident in conjunction with the presence of a minimal number of self-interested and small world network topologies.

V. Future work

This model represents a first step in an ongoing research on peer review processes under the scope of the New Frontiers of Peer Review (PEERE) COST action.

It is known that reputation is crucial in science dynamics, although it is not implemented in the presented model. Further steps are the inclusion of reputation mechanisms that reflect better the real scientific world in the long term, in order to study the effects on the system, and the validation of the model against real-world data and other game-theory models [10].

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TransMob: An Agent Based Simulation of Transport Demand and Residential Mobility in South East Sydney

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***Abstract*— This paper presents an agent-based simulation, called TransMob, of transport demand and residential mobility in South East Sydney, Australia. In this model, each agent represents an individual resident of the study area. Each agent is given an initial travel diary. Agents are grouped in various types of household which generate social interdependencies and additional constrains on travel diaries. This initial synthetic population is then allowed to evolve for 20 years, driven by natural growth parameters, social bonding and migration rates. A micro-simulation component calculates daily traffic conditions and individual travel times, allowing for multi-modal journeys. The transport mode choice component uses a multinomial logit model for individual decisions based on various fixed and variable costs as well as socio-economic characteristics. Residential mobility is simulated through a two-step process: first, deciding to move out; then, selecting a destination for relocation. The first step uses a multinomial logit model, while the second one uses a semi-empirical perceived liveability model to inform individual decisions.**

I. Introduction

THE ability to realistically predict the demand of transport and traffic on the road network is of critical importance to efficient urban transport planning. Agent based models of urban planning have been increasingly introduced over the last decades. Miller et al. [1] developed model ILUTE (Integrated Land Use, Transportation, Environment) to simulate the evolution of the whole Toronto region in Canada with approximately 2 million households and 5 million people over an extended period of time. Besides giving useful information to analyse a wide range of transport and other urban policies, ILUTE also explicitly models travel demand as an outcome of the integration between individual and household decisions based on activities that they commence during a day. Raney et al. [2] presented a multi-agent traffic simulation for all of Switzerland with a population of around 7 million people. Balmer et al. [3] demonstrated the flexibility of agent based modelling by successfully developing an agent based model that satisfactorily simulate the traffic demands of two scenarios: (i) Zurich city in Switzerland with 170 municipalities and 12 districts and (ii) Brandenburg city in Germany with 1008 traffic analysis zones. Many other agent based models for transport and urban planning can be found in the literature with different geographical scales and at various levels of complexity of agent's behaviours and autonomy [4-13]. They proved that with a large real world scenario, agent based modelling, while being able to reproduce the complexity of an urban area and predict emergent behaviours in the area, has no issue with the performance [11]. They also show that for traffic and transport simulation purposes, agent based modelling has been considered as a reliable and well worth developing tool that planners can employ to build and evaluate alternative scenarios of an urban area.

Many models that have been reported in the literature however are unable to explicitly simulate the dynamic interactions between the population growth, the transport/traffic demands, urban mobility (i.e. household relocations), and the resulting changes in how the population perceive the liveability of an urban area. The agent based model presented in this paper represents a heterogeneous population in terms of demographic characteristics, environmental perception, and decision making behaviour. Inherently, the simulated population will evolve over time facilitating the interactions between dynamics of urban mobility (i.e. relocation of the population), transportation behaviours and population growth. Individuals are represented in this model as autonomous decision makers that make decisions that affect their environment (i.e. travel mode choice and relocation choice) as well as are required to make decisions in reaction to changes in their environment (e.g. family situation, employment).

With respect to transportation, each individual has a travel diary which comprises a sequence of trips the person makes in a representative day as well as trip attributes such as travel mode, trip purpose, and departure time. Individuals in the model are associated with each other by their household relationship, which helps define the interdependencies of their travel diary and constrains their mode choice. This feature, together with the interactions between urban mobility, transportation behaviours, and population growth, allows the

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model to not only realistically reproduce how the current population uses existing transport infrastructure but more accurately predict future transport demands. The router of the traffic micro-simulation package TRANSIMS is incorporated in the agent based model to inform the actual travel time of each trip (which agents use in considering new travel modes) and changes of traffic density on the road network.

Major components that constitute the agent based model in this study are (i) synthetic population, (ii) residential relocation choice, (iii) perceived liveability, (iv) travel diaries, (v) traffic micro-simulation, and (vi) transport mode choice. These components equip the model with unique features that allows it to be used as a comprehensive tool for assisting integrated travel – land use planning. These components are briefly described in Section 2 in order to provide a full picture of the model features and capabilities. The focus of this paper however will be in reporting the simulation results in regards to road traffic and transport demands (Section 3). The paper closes with discussions on further developments of the model.

II. Model Components

This section provides an overview of the six components that constitute the agent based model in this study. Details on the model architecture and integration of these components are given in [14].

A. Synthetic Population

The purpose of the synthetic population is to create a valid computational representation of the population in the study area that matches the distribution of individuals and household as per the demographics from census data. The construction of the synthetic population involves the creation of a proto-population calibrated on socio-demographic information provided by the Australian census data (full enumeration). Different to the majority of existing algorithms for constructing a synthetic population, the algorithm used in this study uses only aggregated data of demographic distributions as inputs, i.e. no disaggregated records of individuals or households (e.g. a survey) are required. The resulting synthetic population is made of individuals belonging to specific households and associated with each other by household relationship.

This initial population is evolved according to annual increments during the simulation period. Each individual and household is susceptible to various demographic (e.g. aging, coupling, divorcing, reproducing of individuals) and economic changes controlled by conditional probabilities. The consequent changes in the structure of households as a result of these processes are also captured. Further details of the algorithms for the construction and evolution of the synthetic population used in this study can be found in [15].

B. Residential Location Choice

Household relocation modelling is an integral part of both the residential and transport planning processes as household locations determine demand for community facilities and services, including transport network demands. The approach used to model residential location choice includes two distinct processes: the decision to relocate, and the process of finding a new dwelling. A multinomial logit model was used to represent the process by which households make decision to relocate. The attributes of this model are change in household income, change of household configuration (e.g. having a newborn, divorced couples, newly wed couples), and the tenure of the household. The HILDA data was used to regress the coefficients associated to each of these attributes needed in the binomial logit model. Further details on the development of the model for triggering household relocation can be found in [16].

Once a household is selected for relocation, the second decision determines where the household will relocate and whether they will be renting or buying a dwelling in the target location, if a suitable a dwelling is found. This process of finding a new dwelling is modelled as a constraint satisfaction process, whereby each household will attempt to find a suitable dwelling based on three factors, affordability, availability, and satisfaction.

C. Perceived Liveability

A significant departure of the current model to other existing approaches is the assumption that residential location choice is based not only on availability and affordability principles but also on the perception that individuals have of the quality of their living environment. The perceived liveability component uses a semi-empirical model to estimate individual levels of attraction to and satisfaction with specific locations. The semi-empirical model is a statistical weighted linear model calibrated on a computer assisted telephone interviewing (CATI) survey data collected in the study area. Further details of this semi-empirical model can be found in [17, 18].

D. Travel Diaries

Each individual in the synthetic population is assigned with a travel diary which comprises a sequence of trips the person makes in a representative day as well as trip attributes such as travel mode, trip purpose, departure time, origin and destination. Because these details of travel behaviours of the population are not completely available in any single source of data (for confidentiality reasons), the process of assigning travel diaries to individuals comprises two steps. The first step assigns a trip sequence each individual makes in a representative day using the Household Travel Survey data. Details of each trip in this trip sequence include trip purpose, travel mode, and departure time. The second step assigns locations to the origin and destination of each trip in the trip sequence.

Assigning trip sequences to agents

The Household Travel Survey (HTS) data was used to assign trip sequences to individuals in the synthetic population. This data is the largest and most comprehensive source of information on individual patterns for the Sydney Greater Metropolitan Area. The data is collected through face to face interviews with approximately 3000-3500 households each year. Details recorded include information of each trip (e.g. departure time, travel time, travel mode, purpose) as well as socio demographic attributes of the interviewed household.

The assignment of trip sequences to the synthetic population comprises two steps. The first step deterministically searches in HTS data for households that best match the household type, the number of children under 15 years old, and the number of adults of a synthetic population household. This deterministic search gradually relaxes the constraints on exact matching conditions so that the search always returns at least one HTS household. The second step randomly selects a HTS household from the list of households identified in stage 1 and assigns travel diary of individuals in the HTS household to those in the synthetic population household. The random selection follows a uniform distribution. Further details of the algorithms for the assignment of trip sequences to the synthetic population can be found in [19].

Assigning locations to trip origins and destinations

Once the trip sequences for all the households in the synthetic population are assigned then the following procedure is carried out to assign activity locations to each trip in a sequence. This procedure had to be followed because the HTS data used for this study did not contain activity locations to ensure the confidentiality of the data and so alternative arrangements needed to be made to ensure that each agent was assigned a location of where to go for a particular activity type either inside or outside the study area. In the case of activity locations outside of the study area, main entry and exit points which acted as the origin/destination of trips coming into or going out of the study area. These main entry/exit points are located near where main entry/exit roads pass the boundary of the study area.

Attributes of activity locations in the study area that are available to this study include the geolocations (i.e. coordinates) and the type of the locations. In order to assign specific coordinates to origin and/or destination of a trip, an activity type must first be determined based on the trip purpose. Based on location type and trip mode, a set of coordinates associated with this location type is assigned to the destination. Details of these two processes are given below.

A flow chart of the assignment of activity types to origin and destination of a trip is shown in Figure 1. The algorithm described in this flow chart applies to all trips of everybody in the population. Depending on the trip purpose, further constraints are applied to correct the assigned activity type. For example, activity types associated with trip purpose “Education” are “Child_care_centre”, “Kindergarten”, “Education_primary”,“Education_school”,“Education_univer sity”. Selecting the type of destination depends on the age of the individual making that trip.

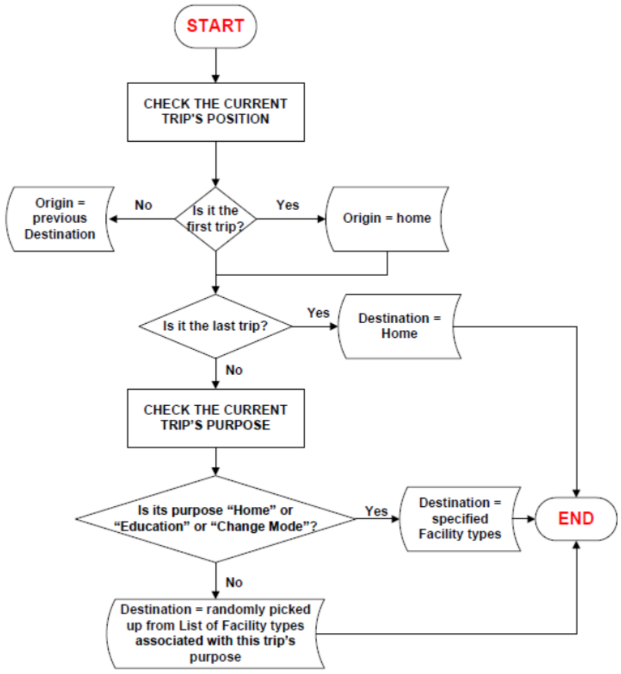


Figure 1: Flow chart of the assignment of activity types to origin and destination of a trip.

A flow chart for the assignment of coordinates to trip origin and destination is shown in Figure 2. The algorithm described in this flow chart applies to all trips of everybody in the population. Travel destinations are assigned to account for the constraints of people in the same household travelling together, e.g. destination of a trip of an adult who takes a child to school is similar to the destination of a child. The Journey To Work data is used to assign work locations to work trips. This dataset provides the distribution of trip counts to/from a travel zone from/to another travel zone by each travel mode. For non-work trips (e.g. social and recreational trips), the location of trip destinations is assigned on a random basis.

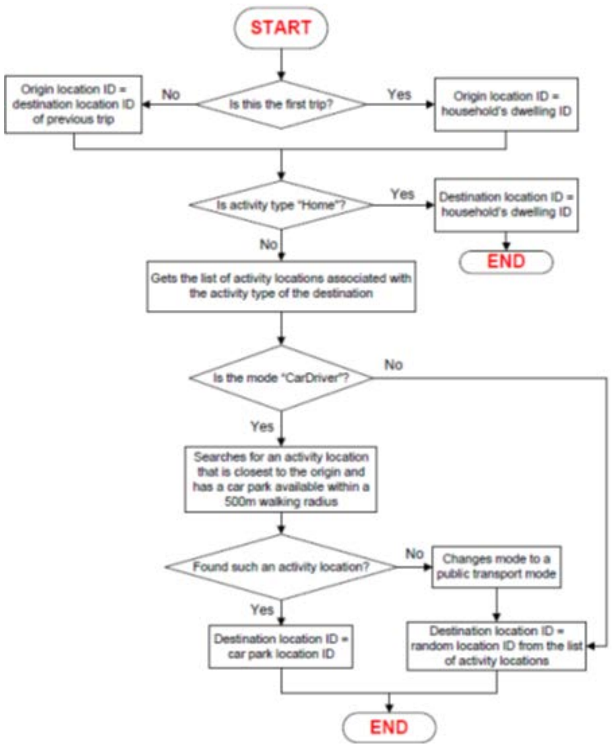


Figure 2: Flow chart of the assignment of activity locations to origin and destination of a trip.

After each individual has been assigned with a travel diary and specific locations for their trips, corrections to their travel diary may be required to ensure that (i) any children under 15 years old always travel (i.e. have the same modes) with an adult in the household, and (ii) any two individuals who depart and arrive at the same time for the same trip purpose will have the same travel mode and destination. Corrections may also be required to the trip modes of an individual who drives in some trips of his/her travel diary to ensure that a car is used throughout these trips. These corrections are particularly needed after individuals make their travel mode choice (see Section 2.6) during the simulation. This is because the travel mode choice model in itself does not have the visibility of the constraints of co-travelling of individuals in a household nor the connection of trips in an individual's travel diary.

Updating travel diaries during the simulation

Sections 2.4.1 and 2.4.2 describe the assigning of initial travel diaries to the synthetic population. Due to changes in the synthetic household attributes (e.g. household type, number of children under 15, etc) as the population evolves, travel diaries may need to be reassigned in subsequent simulation steps to these households in the model. Figure 3 shows the process that is used to reassign/update travel diaries in households whose attributes are different the previous simulation step.

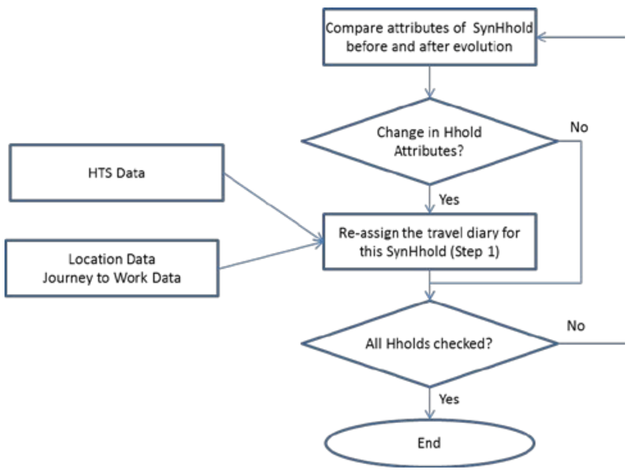


Figure 3: Travel diaries assignment for successive years.

E. Traffic Micro-Simulation

TRANSIMS was chosen as the traffic micro-simulator as, in its current iteration, it is a clean, efficient, C++-based (including good use of STL) platform that supports an individual (person and vehicle) level of modelling, and supports detailed micro-simulation of traffic to support the requirements of our software, including but not limited to:

- road-by-road and minute-by-minute analysis of traffic patterns; and
- details of what individuals are going where on public transport, and analysis of usage.

Normally one would use a process analogous to simulated annealing to arrive at the solution; running the router to establish initial routes, then finding when vehicles jam, and either redirecting them off the street temporarily into a park (if the numbers are sufficiently low) or by then re-routing them using the router and then running the simulation until numbers jammed are sufficiently low. Given the typical travel volumes (around 100,000 commuters), and our desire to simulate a 20-year period, we are forced to run only one typical weekday and weekend in simulation per year, and run only one iteration of the router. We have compared this with test runs of multiple iterations of router and the core micro-simulator of vehicle movements, and found that travel times are within 5%; this we consider sufficient for our purposes..

F. Transport Mode Choice

The purpose of the travel mode choice algorithm was to accurately describe the decision-making processes of individuals travelling on the transport network in the study area, thus enabling the prediction of the choice of travel modes of individuals in the population. Travel modes considered in this study are car driver, car passenger, public transport, taxi, bicycle, walk, and other.

A multinomial logit (MNL) model was developed for this purpose. At the heart of the MNL formulation is a linear part-worth utility function that calculates the utility of each alternative travel mode choice. Independent variables for this function include the difference of fixed cost and difference of variable cost of the selected travel mode with the cheapest mode. The variable cost is dependent on the estimated travel time, which is the output of the traffic micro-simulation. Another independent variable is the individual's income, acting as a proxy for the individual's perception of value of time. Multinomial logit regression was used on the HTS data to estimate the utility coefficients vector for the possible travel modes..

III. TRAFFIC SIMULATION RESULTS

The agent based model described in Section is applied to simulate the dynamic interactions between population growth, urban relocation choice and transport demands for Randwick - Green Square, a metropolitan area in south east of Sydney, Australia. This area has a population of approximately 110000 individuals in around 52000 households that live in private dwellings.

The simulation period is from 2006 to 2011. The initial synthetic population is constructed using the 2006 census data that is available from the Australian Bureau of Statistics. This initial synthetic population was validated that it matches the demographics of the real population at both individual level and household level, and thus is a realistic computational representation of the real population in the area [15]. It was also shown that the synthetic population in year 2011 (i.e. after 5 simulation years) matches the demographics of the population in the study area as described in the 2011 census data. This affirmed that the algorithm to evolve the population while simulating the evolution at individual level can capture the dynamics of household structures in the population.

Figures 4 and 5 respectively show the percentage of trips by each mode and each purpose with respect to the total number of trips made by the whole population for year 2006 (initial year) and simulation year 2011. Figure 6 compares the percentage of individuals in the synthetic population against that in the HTS data by the number of trips made daily. The distributions in these graphs are in very good agreement with the HTS data for the whole Sydney Greater Metropolitan Area.

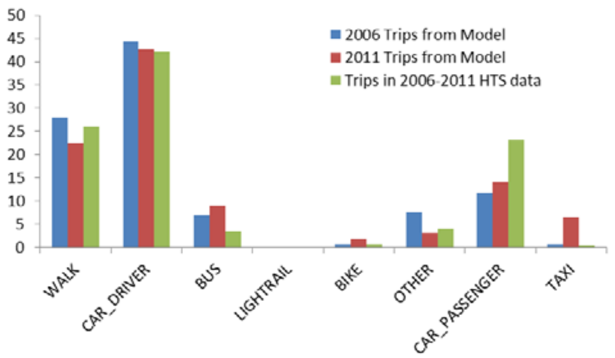


Figure 4: Percentage of trips by modes from simulation years 2006 and 2011 versus 2006-2011 HTS data.

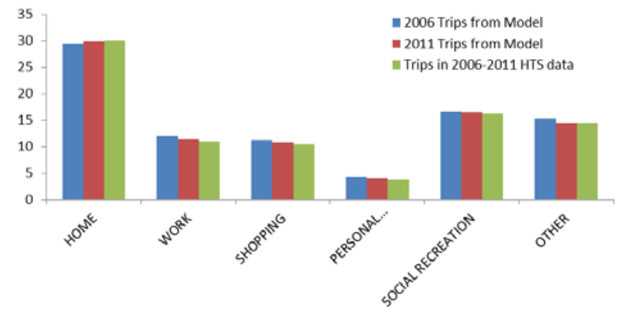


Figure 5: Percentage of trips by purposes from simulation years 2006 and 2011 versus 2006-2011 HTS data.

Figure 6: Percentage of population by number of daily trips for simulation years 2006 and 2011 versus 2006-2011 HTS data.

Trip counts by purposes over 24 hours of a representative day in year 2011 are shown in Figure 7. In this figure, trips go to work and go to school both peak at 8.00am to 9.00am. Counts of trips go to work however are higher than trips to school at earlier hours (6.00am to 8.00am) which reflects early workers. Trips to work also have a smaller peak between 1.00pm and 2.00pm to reflect trips by people doing afternoon and/or night shifts. Trips for shopping, social activities, recreational and personal services (i.e. 'visit') reach their peak at around 9.00am to 12.00pm and gradually drop in the afternoon. These observations affirm that the model can realistically reproduce and predict well the patterns of travel demand of the population in the study area.

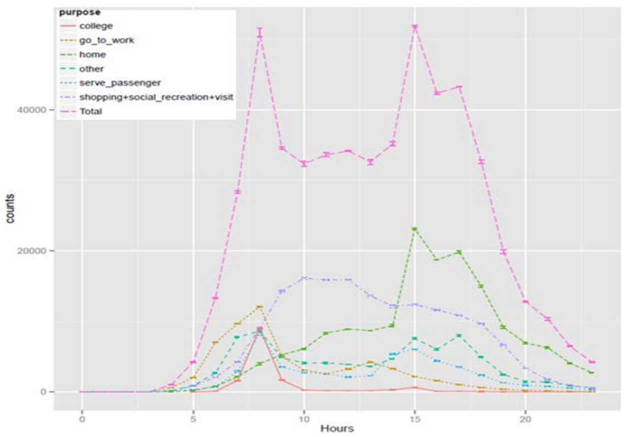
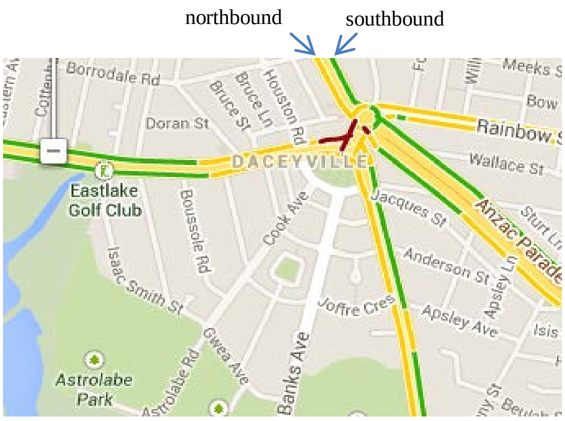


Figure 7: Trip counts by purposes over 24 hours of a representative day in year 2011.

Traffic density (that was outputted from TRANSIMS router) at two major intersections along Anzac Parade, the main road in the study area, in the morning peak hour (8.00am to 9.00am) compared against their congestion profiles from Google Maps [20] are shown in Figures 8. The model is able to correctly predict that northbound traffic density is relatively higher on the part of Anzac Parade north of the intersection with Rainbow Street. However, the southbound traffic on Anzac Parade is relatively less congested compared to the northbound. These results are in agreement with observed traffic profiles on Google Maps.

Simulated Northbound Traffic

Simulated Southbound Traffic



Observed Congestion Profile (Google Maps)

Figure 8: Traffic density on Anzac Parade near the intersection with Rainbow street (morning peak).

Such agreement however does not occur on all parts of the road network. This could be attributed to the randomness in the assignment of activity locations to origin and destination of trips in the travel diaries of the population (see Figure 2). While the assignment of destination locations of trips related to work is constrained by the Journey To Work data, the randomness in assigning destination locations to trips of other purposes does not guarantee a realistic representation of traffic profiles in the model. Note that non-work trips have a significant proportion in the total number of trips made by the population in the study area (see Figures 5 and 7).

IV. CONCLUSIONS

This paper has presented an agent based model for the simulation of transport demands and land use for an urban area in south east Sydney, Australia. Being comprised of six major components (synthetic population, residential location choice, perceived liveability, travel diary assignment, traffic micro-simulator, and transport mode choice) the model is able to capture the decision making of the population with respect to relocation and transport, and thus is able to explicitly simulate the dynamic interactions between population growth, transport demands, and urban land use. This is a unique feature that has not been found in many other agent based models for urban transport and urban planning.

Various aspects of the simulation results on transport demands of the study area were presented, particularly the percentage of trips by each mode and each purpose with respect to the total number of trips made by the whole population, percentage of population by number of daily trips and the distribution of trips by each purpose over 24 hours of a typical day. Being in good agreement with the corresponding survey data, these results affirm that the model's capability to realistically reproduce and predict travel demand of an urban area. This is because individuals in the model are associated with each other by their household relationship, which helps define the interdependencies of their travel diary and constrains their mode choice.

Traffic density (from TRANSIMS router) at various locations along the main road in the study area also matches with the observations of traffic congestion on the same road from Google Maps. Mismatches however occur on other (smaller) roads in the study area. This could be attributed to two factors. The first is the lack of a survey data on the origin and destination of non-work trips. The randomness in assigning a location to the destinations of these trips obviously cannot guarantee a realistic representation of traffic demands in the simulation model. The second factor is the limited ability of the TRANSIMS router to realistically reproduce the reasoning of a person in choosing a possible route for the trips the person makes, including dynamic routing to avoid heavy traffic in real time.

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Comparing Two Models of Cultural Standardization Emergence in Hunter Gatherer and Sedentary Societies

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Juan A. Barceló

In this contribution we present some experimental results of two ABM models implemented to simulate how cultural identities and cultural standardization may have emerged in a prehistoric past as a consequence of the everyday-life interactions in hunter-gatherer or sedentary early complex societies. Our models are based on archaeological data from ancient Patagonia in South America and Late Bronze Age in Europe. Our purpose is to analyze how diversity and self-identification may have emerged in the small-scale societies of our prehistoric past. We have not built realistic models of cultural diversity and ethnogenesis but just explored some possible consequences of theoretical assumptions. We have not modeled the decision process from the point of view of individuals, but at the level of the population. Social dynamics has been formulated as a set of factors constraining action. The agent does not decide, but probabilities for action are re-calculated at each cycle as soon as local conditions change. This is not a mistake, nor a limitation. It is a way of analyzing the consequences of actions without regarding the cognitive causes of action.

We consider that as a consequence of different forms of social interaction and exchange between related individuals cultural consensus may emerge, and human groups can aggregate into greater groups culturally homogenous, what affect social reproduction, increasing similarity in the long run, and reducing the risk of being attacked by groups identified as "enemies" (out of the new cultural consensus).

In the case of hunting and gathering societies, technology and knowledge about how to interfere with natural productivity were limited. In such conditions, humans were conditioned by their environment and, because of their extreme dependence to local carrying capacity and diminishing returns from labor; they were obliged to constant geographical mobility, given that they could not restore what they extracted from nature. In such conditions, the more people interacted in looking for animals and participating in collective strategies, the better, because it contributed to increase labor efficiency. On the other hand, sedentary societies substituted territorial mobility by sedentariness, and agriculture. The relevance of technology (metal tools) was higher, and the nature of social interaction (both exchange and war) more complex. But also in those circumstances ethnicity appears as long-term cultural standardization that influence the updating of social identities and the possibilities of economic cooperation.

In our Hunter and Gatherer simulation, agents are modeled as a number of individuals acting as a decision unit, that is, what we usually name "family" in real live, and what anthropologists define as "domestic unit" or "household". They are defined in terms of their LABOR (l_i) and CULTURAL IDENTITY. Each agent has its own TECHNOLOGY (β_i), an ENERGY-CONSERVATION factor (d_i) expressing the efficiency of storing and preservation methods, and a SURVIVAL THRESHOLD ($\bar{e}_i$), defined on the basis of an individual needs of 730 kilocalories per year (2000 calories per day). The sedentary society simulation is defined around AGENTS that represent regions, defined in terms of the statistical mode of all archaeological sites within a determined buffer zone. Such virtual "geographical regions" are defined in terms of their population, that is, the number of labor units, cultural identity and the number of tools people living in the region have at the current time. Additional attributes and parameters are the amount of produced food, the surplus of food the agent can accumulate and the survival threshold, which depends on the number of labor units within the agent. Each agent (Region) is connected to other through cost-weighted geographical distances, in such a way that there are no possibilities of Random connection between them. Distances based in cost-weighted models try to define the least costly path to reach each known point using the path with least accumulated travel cost.

Among the specificities of our models, there is the way we are dealing with the very idea of CULTURAL IDENTITY. We have adopted the classical Axelrod approach using a vector of X dimensions that represents an organized list of meanings, values, beliefs and symbols inherited at birth, learnt within the evolving group, modified all along the life of the agent and transmitted to the new generation.

In both cases, we have imagined a world without topographical barriers, where resources are irregularly distributed across geographical space, and with a founding population having a single homogenous identity, with a constant, but random internal change rate. At each patch, resources vary in their abundance and in their difficulty of acquisition. There are also seasonal variations. Resources at each patch have also a DIFFICULTY level (h_i). It is a uniformly distributed parameter counting the difficultness of resource acquisition (the more mobile the resource –animals- and the less abundant, the more labor or more technology is needed to obtain resources up to survival threshold.

One time step (cycle or "tick") in the simulations roughly represents what an agent is able to do and move in six months. Different sub-processes are responsible for all system dynamics: agents hunt-and-gather, produce food and exchange or make war to survive and they use existing interaction flows to decide whether *cooperate*, exchange or steal the other. Consequently, they need to *identify* other agents and build social networks, which evolve to configure *social aggregates*. Within such aggregates, identity evolves and updates, and it is transferred to new born agents when *reproducing*.

> SURVIVE: Agents use of their accumulated surplus to survive, and when it is not enough, they are obliged to hunter and gather or to produce food by agriculture
>
> HUNT-and-GATHER. Energy is obtained by agent *i* by means of labor $(l_i(t))$ with the contribution of its own technology, whose efficiency is estimated as β_i(t).
>
> PRODUCING FOOD (AGRICULTURE). Food is produced by labor, which has always the same efficiency. However, there is a variable parameter representing local conditions of soil quality, water availability, etc., whose effects should be compensated using technology, which vary from agent to agent, and between time-steps.
>
> EXCHANGE: When produced food is not enough because of low supply of labor or technology, or the high local difficulty of producing food, agents ask other agents for part of their surplus or the part of their technology they do not need. It is important to take into account that technology loses its efficiency at each cycle, and it should be substituted from time to time. In some scenarios, the only way to renovate technology is through exchange or robbery. Asking for help in the form of produced food or produced tools is mediated by the actual identity similarity and weighted by cost-distance.

Identity similarity should be calculated at each time on the basis of the binary vectors containing all we know about material culture. It should be taken into account that such identity is in constant renegotiation and updating. When identifying other agents in the area, each agent calculates the normalized Euclidean or Hamming distance between each pair of identity vectors. The Hamming distance between two strings of equal length is the number of positions at which the corresponding symbols are different. How big should be this similarity value to allow cooperation between agents or increase the probabilities of being attacked? Agents calculate at each time a Similarity Threshold on the basis of the percentage of consensus needed, depending on how much they need food or tools from others to survive. The more at risk they found themselves, the less tolerant to the others difference.

But Cultural similarity is not enough. Even in the case of a similarity above the similarity threshold, the agent with food or technology in excess should decide whether the proposed exchange has long term benefits: the more the actual cultural consensus, the less risks of being attacked later. We have modeled this decision in terms of a variation of the classical Prisoner's Dilemma.

In case there are no agents with a cultural similarity above the actual value of similarity threshold to exchange food and/or technology, the agent may steal what culturally different agents have produced. The agent selects the nearer agent (in terms of cost-weighted distances) with the maximum cultural difference, and attacks if it expects it will win because it has more warriors and weapons.

Cultural identity is in a state of constant updating and modification. We have implemented two mechanisms, a random parameter simulating local change, invention or variation within a community, and a collective mechanism of cultural consensus formation, in such a way that cooperating agents update their culture towards the coincidence with the more successful agent in producing food and/or technology

Preliminary Results. We have calibrated our models to historical data in the sense proposed by Epstein (2008). In general, our simulations show that social aggregates emerge constantly as a consequence of the benefits of cooperation at work (communal hunting or food/technology exchange). As a result of economic interaction, agents aggregate in space, configuring what we can consider social networks of cooperation. Such networks constitute an initial form of ethnogenesis. Network embeddedness means that everybody did not interacted equally with everybody else, but was constrained by needs (expected benefits), geographical neighborhood and prior cultural consensus (common history). Agents within the network interacted among themselves more often than with others out of the network, which means that a subset of the population may be excluded from positive interaction and hence the process of similar identity negotiation and innovation diffusion.

The degree of ethnicity and cultural standardization has been measured in our simulations in three steps: fractionalization, generalized resemblance and demographic polarity. Fractionalization measures the probability that two randomly drawn agents belong to two different groups (*ethnia*). It gives us a measure of the *depth* of the divisions that separate members of one group from another, which is a necessary factor for inferring *social tension.* Those results should be interpreted as the expected dissimilarity (in Euclidean distance terms) between two randomly drawn individuals.

In the cases we have explored, the poorer the world, the higher the expected dissimilarity. When the world seems rich enough and fractionalization is less conspicuous, expected similarity is far greater. These results seem to be concordant with the process of cultural hybridization. What appears to be fractionalized when resources were scarce and concentrated became homogenized when technology increased suddenly its efficiency (imported colonial items, horse domestication) and resources increased by foreign factors.

Generalized resemblance does not solve our problem about the emergence of segregation and territoriality when group fractionalization increases. “Polarization” is needed to transform difference into competition. It is here calculated in terms of the “distance” between two groups corrected by the sizes of each group in proportion to the total population. Results capture how far the distribution of social aggregates may be from a bipolar case. In any case, although never very high, demographic polarization attains higher values when the world has the more abundant resources, and when fractionalization has low values. These results contrast with the expected increased territoriality as a consequence of resource scarcity and spatial concentration.

CONCLUSIONS

Our model is in the lineage of Axelrod essays to understand the Diffusion of Culture and its effects. Axelrod modeled a population of actors holding a number of cultural attributes which interacted with culturally similar neighbors as interaction partners to suggest an idea of homophily. Our model differs in important aspects: mobility and transmission of cultural features are allowed; Culture is not fixed, but evolves as soon as cooperation appears to be advantageous; Random cultural drift simulates internal process in addition to external interaction ; Survival depends on cooperation ; Cultural transmission depends also on survival and hence on cooperation; Cooperation and reciprocity depends on the probabilities of survival

We propose an analytical view of *ethnicity*, based on the idea that the emergence of identity is a consequence of the very fact that some individuals interact more often with a restricted group of people than with people out of that group. That means that people embedded in social networks interact with a subset of population and define themselves in terms of the similarity with the people they interact. So both “ethnogenesis” -as a collective process- and “identity formation” -as an individual process- could be understood as emerging results of stress between a set of contradictory forces: (a) *social inertia*, as knowledge acquired by direct inheritance, (b) *cultural consensus*, as knowledge socially built during cooperation and labor exchange, and (c) *cultural innovation*, as knowledge adaptively acquired and built during isolated problem-solving situations.

Cultural differentiation existed in prehistory, but cultural groups adopted the form of networks of cooperation and exchange instead of “nations” in the modern style with clear-cut and well defined borders and frontiers.

Investigating Opinion Dynamics using the FreqNet model

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Keywords— attitude dynamics, social simulation, agent based models

Abstract

Human life is based on social interactions. These interactions are dictated by the attitudes and beliefs people have. Personal attitudes and beliefs are not constant over time but are influenced on an individual level. The interactions with friends, coworkers and others can influence one?s opinion. Such an attitude change can occur during discussions. It is hypothesised that these changes are such that when two individuals meet, the closer their opinions are, the more likely their opinions converge, Sherif and Hovland (year). On the other hand, when they differ a lot from each other they will experience contrasting opinion, and as a result diverge opinions, resulting in a polarisation.

Extending earlier research, Jager and Amblard (2008) have introduced the FreqNet model as a formalisation of dynamic relationships. This model is a two-dimensional opinion dynamics model that is based on human similarity and includes the frequency of contact. In this model the social network of contacts is evaluated. The social ties are all weighted according to the similarity of the agents. Apart from their attitudes, individuals differ only on how important they find the attitudes. First experiments indicated that if people connect based on similarity of attitudes, the tendency towards polarisation becomes stronger. Jager and Amblard (2008) found that attitudinal processes have a serious impact on the resulting network characteristics.

In this presentation we shall elaborate upon several open questions concerning the FreqNet model. First, large series of experiments need to be done to shed light on the characteristics of the agents and their interactions. It is of interest to investigate which type of people interact with each other and if they are more similar then others. It is possible that these behavioural patterns are not constant over time. Changes in these patterns could be predictors of group behaviour.

The investigation of these question can shed some light on important issues regarding opinion shifts. Possible, we can find some markers that are predictors for opinion shifts. It could, for instance, be interesting to predict polarisation. These markers could be on an individual level. The characteristics of the agents may very well relate to the changes of position in the network. If possible, agents

can be identified that responsible for behavioural changes. The characteristics of these leaders are of interest, for example there position in the network, their attitude in the beginning.

The ultimate goal is to let agents shape their own network based on their attitudes and behavioural processes. Inclusion of the dynamics of social networks will make the model even more realistic. With this improvement emergence of social networks can be studied as well.

In finding answers to our questions recently developed statistical methods shall be used that have the ability to deal with time varying networks and ties that have variable strengths (Karsai et al. 2014).

To validate FreqNet empiracal data will be used. As a consequence of gas mining earthquakes are measured more strongly and more often in the northern parts of the Netherlands. The changes of opions on gas mining in this region form a good studyground for opinion dynamics. Therefore, behavioural data on this topic will be used in validating the FreqNet model.

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Behavioural Responses to Epidemics: Report from a Virtual Experiment (poster)

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I. Introduction

Existing epidemiological models have largely tended to neglect the impact of individual behaviour on the dynamics of diseases. However, awareness of the presence of illness can cause people to change their behaviour by, for example, staying at home and avoiding social contacts [2, 6-8]. Such changes can be used to control epidemics but they exact an economic cost [3]. We present results from a study that involved mathematical modelling, computer science and health psychology [5]. In our model, disease spread is controlled by allowing susceptible individuals to temporarily reduce their social contacts in response to the presence of infection within their local neighbourhood. We ascribe an economic cost to the loss of social contacts, and weigh this against the economic benefit gained by reducing the impact of the epidemic. We designed and carried out a series of experiments involving participants playing a computer game in which they could respond to epidemic threats by changing their behavior [1,4]. These choices were fed into a simulation model which updated the threats in response to participant actions. The experimental setup involved participatory simulation [9] using a back-end agent-based simulation model implemented in NetLogo [10].

The results show that participants responded to increasing infection load in their local neighbourhood by reducing their social contacts, as they would be expected to do in reality. There was a large variability in their response, both among the participants and within each game. We used an agent based model to scale up from the individual to the population behaviour. We show that the most common response was to maximize the individual gains by attempting to remain uninfected for as long as possible. However, this individual behaviour leads to a high level of disease prevalence at the population level.

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Towards Modeling a Multi-Agent System for Balkan Neolithic Spread

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The present research concerns the modeling of the expansion of an archaeological society. In particular, the Neolithic agriculture spread from Western Anatolia to the Balkans has been simulated. Despite the fact that the Neolithization of the Balkans has been the subject of several studies, purely archaeological based approaches have revealed their limits in understanding and explaining what cannot be inferred from the archaeological evidence. One of the computer models, named Multi-Agent, provides a new method for exploring this topic from a different analytical perspective. This work aims to better understand the behavior of this prehistoric farming society. In order to achieve this objective, the subsistence system of the first European farmers was reconstructed, as well as their interactions amongst each other and with the natural environment, and their reaction to climate variations.

The research area accounts for the entire Balkan Peninsula with the Aegean Sea as the southern limit and the ecological barrier situated in Southern Hungary and Northern Romania as the northern boundary. The model also includes Western Anatolia being as it is the point of origin for the spread of Neolithic in Europe.

The simulated period spans from 6500 BC, which is the date of the first documented presence of Neolithic famers in Greece, to 5500 BC, when the entire Balkan Peninsula was completely occupied. This area is not completely homogenous, as it contains different cultures and regional variations. However, several common elements exist, including the presence of small nuclear family houses and the same cultivated plants and domesticated animals. This permits us to consider the model area uniform, excluding however for relevant local particularities such as the strong Mesolithic presence in the Danube Gorges' region.

The preliminary part of the study required a data gathering in order to create a transnational geographical database which includes all of the known Early Neolithic sites in the Balkan Peninsula. This database contains a total of 1400 records belonging to approximately 1000 sites. Among these, almost one hundred have radiocarbon dating, for a total of more than 500 dates for the Early Neolithic Period. An audit of the database has been made by prioritizing recent AMS dating, conserving only widely accepted dates, and excluding those which are too old and debated. A geostatistical analysis based on radiocarbon dating and geographical coordinates, like the ordinary kriging technique, was then performed. In this way, a general view about paths and timing of the spread was identified.

The model used in this research is an adaptation of the OBRESOC model, a Multi-Agent simulation of LBK Neolithic culture spread in Central Europe (http://www.evolhum.cnrs.fr/obresoc/). Model portability was required in order to make it operational for the Neolithic data observed in the Balkans. A modification of the type of households, farming system, animal stock, and of several parameters was necessary in order to fit the characteristics of the region.

The simulated agent is the household and several households in the same pixel (1 square kilometer area) constitute a village. Every household represents a nuclear family. Individuals within households can die, marry and reproduce, according to paleo-demographic life tables. They can separate and move to create a new household, following the rules of the Chayanovian scalar stress, which gives estimates of the scission point.

Agents cultivate cereals, own herds of domesticated animals, hunt and gather wild resources. All these actions are estimated on the basis of archaeological inferences. Since some practical behaviors cannot be simply inferred from these findings, their estimation required also the use of anthropological and ethnographical data.

The result is the creation of a complex economic and social system, where the behavior of the agents reflects the real necessities of a pre-industrial farming society.

The place where colonists establish their settlements is not casual: the site has to respond to several criteria for optimum farm production. For that reason a best patch map is created, divided in pixels of 1 square kilometer's size that constitute the basic geographical unit. Every pixel has a value, deduced from altitude, land fertility, climate reconstructions, that makes it more or less likely to be occupied by the Neolithic settlers. This data has been found in paleo-climate and pedological studies. Furthermore, pixels where an archaeological site has been found in reality will consequently have a favorable value for being chosen.

Every turn of the simulation represents a calendar season, and all the information present in the model is updated every turn. The agents adjust their behavior according to the other variables, in order to ensure economic production, reproduction and survival in case of crises. When the scission is triggered according to scalar stress, agents will move to create new settlements, densifying the already occupied area or, if more advantageous, expanding the pioneer front following the best patch.

In order to simplify and reduce the number of simulations, a sensitivity analysis is performed. It consists of detecting which variables have greater influence on the final outcome.

The results of the simulations are analyzed and compared to the observed archaeological history in order to see which scenario is the most likely to represent the Neolithic spread.

With the Multi-Agents model we are able to better understand elements of the Neolithic way of life that could never be detected from purely archaeological observations. The simulation is based on estimations that cannot be found in archaeological records. The combined approach of using multidisciplinary data can help to uncover unidentified and complex scenarios that were previously unknown.

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Towards Modeling a Multi-Agent System for Balkan Neolithic Spread

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Introduction

The aim of this work is to investigate the spread and the behavior of the first Early Neolithic farmer societies in Europe using a Multi Agent model.
The agent-based approach was chosen with the purpose of testing alternative scenarios that cannot be derived from a purely archaeological observation.
The research area (fig.1) accounts for the entire Balkan Peninsula, as well as Western Anatolia, which played an important role in the spread of Neolithic in Europe (Özdoğan 2011).
This area is not considered archeologically homogeneous, being that it was host to several different cultures (fig.2). However, many similarities are common to the entire area, such as monofamiliar households, farming system characteristics, animal livestock. This allows the model to work on a super regional scale, while still being able to take into account local particularities.
Some questions can consequently be formulated: was there only one front of expansion, or is it possible to detect various fronts? Which was the direction of the spread? Which were the characteristics of the farming system, and was it already formed when it reached Europe, or did it develop locally?

This work is structured on two different levels: a geostatistical analysis and a Multi-Agent model.

Figure 1: research area

Methods

Geostatistycal analysis

The present geostatiscal analysis aims to represent the spread of the farming system on the map.
Data is constituted by a transnational geographical database (Turkey, Greece, Bulgaria, Romania, Macedonia, Serbia, Hungary, Albania) including approximately 1000 sites and more than 500 ^{14}C dates from nearly 100 sites.
The database was audited and ^{14}C dates considered too old (before 1970s), suspected of old wood effect, and with too high standard deviation were excluded.
Kriging technique of spatial interpolation was then performed. The resulting scenario interpretation can help to understand the paths and the timing of the Neolithic spread (fig. 3).

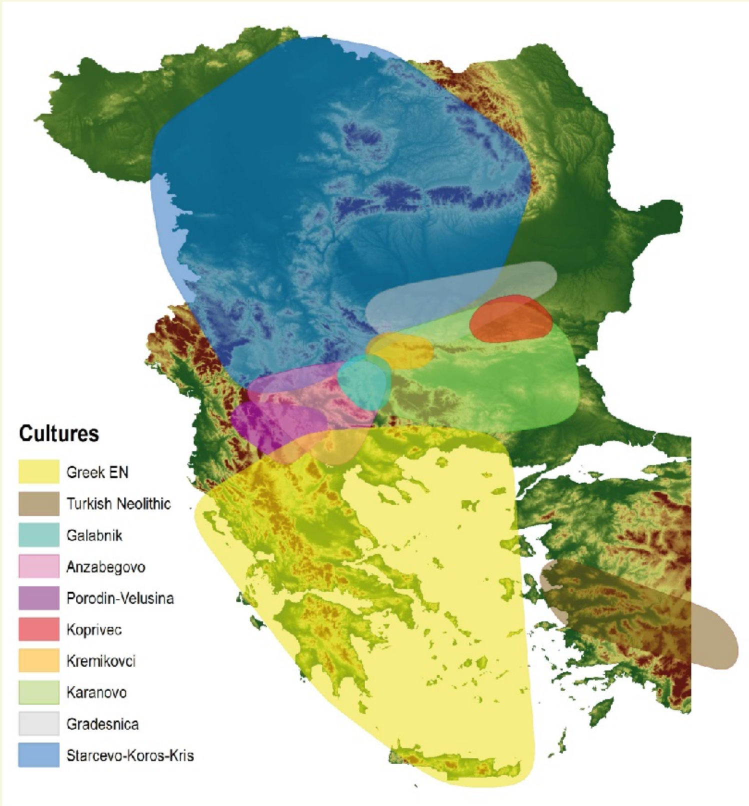

Figure 2: main cultures

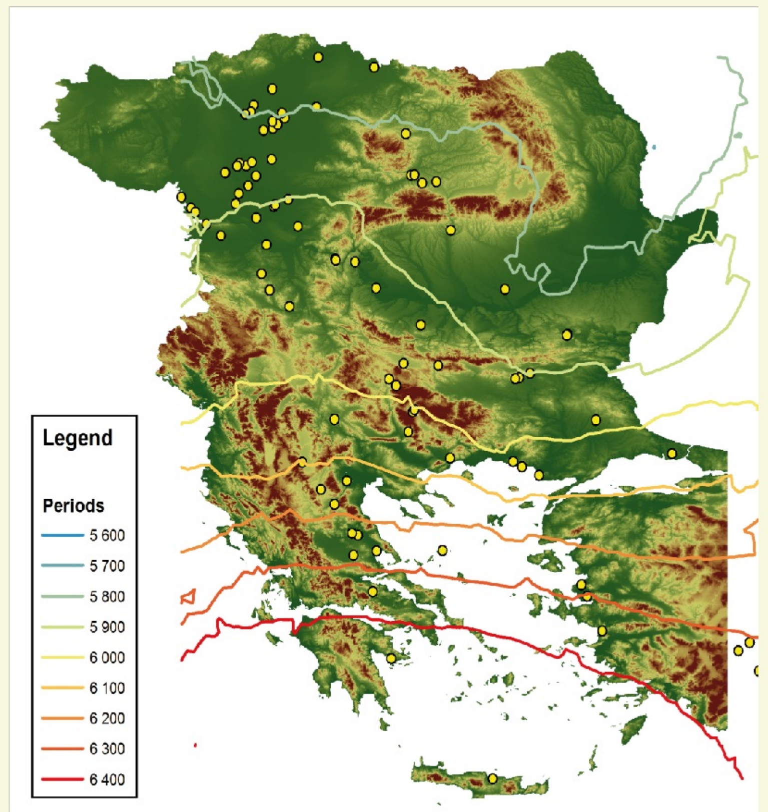

Figure 3: a kriging scenario

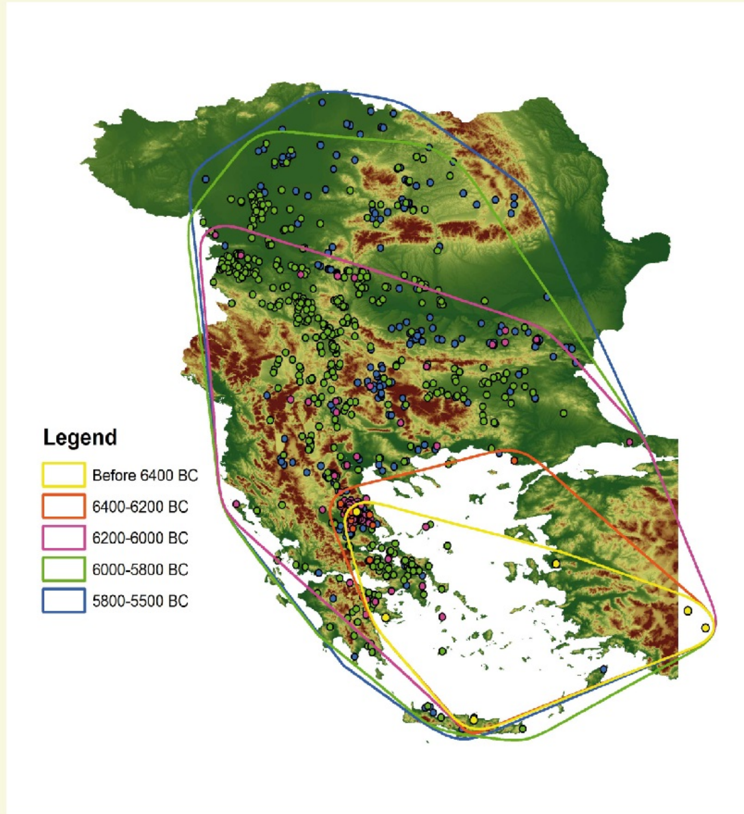

Figure 4: observed archaeological timing

Multi-Agent model

The present Multi-Agent model aims to simulate the functioning of the farming system as well as its spread. It focuses on the mechanisms of the expansion, in an attempt to explain how this process may have devolped.
The model was built up from ethno-archaeological inferences on the palaeoenvironment together with partial intermediate anthropological and ethno-historical models.
Each agent corresponds to a household, representing a nuclear family. Individuals within households die, marry and reproduce. They separate and move to create new households following the rules of the Chayanovian scalar stress, which provides estimations of the scission point (Chayanov 1923). Agents cultivate cereals, own herds of domesticated animals, hunt as well as gather wild resources.
The result is the creation of a complex economic and social system, where the behavior of the agents reflects the real necessities of a pre-industrial farming society.
The paleoenvironment data are employed in order to create the best patch map. Every pixel of 1 square kilometer receives a value, deduced from altitude, land fertility and climate reconstructions, that corresponds to the favorability of the area and the likelyhood of it being occupied by the neolithic farmers. Pixels where an archaeological site has been detected also receive a favorable value.
Every turn of the simulation represents a calendar season, and all the information present in the model is updated every turn. The agents adjust their behavior according to the other variables, in order to ensure economic production, reproduction and survival in case of crises. When the scission is triggered according to scalar stress, agents will create new settlements, densifying the already occupied area or, if more advantageous, expanding the pioneer front following the best patch.
The model object of this research is a regional adaptation of OBRESOC model, which is a simulation of LBK Neolithic culture spread in central Europe (Boquet-Appel et al. 2014)

Expected results

Simulations' results will be analyzed and compared to the observed archaeological records in order to see which scenario best fits the data. Of particular interest will be contrasting the timing of the dispersion in the model to the observed timing from archaeological data (fig.4).

Conclusions

The Multi-Agents model approach uses comprehensive data from differente disciplines, making it possible to test and explore new scenarios within intermediate models that cannot be produced from purely archaeological records.
After performing the simulations and analyzing their results, the original archaeological questions can be resumed and reexamined adding new perspectives.

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A Dynamic Model of Urban Green Spaces, Residential Mobility and Real Estate Market

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***Keywords:* Agent-based modelling, hedonic pricing analysis, locational choice, residential mobility, human decision-making, land use, urban green spaces.**

ABSTRACT

RESIDENTIAL mobility and locational choice are one of the major drivers of urban land use change. Locational choice in turn is influenced by different factors, such as market value of housing, proximity to city center and working place as well as neighborhood characteristics (e.g. presence and quality of schools, hospitals etc.). We argue in this contribution that also environmental characteristics - which are represented by urban green spaces in the given study – are significant. In fact, the variety of urban green spaces, such as street trees, urban parks, forests and backyards provide urban ecosystem services: recreation, local climate regulation as well as air quality improvement [2] that might considerably influence the place that people prefer to live.

To better understand the locational choice, either hedonic pricing or agent-based modelling can be applied. We suggest systematically including both methods. The study is carried out for the city of Leipzig, Germany, a city of about half a million inhabitants with quarters of influx of population and other of significant abandonment. The empirical framework of the anticipated agent-based model will be based on the findings of hedonic pricing analysis that will demonstrate how real estate prices for residential housing are influenced by urban green spaces [7]. Hedonic pricing is based on the principle that the price of a marketed good is influenced by specific implicit characteristics of that good that can be disentangled and understood to either raise or lower the overall price [6]. The conventional influencing factors are house appearance and neighborhood characteristics, but also environmental characteristics. Therefore, as a first step, the aim was to estimate the extent to which price and demand can be affected by various external factors or, in other words, what is people's willingness to pay for the particular good considering those factors.

The poster demonstrates the conceptual framework under development for simulating human decision-making in relation to locational choice and urban land use. This modelling is foreseen as a further step in the analysis of relationships of real estate market, residential mobility and the affiliated spatial pattern of urban ecosystem services demand and supply.

For the purposes of the given study, it is planned to simulate the feedbacks between urban green spaces, housing prices and residential decisions of the households. In other words, it is proposed to add the human decision-making to the locational choice and land use aspect with the help of the agent-based model. That will enable to get an insight how households consider market value as well as provision of urban ecosystem services (i.e. urban green spaces) in their locational choice.

NetLogo will be used as a modelling tool representing the interaction within the housing market between the owners of housing units and tenants. The latter have budget constraints and are heterogeneous in terms of their preferences but not in their decision-making algorithm. Additionally, the proposed agent-based model will be based on the Alonso's monocentric city model [1].

There are several studies on the agent-based modelling in the urban context [4], [5], [3]. In the frame of this study, it is planned to extend existing approaches, on the one hand, by placing emphasis on the proximity and different types of urban green spaces as one of the model inputs. On the other hand, in contrary to the most studies, renting prices will be used within a model. Thus, the formation of housing prices will follow a different approach than the previous models.

The anticipated agent-based model can be used for elaboration of scenarios for the joint development of urban green spaces and housing (e.g. in respect to the decisions on creation or removal of the green spaces) as well as demographic change. Additionally, it may be feasible to adapt this model for other cities.

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Topic Recipe-based Social Simulation for Research Dynamics Analysis

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***Abstract*—In this paper, we introduce an agent-based modeling and simulation model for research dynamics analysis. Since researchers constitute research systems in research dynamics, modelling the behavior of a researcher is a key to this method. A researcher makes topic recipes for research products projecting his/her interest and fulfilling financial needs under his/her capability and topical trends. A topic recipe means a combination of topics in a research field. A topic can be related to a methodology or domain knowledge. However, the researcher chooses the favorable topic recipe among the recipes for each. We analyzed the forecasting power of our model. We also examined research dynamics, in terms of foresight, with respect to the social network structure of researchers. In result, we confirmed many topical trends generated by our model had similar pattern to the real topical trends. However, there still are future works to improve the forecasting power.**

Keywords: Social simulation, Research dynamics analysis, Topic recipe, Forecasting, Foresight, Topic modeling

I. Introduction

RESEARCH dynamics is a stream of studies on research that focuses on the evolution of research system over time. It pays attention to the dynamic interactions between constituents of the system. The system consists of researchers with a certain relationship among them. The system yields research products of researchers. The products are scientifically measurable and compositions of topics as in latent Dirichlet allocation [4]. Research products are also input for the individual knowledge function [2] and for the national economic growth function [5]. And thus, the relation between the dynamic changes in the research topics according to the constituents is the interest of research dynamics.

Research dynamics is important to both a researcher and a research policy maker. A researcher could set a competitive strategy against the other researchers [11]. A policy maker would specify operational processes to achieve multiple objectives for national economic growth by utilizing the principles lie in the research dynamics [3].

The vast amount of studies on dynamics analysis has a limit to incorporate a researcher decision-making process along with social interactions in micro level since empirical data limitations exist. But simulation can be the breakthrough for the restriction by uncovering the output of social interactions among researchers deciding what research product to make strategically. We develop researcher agent-based modeling and simulation, which we call social simulation. We believe our simulation for research dynamics analysis not only provides insights for foresight but is capable of capturing topical trends for forecasting.

There are three contributions. First, it extends the present social simulation of computational modeling approach to scientific research dynamics. Second, it suggests social simulation as a foresight tool as well as a forecasting tool for research dynamics analysis. Third, it provides a useful way to alleviate the problem of calibration in social simulation when forecasting topical trends.

II. Literature Review

A. Research Analysis

Scholars have studied scientific research for several objectives: understanding science and technology trends, investigating the relationship among research products and actors in research, scrutinizing the actors' dynamics, assessing the impact of scientific research, forecasting the next research issues, and establishing plans and policies to give incentives to research community to achieve a certain goal of a policy maker .

The scholars utilized various methods to accomplish their goals. The popular methods are estimation by regressing econometric models, input-output analysis, game theory, Delphi, technological road mapping, network analysis, and content analysis with the help of text mining. However, no method has a perfect power to explain phenomena but one method is complementary to another method. For analyzing future, a methodological crossover between fields and the integration of the present methods seems promising [1]. In particular, social simulation as an emerging methodology that simulates complex systems is highlighted.

B. Social Simulation

Social simulation has grown its share throughout disciplines. However, a small number of social simulations are available for research dynamics analysis [9]. Pajares, Lopez, and Hemandez (2003) built a social simulation for industrial sector with an objective to test and to assess firms' strategies, in terms of R&D management [7]. Firms and consumers comprise the artificial society of this social simulation. Firms decide process investment and product innovation strategically. Subsequently, Pajares, Hemandez-Iglesias, and Lopez-Paredes (2004) proposed advanced industrial research dynamics where firms learn decisions on

R&D budget, production, and technology [8]. Cerulli (2012) modeled a stochastic game between a research foundation and a funded firm for an examination of R&D subsidies [6]. The author concluded that a collaborative strategy outweighs a rivalry strategy between the foundation and the firm to reach the social optimum within R&D funding.

Similar social simulations for analyzing various dynamics in a system are on market dynamics, epidemics, emergency dynamics, opinion dynamics, and ecological dynamics.

III. Model

We design a research topic recipe-based decision-making model, consisting of acknowledging the social values for topics, creating the candidate recipes, and choosing one research topic recipe for each time. We build a researcher social simulation model by applying this decision-making model to researcher agents within a social network.

A. Research Topic Recipe Model

Assume a research product is a composition of topics. A researcher considers how to blend topics into a research product. That is, a research product is an implementation of a topic recipe. The researcher would think several candidates of topic recipes and choose the most satisfactory and probable one from the candidates. The researcher may not only refer to individual interests on topics but also consult social values of topics. Social and psychological aspect of getting reputation matters to manufacturing a research product. Self-interest of solving problems also motivates researchers to conduct on making a research product. Money is also a motivational factor to researchers to fabricate a research product. This researcher topic recipe model is divided by four subsequent phases. (1) Acknowledgement of social values of topics: the model starts with assessing social values of topics. (2) Creation of research topic recipes: making research topic recipes is to derive candidate research topic recipes from the topic recipe of the latest research product. (3) Evaluation of the research topic recipes: an agent evaluates the candidates to compare one to another. (4) Selection of one research topic recipe: a researcher agent is likely to produce a research product that would have more valuable.

IV. Experiment and result

We implement our model on the top of NetLogo. We assume the researcher social network is a small world network [12]. We change the rewiring probability to see how social values and topic recipes change according to different social structures. We compare topic modeling result of the abstracts of IIE Transactions with our result by dynamic time warping (DTW). DTW returns the similarity between two different time series data [10].

The first result shows the similarity between the simulation result and topic modeling result. Many are similar in terms of pattern. It implies that the topical trends are the result of an emergent and collective behavior of researchers in research systems. The second result shows the changes in ten topics with respect to the rewiring probability of a social network. The increase in the rewiring probability implies the average path lengths among researchers are shortened and the degree of clustering in researchers becomes higher. It can be done by the development of media such as web.

V. Conclusion

The result of our social simulation shows the potential of its power to forecast and foresee the future topical trends. However, to improve its precision, we may have to conduct more experiments on other variables.

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Topic Recipe-based Social Simulation for Research Dynamics Analysis

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INTRODUCTION

Research dynamics is the evolution of research systems over time due to dynamic interactions between constituents of the systems. Understanding research dynamics is important for establishing Science & Technology policy as research is considered as a driver of national growth.

By taking advantage of computational modeling and simulation, we introduce a social simulation model for research dynamics analysis. In the model, agents make topic recipe-based decisions. It is to complement and advance the present method for research dynamics analysis.

We conduct an experiment to verify the forecasting and the foreseeing power of our model. Our result shows that similar patterns to the real patterns were generated by feeding the first topic proportion only. However, the numbers were not precise. From the forecasting, we could foresee how various outcome would be made by controlling a variable of social network. We suspect delicate but abundant trials are required.

This study contributes in three ways:

Extends the present social simulation on research dynamics.

Confirms social simulation as tools for foresight and forecast.

Alleviates the problem of calibration problem in social simulation.

Topic recipe

Formula of topics as ingredients

A researcher i's topic recipe with n topics at time t is represented as a vector, $\boldsymbol{w}_i(t)$

$\boldsymbol{w}_i(t) = (w_{i1}(t), \ldots, w_{in}(t))$

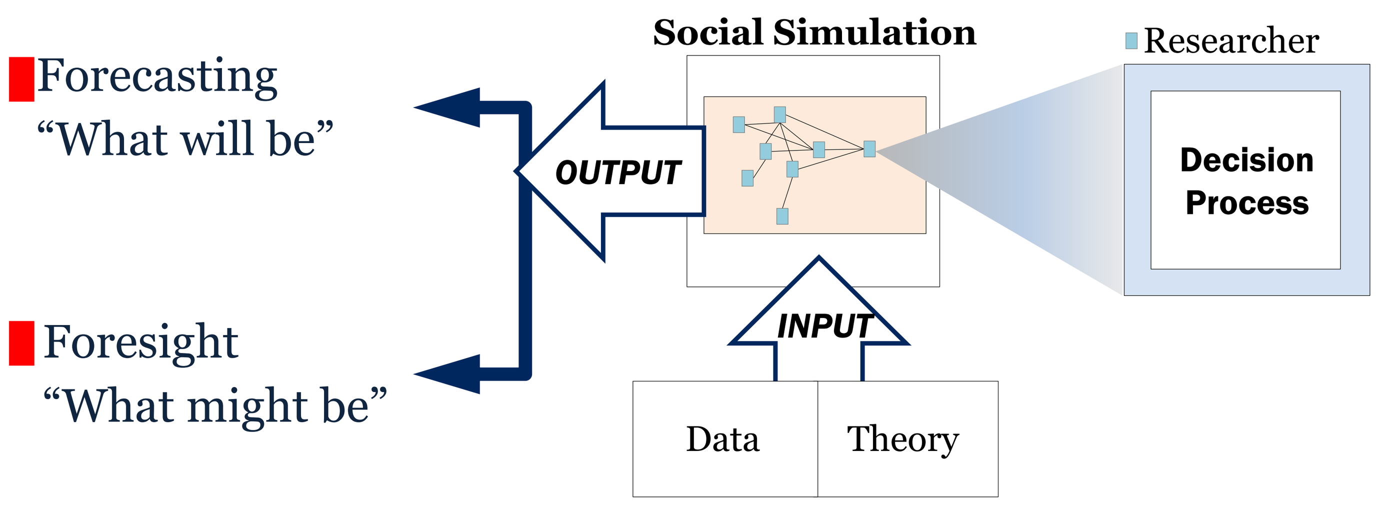
Social values

Popularity of topics

The social values that a researcher i perceived at time t is represented as a vector, $\boldsymbol{x}_i(t)$

$\boldsymbol{x}_i(t) = (x_{i1}(t), \ldots, x_{in}(t))$

MODEL



How to "cook" a paper?

(1) Acknowledge what people like
(2) Consider possible recipes
(3) Evaluate the recipes
(4) Choose a favorable recipe
(5) Generate a research product

* We treat producing a research product with topics as cooking food with a recipe.

Description

Agents in our social simulation follow topic recipe-based decision-making process as well as constitute a small world network.

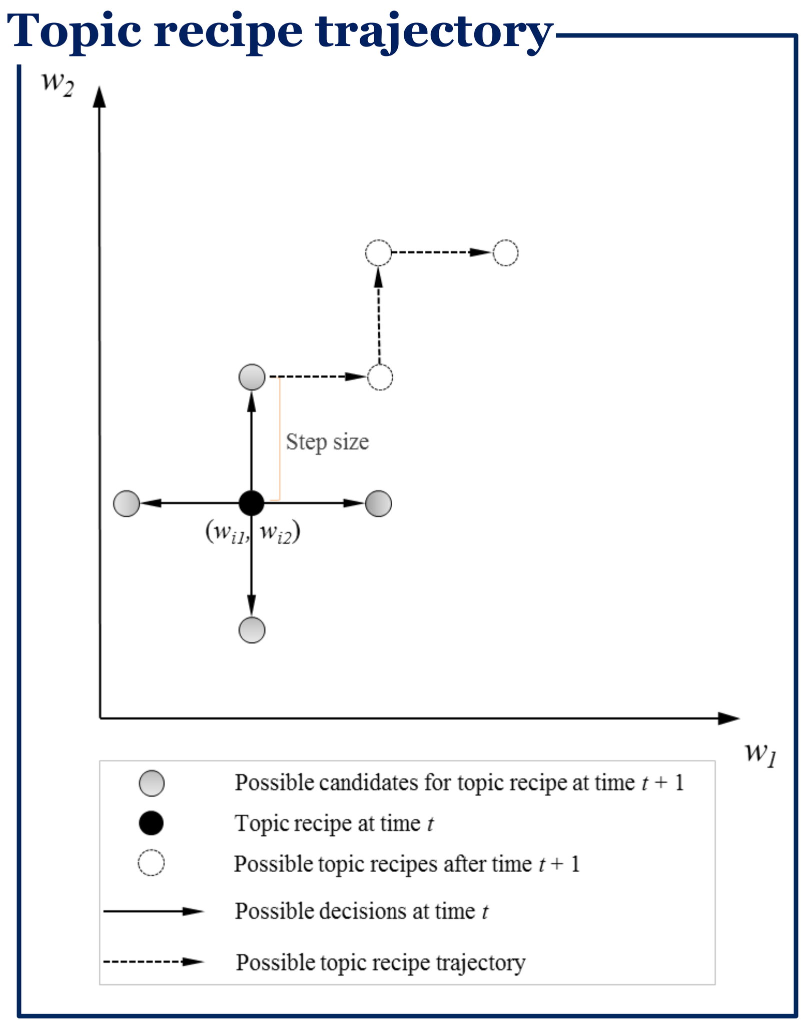
For each time, agents share their social values (Equation 1 and 2) through the network. The values are controlled by social sensitivity, α_i, and social power, of neighbor g, $s_{gi}(t)$.

The agents create possible research topic recipes for the next research product. A topic recipe is equivalent to a combination of weights on topics. Scholarly self-interest and financial interest are the innate factors for generating a new research product (Equation 3). The possible research topic recipes originate from the topic recipe of the current product by random walk approach as in the figure of "Topic recipe trajectory".

And then, the agents evaluate the possible research topic recipes. The scholarly value of a candidate is the weighted sum of the current social values and the scholarly part of every recipe (Equation 4; $p_i^s(t;k)$ is agent i's scholarly value of k^{th} recipe at time t and $w_{ij}^s(t;k)$ is agent i's scholarly weight on j^{th} topic at time t). The financial value of a candidate k is the weighted sum of the fund weight(proportion) and the financial part of every recipe (Equation 5). And, the total value for the candidate k is the weighted sum of them (Equation 6; ω_i^s and ω_i^f are agent i's weight on scholarly and financial values).

Finally, each agent chooses a topic recipe for the next research product probabilistically. The probability of choosing k^{th} candidate at time t is calculated by Multinomial logit rule.

Topic recipe trajectory



LITERATURE REVIEW

RESEARCH DYNAMICS ANALYSIS on

Understanding science and technology trends (Yan, 2014)
Investigating the relationship between research product and researchers (Olmos-Penuela *et al.*, 2014)
Scrutinising actors' dynamics (Martinson *et al.*, 2009)
Assessing the impact of science research (Hall and Reenen, 2000; Lee *et al.*, 2012)
Forecasting the next research issues (Halal, 2010)
Establishing plans and policies (Martin, 2010)

RESEARCH DYNAMICS ANALYSIS by

Econometric models (Kleinknecht and Reijne, 1991)
Input-Output Analysis (Hall and Reenen, 2000)
Game Theory (Dasgupta and Maskin, 1987)
Delphi (Harold and Turoff, 2011)
Technological Road Map (Carvalho *et al.*, 2013)
Network Analysis (Lee *et al.*, 2012)
Text Mining (Blei *et al*, 2003, Yan, 2014)

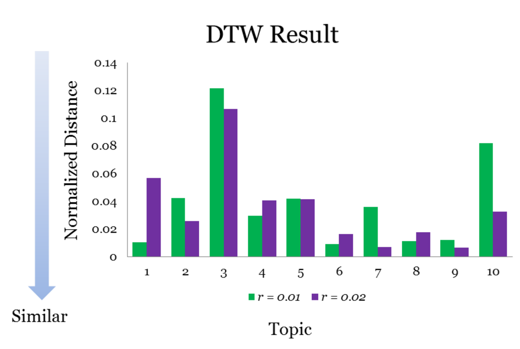
SOCIAL SIMULATION

Industrial sector to test and to assess firms' strategies on investment (Pajares *et al.*, 2003)
R&D budget, production and technology (Pajares *et al.*, 2004)
Stochastic game between research foundation and funded firm for examining R&D subsidies (Cerulli, 2012)

Similar dynamics: Market dynamics (Zenobia *et al.*, 2009; Lee *et al.*, 2013, 2014), epidemics(Burke *et al.*, 2006; Rahmandad and Sterman, 2008), emergency dynamics(Mysore *et al.*, 2006; Narzisi *et al.*, 2006; Carley et al., 2006), opinion dynamics (Deffauant *et al.*, 2001), ecological dynamics (McLane *et al.*, 2011)

RESULT

Forecasting

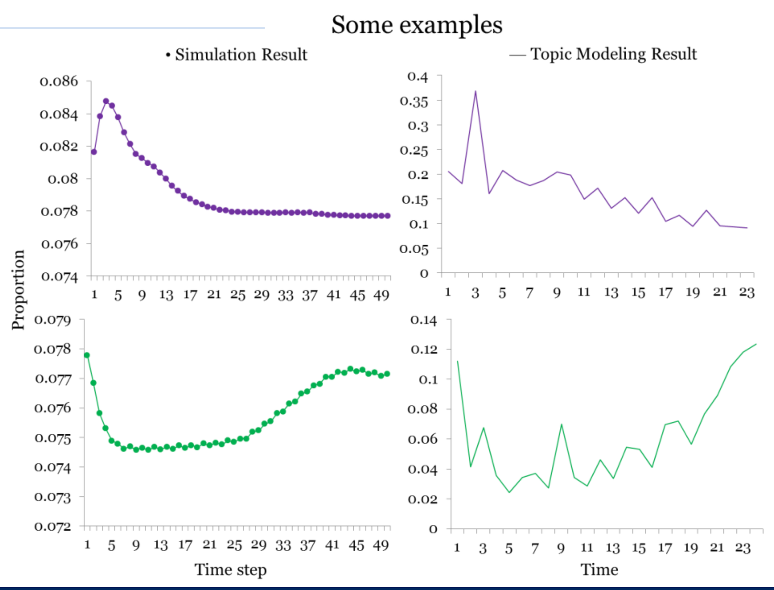


As shown on the left chart, not all but many topical trends were similar between our simulation result and topic modeling result. Scales were different in some degrees but patterns were similar. Our result revealed the fact that research dynamics can be simulated if a proper decision-making process of an agent and a decent social network structure are given. The below figures are two examples of similar patterns (Topic 10 and topic 1).

Some examples

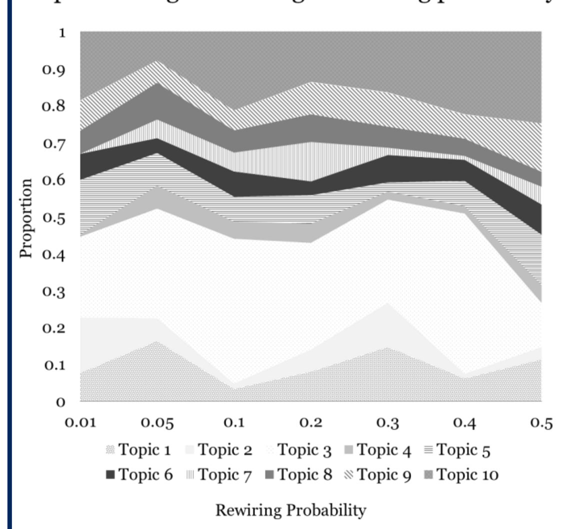
Data: IIE Transactions (1990~2013)
#Agents: 100
#Topics: 10
α: 0.3
Rewiring probability (r): 0.01~0.5
#Replications: 30
Tool: NetLogo 5.0.5
Topic modeling: LDA (Blei *et al.*, 2003)

*Initial proportions of 10 topics are given by the result of LDA.



Foresight

Topical change according to rewiring probability



The figure on the left shows the changes in the final proportions of ten topics as scholars get clustered. It was done by controlling the rewiring probability of the social network of agents. The rewiring probability shortens average path lengths between agents and clusters agents highly.

The development of media such as web makes the rewiring probability high. And thus, the result depicts the topical changes that might be made by the clustering of researchers.

Topic 1: System-Reliability-Maintenance-Failure-Repair-Inspection-Degradation-Replacement
Topic 2: Method-Data-Model-Simulation-Performance-Design-Analysis-Parameter
Topic 3: System-Performance-Throughput-Machine-Production-Buffer-Line-Flow
Topic 4: Problem-Algorithm-Solution-Programming-Optimal-Heuristic-Computational-Optimization
Topic 5: Production-Cost-Optimal-Inventory-Policy-Demand-Product-Order
Topic 6: Scheduling-Time-Job-Machine-Processing-Batch-Algorithm-Heuristic
Topic 7: Surface-Part-Machining-IIE-Transactions-Edition-Article-Materials
Topic 8: Supply-Demand-Price-Information-Chain-Supplier-Manufactuerer-Retailer
Topic 9: Control-Process-Chart-Quality-Sampling-Performance-Monitoring-Statistical
Topic 10: Manufacturing-System-Design-Model-Process-Assembly-Quality-Decision-Control

Dynamic Time Warping (DTW)

A similarity measure for different size of two time series. The larger value implies the larger difference.

Equations

$$\boldsymbol{x}_i(t+1) = (1-\alpha_i)\boldsymbol{z}_i(t) + \alpha_i \sum_{g \in G_i} s_{gi}(t)\boldsymbol{z}_g(t) \qquad (1)$$

α_i: the sensitivity to social influence
g: one in agent i's neighbor set G_i
$s_{gi}(t)$: the degree of social power of g to i at time t
$\boldsymbol{z}_g(t)$: a normalized vector for g's social values at time t

$$z_{ij}(t) = x_{ij}(t)w_{ij}(t) / \sum_{j=1} x_{ij}(t)w_{ij}(t) \qquad (2)$$

$z_{ij}(t)$: j^{th} topic value of $\boldsymbol{z}_i(t)$
$x_{ij}(t)$: j^{th} topic value of $\boldsymbol{x}_i(t)$
$w_{ij}(t)$: j^{th} topic value of $\boldsymbol{w}_i(t)$

$$w_{ij}(t) = w_{ij}^s(t) + w_{ij}^f(t) \qquad (3)$$

$w_{ij}^s(t)$: j^{th} topic value of the self-interest(scholarly) part of $\boldsymbol{w}_i(t)$
$w_{ij}^f(t)$: j^{th} topic value of the financial interest part of $\boldsymbol{w}_i(t)$

$$p_i^s(t;k) = \sum_{j=1} x_{ij}(t)w_{ij}^s(t;k) \qquad (4)$$

$p_i^s(t;k)$: i's self-interest value of k^{th} candidate topic recipe at time t
$w_{ij}^s(t;k)$: i's self-interest weight on k^{th} candidate topic recipe at time t

$$p_i^f(t;k) = \sum_{j=1} d_j(t)w_{ij}^f(t;k) \qquad (5)$$

$p_i^f(t;k)$: i's financial interest value of k^{th} candidate topic recipe at time t
$w_{ij}^f(t;k)$: i's financial interest weight on k^{th} candidate topic recipe at time t
$w_{ij}^f(t:k)$: j^{th} topic value of the financial interest part of $\boldsymbol{w}_i(t;k)$
$d_j(t)$: the fund proportion of j^{th} topic

$$p_i(t;k) = \omega_i^s p_i^s(t;k) + \omega_i^f p_i^f(t;k) \qquad (6)$$

$p_i(t;k)$: i's total value of k^{th} candidate topic recipe at time t
ω_i^s: i's weight on self-interest value
ω_i^f: i's weight on financial value

$$\Pr\{\boldsymbol{w}_i(t+1) = \boldsymbol{w}_i(t;k)\} = \frac{\exp\left(p_i(t;k)\right)}{\sum_k \exp\left(p_i(t;k)\right)} \qquad (7)$$

CONCLUSION

Implications

Forecasting – "What will be"

Our social simulation can induce the similar topical trend patterns to the real topical trends with only the very first data of topical proportions. And, it means topical patterns are from an emergent and collective behavior of researchers in research systems. The detail fluctuation, which can be called noise for now, is not presented in simulation result. It means there still is a room for advancement in the power to forecast topical trends. This advancement may empower the precision of the numbers for topical proportions for each time.

Foresight – "What might be"

Our social simulation can provide how the output may change according to the structural modification in the social network of researchers. This may help a policy maker to decide the extent of coordination between researchers.

Future Work

Limitation

Limited control variables were applied: rewiring probability was the only consideration.

Social power of each agent was identical and constant: $s_{gi}(t)$ was set by the inverse of the number of neighbors and was invariant.

Assume topic model generates good quality of topic assignments.

Future research topics

Not only rewiring probability but also the sensitivity to social influence, the proportion of self-interested part of a topic recipe, the weights of self-interest and financial interest values, the stride of random walk, the number of candidates, the number of agents, the number of topics, and the rule for social influence can be controlled.

Several different topic modelling results can be used as benchmarks.

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City of Uruk 3000 B.C. : Using genetic algorithms, dynamic planning and crowd simulation to re-enact everyday life of ancient Sumerians

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***Abstract*—Virtual reality reconstructions of ancient historical sites have become a valuable technique for popularising science and visualising expert knowledge to general audiences. Most such reconstructions only re-create buildings and artefacts and place them in the context of the virtual environment, but what is often missing in such simulations is the ability to see how ancient people lived their daily life in these environments. Our presented case study shows how the use of genetic algorithms and simulation of physiological needs helped us to populate the 3D reconstruction of the city of Uruk with a large crowd of intelligent agents simulating daily life of ancient Sumerians in Uruk[1].**

I. Introduction

Uruk was an ancient mesopotamian city located in the present day Iraq. It is believed to be one of the first human built cities on Earth. In our reconstruction we simulate Uruk in the period around 3000 B.C and employ Unity 3D[2] as the engine for visualising Uruk.

One of the key challenges of this work was how to have the virtual Uruk populated by virtual agents that re-enact everyday lives of its ancient inhabitants and how to do it with maximal possible automation and cost saving. In the following sections we present the key details of our approach built around genetic algorithms, crowd simulation, artificial physiology and dynamic planning.

II. Obtaining expert data

In order to populate the city with virtual agents, we designed a number of scenarios that we obtained after detailed discussions with subject matter experts and history consultants. As the result of these discussions we identified roles the agents play, scenes they participate in, interaction protocols and social norms. We followed the methodology described in [1] to structure the knowledge received from the experts and transform it into formalisations suitable for developing the underlying multiagent system.

[1]See the video at: http://youtu.be/ZY_04YY4YRo
[2]http://unity3d.com

The agents in the Uruk simulation represent a slice of Uruk society among which are fishermen families, priest, king and a number of workers (i.e. pot maker, spear maker). The agents can sense changes in the environment state, which result in them updating their beliefs accordingly. They are supplied with a number of internal goals and plans to reach those goals. The current implementation features fishermen families where men's daily routines include sleeping, eating, fishing and chatting. The females do house work, sleep, eat bring water from the well and go to markets. The king agent walks around his palace and invites students to ask him about his ruling strategies. The priest agent conducts a prayer in the temple, accepts gifts and explores the city. Other agents represent various workers: pot makers, spear makers, etc. Those workers produce goods, exchange goods with one another, attend the prayer and in their spare time explore the city, provide information to students and simulate social interactions with other agents.

III. Implementation Details

The 3D design of the city was created based on the results of archaeological excavations and available written sources. The objects and artefacts were mainly created based on the details obtained from museums, but several objects were also created following drawings and illustrations from history books. Figure 1 shows Uruk reconstructed in Unity.

One of the key problems with the Uruk simulation was to populate the city with virtual agents simulating daily life of its citizens (Sumerians). The scenarios mentioned in the previous section if implemented in a classical way (where every agent is individually designed and programmed) would be extremely time-consuming and costly to produce. Therefore, we have developed an approach to automate many steps. The automation lies in the technique to automatically generate a crowd of avatars of a desired size using a genetic algorithms approach from a small initial sample of manually designed avatars representing the base population. In order to make these avatars perform complex daily life routines the agents are supplied

Fig. 1: 3D Visualisation of the city of Uruk 3000 BC

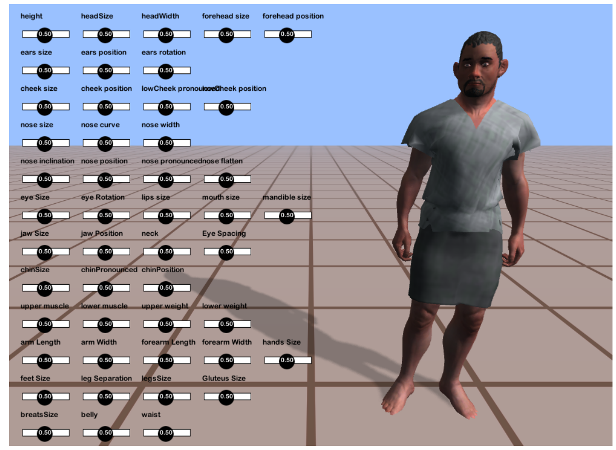

Fig. 2: Unity Multipurpouse Avatar - Modification

with models of physiological needs, so that agent goals can be automatically generated through these needs (like hunger, thirst, fatigue, etc.) becoming more pronounced. The agents must have a way to react to these needs in a way appropriate for the social role the agent is playing in the reconstructed society. Thus, to make this possible we formalise the role flow and social norms of the reconstructed society (that we label as institution). The institution permits agents to find a plan of actions that leads to satisfying each of the needs, while keeping this plan in accordance with the role played by the agent. Finally, to increase believability and improve diversity of agent actions we supply agents with diverse personalities, so that actions of others and the state of the environment may affect an agent's emotional state and result plan variations in response to the same goal. Further we highlight the technical details of the aforementioned techniques. This process is separated into six steps, following the methodology from [2].

a) Step 1: Define Base population: The process begins by defining the base population of the city of Uruk. According to our methodology, the base population has to include at least one pair of avatars, male and female, for each ethnicity living in the city. To define the base population, we propose to use parametric avatars, which is a mesh that can be modified using pre-defined parameters, e.g. height, head shape, eye size. Parametric avatars are well known from computer games, where they form a part of the closed eko-system, not usable for our purpouses. Therefore, we selected the open-source project, Unity Multipurpouse Avatars (UMA)[3], which allows to modify avatar shape directly in Unity 3D (see Figure 2). While UMA permits to modify the avatar body shape, the Marvellous Designer[4] is used to reconstruct avatar clothing, accurately according to the available literature. We then use Blender to create various attachments and trinkets that enhance avatar appearance. UMA uses these objects and distributes them randomly during the generation process (see Section III-A).

[3]http://fernandoribeirogames.wix.com/umabeta
[4]http://www.marvelousdesigner.com

b) Step 2: Configure motivational modifiers: Our aim is to generate avatars not only with unique appearance, but also with a unique (or non-uniform) behaviour. Therefore, in this step, we define the physiological modifiers of the base population. We set various decay rates for hunger, thirst, fatigue and comfort for each member of the population. As a result of this process, avatars generated from the base population obtains varied and mutated values of these modifiers. Since each modifier has a different value, avatars become hungry or tired in distinct intervals, executing their actions non-uniformly. In order to facilitate this in Unity 3D, we designed the component which contains editor of physiological modifiers, monitors the current physiological state of an agent, as well as allows to edit these values at runtime. Figure 3 depicts the interface of the physiology component and the agent drinking water as a reaction to passing the threshold value for thirst.

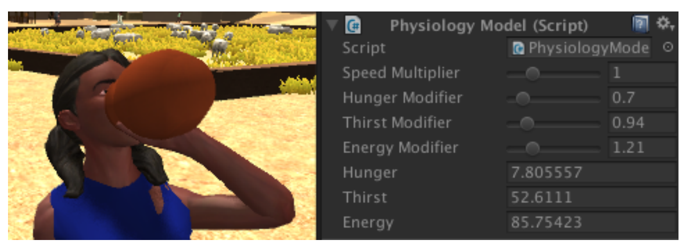

Fig. 3: Physiological needs: agent reacting to state "thirsty"

c) Step 3: Specify personality traits: When agents obtain several possibilities of reaching their goal (e.g. to steal, beg or work to obtain food), we propose them to select the action which best reflects their personality and a current emotional state. Therefore, in this step, for each member of the base population its personality is specified using the popular OCEAN model [3], which captures five personality traits: *openness, conscientiousness, extroversion, agreeableness and neuroticism*. Similar to physiology, we have developed Unity components that facilitate the definition of agent personalities and monitor their current emotional state.

d) Step 4: Formalise Social Norms and Roles: In this step, we formalise the social structure and corresponding actions and rituals of the simulated society [4]. For this task, we specify an Electronic Institution (EI), a well established Organisation-Centred Multi-Agent System (OCMAS). EI establishes what agents are permitted and forbidden to do as well as the constraints and the consequences of their actions [5]. Definition of an EI consists of the following components: dialogical framework (defines the common ontology and roles), performative structure (defines role access), scene protocols (define interactions) and norms (control interactions). The definition stored in the Electronic Institution is used by agents to detect the structure of interactions needed to fulfil their current goal (see Section III-B).

In case of Uruk, we defined roles for Fisherman and Potmaker as well as their corresponding actions in scene protocols, such as fishing and pot making. Also, actions to satisfy physiological needs, such as drinking, eating or resting form part of the institution. Visual counterpart to institutional actions is defined by Behaviour Trees in Unity 3D (see Section III-C).

e) Step 5: Adaptation and Annotation of the Environment: In the previous steps, we have introduced means for automatic goal selection based on physiological needs and defined the institution that facilitates automated plan making based on infrastructure of interactions. When agents want to execute such generated plan, they need to interact with other avatars and objects in the virtual space. In case of objects, they have to be annotated in order for agents to understand their functionality. This annotation includes actions that can be performed with given object (e.g. apple has action "eat", fish has actions "catch" or "cook"), constraints of their use (e.g. fish has action "cook" only if if is owned by agent) and also consequences of their use (e.g. "eating" fish decreases the level of hunger more than eating an apple).

Apart from the annotation of objects with actions they provide, we need to annotate actions with the emotional response that is triggered when performing the action. This drives agent decision to select an action that is most relevant for their personality; such action has to be annotated by following *personality facets* [6]: *temptation, gregariousness, assertiveness, excitement, familiarity, straightforwardness, altruism, compliance, modesty* and *correctness*. Using values of personality facets, the agent selects an action that provides the highest utility for its personality type [7] [6]. See Table I for an example of anotations for *work*, *beg*, *steal* and *search* actions. "Stealing" action is defined for agents with more aggressive personalities (very low correctness, low altruism), "begging" for agents with low-confidence (very low assertivity, higher correctness) and "working" and "searching" for more neutral personalities with varying sense of correctness.

A. Generating the Population

In the last step, we encode avatar's visual, physiological and personality parameters values into genes, which form strings of genes or chromosomes that identify each avatar. Then, using approaches from genetic algorithms, by combining chromosomes from two parents we reproduce the rest of the population automatically, where each new avatar is unique. Figure 4 depict a generated crowd of 100 agents in Unity3D.

Fig. 4: Generated Crowd in Unity 3D

B. Dynamic Planning and Prioritisation

In our approach, rather that giving agents full "recipes" on how to accomplish a specific goal, we give them only ingredients (in the form of annotated actions) and means of combining them to fulfil their goals. These means come in form of dynamic planning algorithm and prioritisation based on the actual goal. First, we take a look at our prioritisation mechanism, then we explain the dynamic planning for the Uruk simulation.

In our approach, we use agent sensors to trigger desires to fulfil a goal. Currently, we have two sensors: physiological sensor, which detects hunger, thirst and energy, and the scheduling sensor, which feeds agent information about its schedule. For example, agents wake up around 7AM and go to work around 8AM. Each sensor feeds desires with a different priority, where physiological sensor has the highest priority. In case that agent is currently performing an action with lower priority, it pauses its execution, processes action with higher priority and then resumes the original action. If action with the same priority arrives, it is stored in the priority queue and executed after the current action. Using this approach we were able to model agent behaviour, when agent feed when hungry, drink when thirsty, or they drop to their knees whenever Uruk king is passing by (high priority action).

Prioritisation decides what goal is currently planned to execute, but dynamic planning transforms this goal into plan of actions. Our dynamic planing solution relies on environment annotation. The virtual environment contains a number of objects that can potentially be used by virtual agents and those objects can be acted upon. Through text annotations, those object specific actions are associate with pre-condition and post-conditions. So, those annotations define how an agent is potentially able to achieve its goal through atomic actions, given all possible states [2].

	Temptation	Gregariousness	Assertivity	Excitment	Familiarity	Altruism	Compliance	Modality	Correctness
Beg	0	0	-0.5	0	0	0	0.5	0	0.5
Work	0	0	0.5	0	0	0	0	0	1
Search	0.5	0	0.75	0.5	0	-0.25	-0.5	0	-0.5
Steal	1	0	1	1	0	-1	-1	0	-0.75

TABLE I: Personality facets of agent actions.

C. Visual Representation of Actions in Unity 3D

While dynamic planning tells agents "what" has to be done to fulfil a goal, agents do not know "how" to accomplish it in virtual space. Agent possibly knows, what objects it has to interact with, yet it does not know how to operate them and how it will be visualised. For example, when agent decides to eat and apple, first, an apple has to be attached to its hand, and then apple eating animation is played. Eating fish is a completely different story, where agent first has to cook the fish, then put it on a plate, then sit down and eat the fish. The number of actions depends on the level of required complexity.

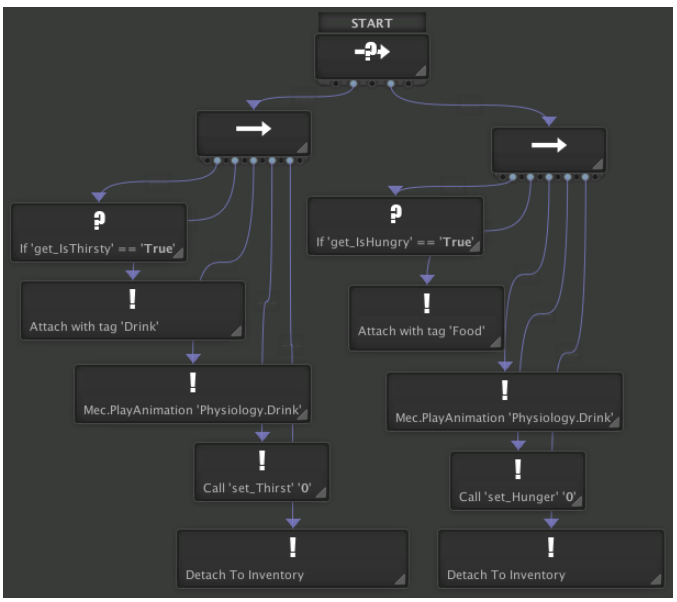

Fig. 5: Excerpt From The Behaviour Tree

To facilitate the definition of visual behaviour of avatars and objects we use behaviour trees and final state machines, provided by the NodeCanvas[5] plugin. Figure 5 depicts an excerpt from the behaviour tree for the actions performed for fulfilling certain physiological desires, such as drinking or eating an apple. Same approach is taken for interactive objects, which also use behaviour trees to drive actions of participants that operate them. For example a chair owns a behaviour tree that instructs participant how it can sit on this chair (different chairs can trigger different sitting animations).

D. Human in the Loop and Avatar Interactions

While previous sections deal only with population of agents, we would like to also discuss the human participation in the simulation and means of interacting with the Uruk simulation. In order to best educate simulation participants we have decided to create a simple plot, which human participant can follow in order to best discover the city, its history and the sumerian culture occupying it. To follow this plot, human has to interact with agents and object to listen to their stories. The dialogue trees have been implemented using the NodeCanvas plugin, which also visualises dialogues in the game. Figure 6 depicts an interaction with one of the agents. It also shows the simple game interface with the mini-map and several GUI elements showing the progress in the game.

Fig. 6: Streets of Uruk

[5]http://nodecanvas.com

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Cooperation maintained by defect and collapsed by reward in a generalized metanorms game

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We propose a generalized metanorms game (GMG) that integrates both punishment and reward in order to analyze the evolution of cooperation in public goods games. Axelrod (1986) developed a meta-punishment game in which players can punish those who do not punish non-cooperators as well as those who do not cooperate. We have expanded this original game to include a meta-rewarding part whereby players can reward those who reward cooperators as well as those who cooperate. The meta-punishment part of the GMG is suitable for modeling order formations in groups to formalize typical public goods games, while the meta-rewarding part is suitable for public goods games in which punishments have no efficacy. For example, it is almost impossible for participants who do not provide information to be punished in knowledge-sharing communities on the Internet, and thus, a framework that includes reward is needed for analyzing the evolution of cooperation.

We performed simulations to clarify the conditions needed to dominate cooperation using GMG. In the meta-punishment part, there is an equilibrium point in which cooperation dominates, but it is unstable, and cooperation eventually collapses in the long term. In the meta-rewarding part, on the other hand, cooperation dominates robustly. We install Social Indicator (SI) in order to promote cooperation in the game. SI is an agent with a fixed and controlled strategy and exists slightly in a group. We tested four types of SIs in the meta-punishment part: (1) always cooperate but never punish the others, (2) always cooperate and always punish the others, (3) always defect and never punish, and (4) always defect and always punish the others. Surprisingly, the SIs that always defect (types 3 and 4) are needed for keeping the cooperation robust. The existence of these SIs enables players to recognize the necessity of punishment for defectors, and thus, free riders for punishment cannot invade. We also use four types of SIs in the meta-rewarding part: (1) always cooperate but never reward the others, (2) always cooperate and always reward the others, (3) always defect and never reward, and (4) always defect and always reward the others. SIs that rewarded only (type 4) have a negative effect on cooperation. We find that specific SIs do not contribute directly for cooperation, but contribute indirectly by preparing environment which lets players recognize the necessity of punishment or reward.

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MARKET DYNAMICS IN THE DUTCH PORK SECTOR

Currently, the Dutch pork sector is subject to social and political debate while, at the same time, farmers experience income pressures as a result of volatile commodity markets (De Greef and Casablanca, 2009). As a policy response, the government promotes the development of so-called 'integral sustainable housing systems', which aim at improving different sustainability goals, such as animal welfare, conditions on environment and working conditions (Coenraadts and Cornelissen, 2011, van der Peet et al., 2013). In trying to address the economic feasibility of new housing systems, added-value markets attempt to combine extra requirements in housing systems with higher meat prices. Farmers respond heterogeneously to external pressures, such as policy instruments and market characteristics, depending on farmers' resources, individual characteristics, but also on their peers and their peers' problem definition (Geels and Schot, 2007, Geels, 2009, Dessein and Nevens, 2007). To gain insight into how the government can contribute to a more sustainable pork sector, this research presents an agent-based model for the simulation of market dynamics in the Dutch pork sector over the past 30 years under external change scenarios, with an explicit role for peer influence dynamics.

For the agent-based modelling framework we extend the Theory of Planned Behaviour (TPB) (Ajzen & Fishbein, 2005). The TPB has three components that influence intention towards behaviour and actual behaviour: Attitude, Subjective Norm, and Perceived Behavioural Control (PBC). We go beyond previous ABMs, by making more room for socially determined behaviour through the subjective norm. For this we experiment with different peer influence mechanisms, such as imitation, norm influences, and similarity influence. We do this by allowing a single agent to have multiple reference groups, e.g. farmers and citizens, which in interrelation influence farmers' reaction to external and peer group pressure. Important heterogeneity factors in farmer decision-making taken from empirical research on pork farmer behaviour are applied to the other components of the TPB. At the conference, we present the first phase of model development, focusing on model exploration and a qualitative validation of the selected attributes of agents and behavioural mechanisms. The first phase of empirical model validation follows the methods laid out by Smajgl and Barreteau (2014): Via semi-structured interviews with experts and life histories of pork farmers we determine which main factors influence market-strategy decision-making. Qualitative validation of the model is done with a focus group workshop centring on the attributes and behavioural mechanisms of the agents in the model.

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Agent-based modelling of agricultural water abstraction in response to climate change and policies: In East Anglia, UK

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***Abstract*—Freshwater is a vital natural resource for multiple sectors. However, freshwater available for abstraction in the UK and in particular agricultural irrigation in East Anglia is becoming increasingly variable and uncertain due to climate and policy changes, and increase in demand. We present an Agent-Based Model (ABM) that has the capability to capture the complexity of this system as individual abstractors interact, learn and adapt to internal and external changes. The purpose of this model is to understand under which policy and climate change scenarios sustainable water resource management emerges from decisions and interactions of water abstraction licence holders. This poster will present the conceptual model and preliminary results.**

I. Introduction

FRESHWATER is a vital natural resource for supplying drinking water for the public, cooling processes for industries, hydropower for energy companies, and irrigation for agriculture. However, freshwater available for abstraction in the UK and in particular East Anglia is becoming increasingly variable and uncertain due to climate change and increase in demand.

Agricultural crop producers use their irrigation licence to meet crop water demands which vary depending on a range of climate and farm variables. Climate and policy changes greatly influence abstractor's short and long term options (e.g. crop type grown, water availability, irrigation practice, long term infrastructure investments). Under the existing licensing system agricultural licence holders have few options or incentives to manage water efficiently. Water licence trading is difficult to administer, time consuming and rarely occurs, nor have farmers access to other abstractors' unused licensed water as permitted abstractions are not currently linked to water availability. Therefore two new licensing options have been proposed by the Department for Environment, Food and Rural Affairs (Defra) [1] which both aim to address these issues, Current System Plus (CSP) and Water Shares (WS). CSP would be a refinement of the current system, addressing the issues mentioned above, by pre-approving temporary low risk trades. WS would be a greater change where each licence holder has a share in the available water resource, rather than a set amount. This option would permit pre-approval of short term trades and a greater range of trades compared to CSP and the existing licensing system.

As climate and policy changes influence abstractor's short and long term options, these variables clearly influence their short and long term decision making (e.g. crop type, irrigation practice, licence trading, and local interaction with neighbouring abstractors and with the environment). Individual abstractors' behaviours affect water availability at the farm, local, and system level as abstractors adapt to climate change and policies. We have developed an ABM to capture the complexity of this system under various scenarios, and to analyse under which conditions a sustainable water resource management system emerges.

The following research questions are addressed:

- What patterns of water resource management emerge on the system level based on local interactions, adaptations and behaviours of farmers?
- What policies lead to a sustainable water resource management system?

II. Study Area

Agricultural crop production in East Anglia is the largest anywhere within the UK, despite the low percentage of the agricultural workforce used in the region (1.42%). In 2010, 1,381,000 hectares (13,810 km^2) were used for agricultural production in East Anglia, mainly for wheat (36%), other cereals (10%), and oilseed rape (10%) [2]. Water abstraction is already a major input in the crop production process in East Anglia, with 3,670 spray irrigation licences in 2012 (71 % of all licences in the region) [3]. These licences will increasingly need to be relied on as precipitation becomes ever more variable and uncertain due to climate change as demand for water in different sectors increases. East Anglia is already the driest region in the UK, with average annual rainfall between 560 and 720 mm (1971 to 2000) [4].

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III. Method

Agent-Based Modelling (ABM) is being used for its capability to capture the complexity of this system as individual abstractors interact, learn and adapt to internal and external changes. It has been widely applied for land use change [5]-[7], water management [8], [9], and some irrigation studies [10]-[12]. This research addresses these three aspects together as they are crucially interlinked through farmers' behaviour.

Recently, empirical based ABM has gained importance in order to simulate more realistic decision making and behaviour under future scenarios [13], [14]. As systemic patterns of water resource management are not available to assess new licensing policies, it is necessary to know what sort of patterns emerge, based on robust (empirically based) local interactions and behaviours. Therefore, a survey was conducted to identify agricultural abstractor's short and long term behaviour under a range of water availability scenarios within the central area of East Anglia, UK. The survey was based on the Theory of Planned Behaviour (TPB) [15]. The purpose of this survey was to understand how agricultural abstractors behave and interact under different water availability scenarios.

IV. Model Description

Here we present the conceptual ABM based on the Overview, Design concept and Details (ODD) protocol [16].

1. Purpose

The purpose of this model is to understand under which policy and climate change scenarios sustainable water resource management emerges from decisions and interactions of water abstraction licence holders.

2. Entities, state variables, and scales

The main agents are represented as agricultural abstraction licence holders (i.e. farmers). They are characterised by state variables, referring to their different short and long term behavioural strategies and attributes. Farmers' state variables include a range of behavioural variables derived from TPB (i.e. attitude, subjective norm, and perceived behavioural control), and other agent attribute variables such as farm characteristics and social demographics.

The agents environment is represented as a grid based spatially discrete landscape, which closely resembles that of the central Anglian region, UK. The exact farm boundaries are not represented due to reasons of confidentiality. The spatial extent of the model is defined by the spatial extent of the hydrological catchment of the central Anglian region, each cell representing 1ha. These landscape entities will be represented by cells, which are characterised by including elevation and run-off. Links between grid cells form a hydrological network of the model catchment.

Agents and grid cells are updated to record the change in state variables on a weekly timescale. One time step therefore represents one week (52 time steps represents a year) and simulations are run for 35 years to match the climate change projections used [17]. A range of scenarios will be simulated including; climate change induced water scarcity and surplus, particular licensing policies including CSP and WS, and increased demand from other sectors.

3. Process overview and scheduling

Simulations start with all abstraction licence holder entities located on the landscape corresponding to their natural geographic network location. Pseudo-code below illustrates the main procedure and the possible water surplus and shortage decisions available depending on their agent behavioural strategy.

Abstraction licence holders have two decision periods; short term in season decisions (week 1 to 52) and long term strategic decisions (week 52). Abstractors decide every time step to 'seed', 'irrigate', and then 'harvest'. These are short term in season decisions. In week 52, abstractors make long term strategic decisions depending on whether they have experienced a water shortage or surplus for the majority of the season, or over consecutive seasons depending on their behavioural strategy. At the end of each time step, abstraction licence holder and grid cell state variables will be updated to record changes which may have occurred the previous time step (changes may occur depending on agent entities state variables, particularly behavioural strategies).

The in season shortage decisions include the following options; use maximum abstraction licence, to spread water evenly between all crops or to irrigate their most valuable crops, restrict application (i.e. deficit irrigation), or buy more water to meet crop requirements. In the case of an in season water surplus farmers can decide between; selling surplus water to maximise profits, use their abstraction licence to meet crop water requirements and leave the remainder of their licence unused, or abstract surplus water for storage.

Options of the end of season strategic decisions in case of repeated shortage are; grow the same crops but over a smaller area, grow less water intensive crops, increase storage capacity, increase application efficiency, buy more water for the duration of the growing season, apply for a larger abstraction licence, or change nothing. If repeated surplus is experienced in previous seasons farmers could; grow the same crops but over a larger area, grow more water intensive crops, sell surplus water for the duration of the growing season, or change nothing.

```
for every week
  set_climate (adjust temperature and precipitation)
  set_policy (adjust policy variables e.g. water trading)
  for all abstractors [
    seed (depending on climate and behavioural strategy)
    irrigate [
      if shortage [do-in-season-shortage-decisions]
      if surplus [do-in-season-surplus-decisions]
    ]
    harvest (depending on crop and behavioural strategy)
    if week 52  [
      if seasonal shortage [do-strategic-shortage decisions]
      if seasonal surplus [do-strategic-surplus decisions]
    ]
  ]
end
```

V. Conclusion

This conceptual ABM aims to simulate what patterns of water resource management emerge on the system level based on local interactions, adaptations and behaviours, and what policies lead to a sustainable water resource management system. Therefore, this empirically based ABM could provide important answers to the increasing water variability and uncertainty in the agricultural sector. This poster will present the conceptual model and preliminary results.

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An agent-based model of a social-ecological system: A case study of disease management in potato cultivation

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The Netherlands is a large producer of seed, ware and starch potatoes (*Solanum tuberosum*) and therefore has a high density of potato. Damage due to pests and diseases has been identified as one of the main factors that is responsible for yield loss. One of the most important diseases in potato production is *Phytophthora infestans* (late blight). This pathogen has a short life cycle and because the spores disperse by wind, a late blight epidemic can spread over large regions. Climatic conditions in the Netherlands are favourable for late blight which can lead to large outbreaks. The application of fungicides is the most important control method, but the costs are enormous and the chemicals are very harmful to the environment (Haverkort et al., 2008). Sustainable management of the disease includes the use of resistant varieties which are recently being developed by commercial breeding companies. However, when more farmers grow resistant cultivars there is an increased risk that new *Phytophthora* strains with compatible virulence genes emerge. As a result, resistance of several cultivars has been broken in the past. Resistance management practices are required to protect new and scarce resistant genes in varieties from breakdown in the future. Since the overall infection in a landscape depends on decisions of stakeholders as well as disease epidemiology, this is an example of a social-ecological system.

The system consists of several stakeholders such as farmers, breeding companies and governmental organisations, each with their own set of interests. Farmers aim to maximize their profits and can decide to take crop protection measures such as the application of fungicides, the removal of infection sources and the use of resistant cultivars. In adopting these strategies farmers are strongly influenced by other stakeholders. For example there is a Dutch governmental policy that states that potato fields have to be burned down when infection with *Phytophthora* reaches a certain level. Furthermore, for the availability of resistant cultivars farmers rely on breeding companies. Since breeding and propagation of new potato cultivars requires large investments and takes place in a highly competitive market, breeders generally aim to market new resistant cultivars as quickly and widely as possible. Spatial allocation of cultivars with different resistance genes could help to avoid loss of resistance, but this requires cooperation between farmers and breeding companies. Both farmers and breeders are hesitant to adopt spatial strategies since they are afraid for transaction costs and reduced autonomy in cultivar choice. Since in this system many different stakeholders and processes are involved it is necessary to use a complex adaptive system approach in order to analyse sustainable use of resistant cultivars in *Phytophthora* management strategies.

An agent-based model (ABM) was developed to understand how *Phytophthora* management strategies by farmers affect the spread of *Phytophthora* infections through a landscape and the durability of resistant cultivars. To collect input for model development, in-depth interviews with farmers, breeders and experts were carried out to identify current *Phytophthora* management strategies and the factors involved in decision making. The findings were compared to data in literature and social theories on farmers' decision making. The epidemiological model of *Phytophthora* was achieved by simplifying an existing model (Skelsey, 2008).

This resulted in a model with many different levels, interactions and feedback mechanisms. The model represents an agricultural landscape that consists of farms and fields in which farmers and breeding companies operate. A fraction of the fields is occupied by potato crops which can be infected by *Phytophthora* that disperses through the landscape. Important processes in the model are farmers' decision making, marketing strategies of breeding companies and biophysical processes such as potato growth and dispersal of *Phytophthora* within a certain landscape configuration.

Two different farmer types, conventional and organic farmers, are distinguished in the model since they considerably differ in their management practices. *Phytophthora* management strategies include the application of fungicides, the removal of infection sources in potato fields and the use of resistant cultivars. Farmers' decisions on *Phytophthora* management are based on yield optimisation, the farmers' network, personal characteristics and availability of cultivars by breeding companies. *Phytophthora* dispersal in the landscape is affected by weather conditions, potato variety and planting patterns. Potato growth is dependent on the specific cultivar and infection level of *Phytophthora*. The processes are updated at a daily time step and the model is run for several years to study long term effects of farmers' management strategies.

To analyse a specific case study a model is being developed that represents a 10km by 10km agricultural region in the Netherlands that includes the model components and processes previously described. At the moment the agent-based model is still under development and at the conference the first results of the simulation will be presented.

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On infrastructure network design with agent-based modelling

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***Abstract*—We have developed an agent-based model to optimize green-field network design in an industrial area. We aim to capture some of the deep uncertainties surrounding infrastructure design by modelling it developing specific ant colony optimizations. Hence, we propose a variety of extensions to our existing work, first ideas on how to realize them and three cases to explicate our ideas. One case is the design of a CO2 pipeline network in Rotterdam industrial area. First simulation results have shown the relevance of the approach.**

***Keywords*—Infrastructure design, network planning, ant colony optimization, deep uncertainty, socio-technical systems**

I. Introduction

IN previous work, we have shown the applicability of agent-based modelling for optimization green-field network design in an industrial area [1]. Infrastructures enable suppliers and consumers of goods and services to connect [2]. Infrastructures develop over decades and network design is an activity under deep uncertainty. How 'good' the eventual design is depends on who pays the costs, who receives the revenues and how the risks are distributed [3]. In designing infrastructure networks, computer power is only used in a late phase, for drawing detailed layouts. At the point where computers come in, most of the decisions are already made. We see a huge potential for modelling in earlier phases, in which networks are designed from scratch or in which expansion or new connections are proposed.

We have already developed an agent-based model and a geometric graph method that enable designing good networks that can transport a commodity from one source to several sinks, in which the building costs depend to a large extent on the pipeline length (e.g. due to digging costs), but also on the pipeline capacities (e.g. due to materials costs). The networks are built in areas that pose limitations on the possible routing of pipelines due to existing buildings, obstacles like rivers or mountains, or zoning rules (e.g. protected natural areas). We formulated the simplified planning problem as an optimization problem with the objective to minimize the expected building cost, taking into account the various aspects and constraints of the system. For details see Heijnen et al. [1]. We have applied the agent-based model to CO_2 pipeline design in Rotterdam industrial area (see Illustration 1)

We argue that other uncertainties, e.g. in the participating actors in the network, on potential future expansion can be done with possible extensions to the agent-based model. In this abstract we aim to explore what extensions we will explore in the near future, by introducing a variety of cases.

II. Objectives and Approach

We aim to gain more insight in the consequences of fundamental uncertainties around planning investments in networked infrastructures. We conjecture that to some extent they may be covered with an ABM.

Important aspects are:

- Connecting multiple sources to multiple sinks
- Cost differentiation in networks on a variety of bases, such as for splitting and corners and related to the area.
- Time dependencies in and uncertainties of participating of actors
- Convertor stations that are nodes that enable conversion between different 'qualities'
- The multi-actor system, such as actors owning different parts of demand or supply side of the infrastructure, which has consequences for risks, negotiation, vested interests and cooperation.
- Decentralized and centralized production and consumption
- Larger variety in the relevant time scales (operation and investment)
- Uncertainties in developments upstream and downstream.
- Interactions between (existing and new) infrastructures
- Locational aspects, such as existing infrastructure, terrain.
- Political/juridical aspects, such as permitting.

We conjecture that agent-based models, possibly in combination to other paradigms, will help to explore each of these aspects in concrete cases, which we will describe in section III. We expect it can be done for instance by making the the agents (ants) more intelligent, taking into account more properties of the terrain. In addition, the nodes and nest can be made more intelligent, therewith guiding the ants to make better designs. In an optimization (such as an ant colony optimization) time is typically not represented at all: the tick that passes by is a form of iteration, but not time. Advancements are necessary to uncertainties in the system dynamics (e.g. when will which company want o participate from the list above).

III. Cases

We illustrate possible choices based on three cases:

1. CO_2 pipeline design in Rotterdam industrial area.

In this case (illustrated in figure 1), we aim to find out what a robust design would be of a pipeline network in the industrial area of Rotterdam. Developing it in the real world would be a huge 100-500 million euro cooperative project, depending on the participating actors. We hope that the agent-based model in this case will help in the discussion amongst possibly participating actors.

2. Power cable of TenneT between the Netherlands and Denmark

A new power cable between these two countries is embedded strongly in the current international and national network. A good layout would strongly depend on expected developments in 1) production in consumption of electricity and their locations, 2) solar and wind energy and 3) energy storage. Whereas the costs of the network are close to the current application, the performance of the system in the new layout and the added value of a new line is not easy to determine.

3. Different quality gas network

Large part of the Dutch gas infrastructure is based on the so-called Groningen-gas quality standard. This standard is based on the gas from the Slochteren field in Groningen, in the Netherlands which is gradually depleting. A new role of natural gas in the Netherlands can exist in requires us to rethink what standards of gas to supply from where to where.

IV. Conclusion

Our past work has shown that an ant colony optimization can be used effectively for a good-enough first layout of a tree-shaped infrastructure network [1]. By expanding on this work, we hope to capture more of the uncertainties surrounding network infrastructure planning in the real world. We have listed many of the sources for uncertainty. By exploring cases on CO_2 pipelines in industrial areas, high capacity interconnectors between countries to more densely connect electricity grids and by looking at a variety in quality of gas networks we hope to explicate what the consequences are of such uncertainties, to contribute to infrastructure network planning and to improve the networked infrastructures that we rely on day by day.

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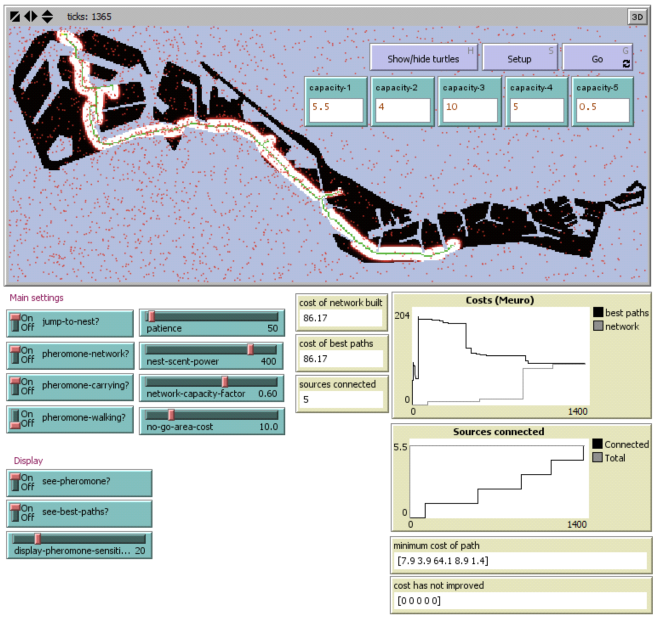
Illustration 1: Simulation of CO2 pipeline network Rotterdam design



Does follower of majority accelerate polarization or diversity of culture?

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Keywords: Culture Diversity, Social Media, Agent-based modeling

Social media has enabled the posting and reception of free individual information and influences the opinions and interests of individuals. However, there are concerns about issues like overconcentration or fragmentation of opinions due to selective contacts, where information conforming to the majority in a group or information that is similar to one's own is actively selected.

Axelrod proposed a model to study if the localized interactions bring about global polarization and showed that while localized convergence leads to homogenization of society as a whole, there also remains a group with few different characteristics [1]. Many secondary studies are being carried out taking this as a basic model that suggests the possibility of the coexistence of cultural diffusion and maintenance of cultural diversity [2].

We propose an agent model to analyze the impact on the diversity of opinion distribution of the society caused by the diverse social media developments in recent years and the information type provided on social media. The users of social media receive information from the neighboring users or from the topics that trend on the website. We extend the Axelrod simulation model to introduce a model where individuals interact with aggregated information of the group. Then, we carry out a simulation based on the proposed model and study the impact of the aggregated information on the cultural diversity of the society.

In this study, aggregated information is defined as a characteristic of the majority, possessed by the Agent within the W Hop in the vicinity of the agent. Then, we carry out simulation to observe the difference in cultural diversity when the range of aggregated information W and its utilization rate B are changed.

From the results of the simulation, we understood that the aggregated information is effective in maintaining the cultural diversity, and difference in that effect can be seen from the range of aggregated information. To be specific, we analyzed the effect of aggregated information in different ranges of local, intermediate, and global, and understood that the aggregated information in the intermediate range is useful in the maintenance of cultural diversity. This paper made it possible to operationally handle the effect on global cultural convergence caused by the development of information society in recent years, with interactions based on similar principles.

Our future work is introduction of a network structure. It is necessary to verify the impact on diversity of society due to the interaction with other users or community through a network.

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Simulating Value Co-Creation in B2B Financial Service: An Application of Empirical Agent-Based Modeling

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Value co-creation is a key concept in understanding the essence of service [1]. That is, no value is generated in service without well-organized interactions between customers and service providers (employees and management). To quantify the possible outcomes of such co-creation, agent-based modeling is one of the promising methodologies. Indeed, this methodology is expected to contribute the development of "service science" as an interdisciplinary research area [2]. Our study applies this for a B2B financial service, focusing on when and how value co-creation would occur there.

We built an agent-based model to simulate the invisible process enabling value co-creation in a B2B financial service. The model involves a large number of agents representing customers (owner/management of borrower firms) and employees (liaison persons of a financing firm). As a consequence of interactions between them, each agent forms the attitude toward the counterpart in terms of cognitive/affective aspects, that will affect the stream of customer profitability. This process is modeled in part following a spirit of Customer Equity model of [3]. In addition, the network among customers is incorporated into our model to reflect the possible peer-to-peer influence.

We obtained the data for parameterizing each agent's behavior from a regional B2B finance service group in Japan, involving customer attitude surveys/profitability records for about 3,000 customers and their corresponding employees. Also, possible networks among customers are incorporated based on the transaction data recorded. Most parameters are adjusted to replicate more precisely the observed macro/micro behaviors of agents.

By simulating our empirically validated agent-based model, we can examine under what conditions value co-creating activities simultaneously improve the utilities which each customer or employee gains and the long-term profitability for the financing firm, as suggested by the concept of service-profit chain [4]. We report the status quo of this ongoing study exploring how to improve the matching procedure between employees and customers and the allocation of marketing efforts among customers (customer portfolio). Finally, we discuss the limitation and the further development of this study.

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Robustness of cooperation to movement patterns in a Hunter-Fisher-Gatherer model

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1. Context of study

Most societies often face social dilemmas in which there can be contradictions between individual interests versus those of the community as a whole.

Hunter-fisher-gatherer societies can be considered as paradigmatic examples of these phenomena. The fact that many of these societies tend to live permanently disaggregated produces a specific need for maintaining the social tissue as well as for reproducing social and economic knowledge and values that depend on individual behaviour. Therefore, aggregation events are of special relevance as they represent the optimal occasion to deal with specific social aspects that in these cases need extraordinary circumstances to be held.

Our case of study is focused on cooperative processes developed by historical hunter-fisher-gatherer-societies from the Beagle channel (Tierra del Fuego), that developed their existence mainly through an economy focused on the exploitation of coastal and maritime resources. Yamana households moved across the territory in their canoes in search for needed resources. In spite of this, Yamana society has different ways to strength social cohesion: visiting each other or because of the celebration of different types of ceremonies. Initiation ceremonies were of special relevance, and the need for maintaining the group meanwhile these rituals were being developed became essential. The finding of a beached whale, and the subsequent aggregation event that took place through a public call, created the ideal context for the development of economic and social processes in a cooperative way.

Together with the enormous amount of meat, blubber and raw materials provided by the whale, this finding gave the possibility to invest most of the day in communal life for a long period.

2. The WWHW Model

The Whale When Hale Whale (WWHW) is an agent-based model oriented to allow the exploration of the emergence and resilience of cooperation in hunter-fisher-gatherer societies (Briz i Godino et al, in press), such as the Yamana.

In the model there are two types of agents, the whales and the people. The whales are an enormous valuable perishable food resource that appears from time to time (according to a certain probability). The whales can only be seen within a certain range. The people represent household/canoes. They walk around the environment where they have a chance to find beached whales. In the model, we have implemented two patterns of movement: random walk and Lévy flight, in order to explore whether the type of movement influences the emergence of cooperation.

When a people agent finds a beached whale, she has to face the dilemma whether to make a signal to call other people and share the resource, having an aggregation event and so cooperating; or to exploit the resource by herself (defecting). If the people agent decides to make a public call to share the whale, an aggregation is celebrated. People travel where the whale is beached to share the resource. These aggregation events are considered a great opportunity to exchange social capital, improve work skills, celebrate rituals and ceremonies, etc. As a result of these aggregations, the people agents increase their stock of meat and social capital. These two variables are used to calculate the success (fitness) of the strategy of the agent (the strategy of the agent is given by a probability of cooperation). The relative importance of social capital over meat is modulated by a parameter that allows us to investigate the influence that these two variables have in the evolution of cooperation.

Moreover, a mechanism of reputation is implemented, which rewards the cooperative behaviours (call to share a whale) and punishes any public defection, i.e. whenever an agent is seen defecting. This reputation variable conditions the social capital a people agent can achieve in an aggregation, penalizing defective behaviours over cooperative ones.

An evolutionary mechanism leads the strategy selection of the agents. Every generation (a generation is a parameterizable number of discrete time steps), the people can imitate the most successful strategies of other people. We have implemented two strategy selection alternatives: random-tournament and roulette wheel. A person will imitate other person strategy if the fitness of the strategy of the other person is higher than her own. There is also a probability of making a mistake in imitating or to explore new strategies.

3. New experiments

We have conducted a set of new experiments in order to explore the influence of the movement pattern of the people in the emergence and resilience of cooperation. We have implemented the two movement patterns mentioned before: the simple random walk pattern and the Lévy flight pattern.

The model seems robust to changes in the movement pattern of the people agents. The Lévy flight pattern is said to be a more efficient resource search pattern than the random walk for sparse resources that are distributed randomly (Viswanathan et al., 1999). But the fact that all the population is beneficed of this search improvement could be responsible for its smooth influence, resulting in no impact of the movement pattern on the dynamics of the cooperation.

However since these findings have not been verified for a wide range of parameter combinations, further research is required.

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Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

Exploring the dynamics of the world energy system: An agent-based - system dynamics model

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Abstract

Due to limitation of some energy resources, there are concerns whether the world energy system (WES) can supply sufficient energy for societies in the future. Scientists develop models to gain insights into the system. GEMBA is a system dynamics model developed by Dale to explore the global energy supply using biophysical economics approach. Biophysical economics theory analyzes the economy based on the physical properties and structures of real economic systems and it considers natural resources and their impacts on the economic processes.

GEMBA like other system dynamics models adopt a top-down view on the WES. The top-down view assumes that all elements of a system have global knowledge about the system. Many of such models do not capture some characteristics of a WES such as geographical resource distribution and demand diversity. In addition, it is often not possible to analyze the emergent effects from variations in low-level elements on the system behavior in top-down analysis.

We developed an exploratory agent-based model, by taking a biophysical economics lens, for bottom-up analysis of a WES and relevant natural resources. We decomposed the world into a number of geographical regions to capture resource distribution and demand diversity in the WES. Our Multi-Region World Energy Model (MRWEM) combines the GEMBA with the concept of energy-return-on-investment (EROI) for imported energy. So, in MRWEM the internal behaviors of the world regions are modeled with GEMBA and the system dynamics approach while the inter-regions behaviors are modeled with agent-based modeling approach.

MRWEM exhibits a number of advantages over GEMBA. First, it provides insights on the inter-regions energy movements and trade which is impossible in GEMBA. Second, MRWEM provides flexibility in analysis as changes in the model can be done at the level of regions not the whole world. Also, MRWEM facilitates analysts to analyze the WES using different geographical decompositions. Moreover, it shows that the hybrid adoption of agent-based modeling and system dynamics is possible and insightful when the level of abstraction is very high.

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Exploring the dynamics of the world energy system

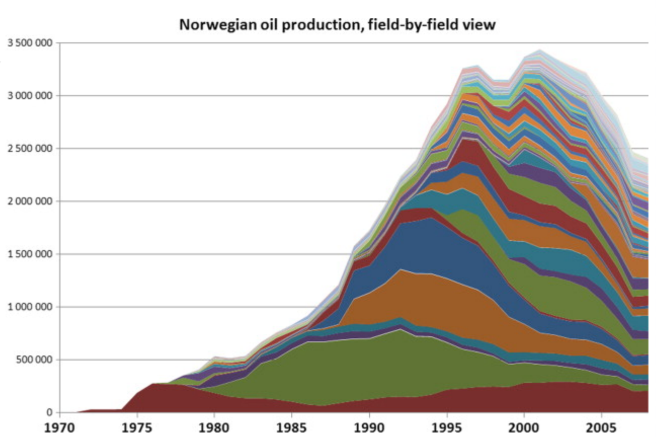
An Agent-based - System Dynamics model

S.A.R. Mir Mohammadi Kooshknow, A. Ghorbani , G.P.J. Dijkema

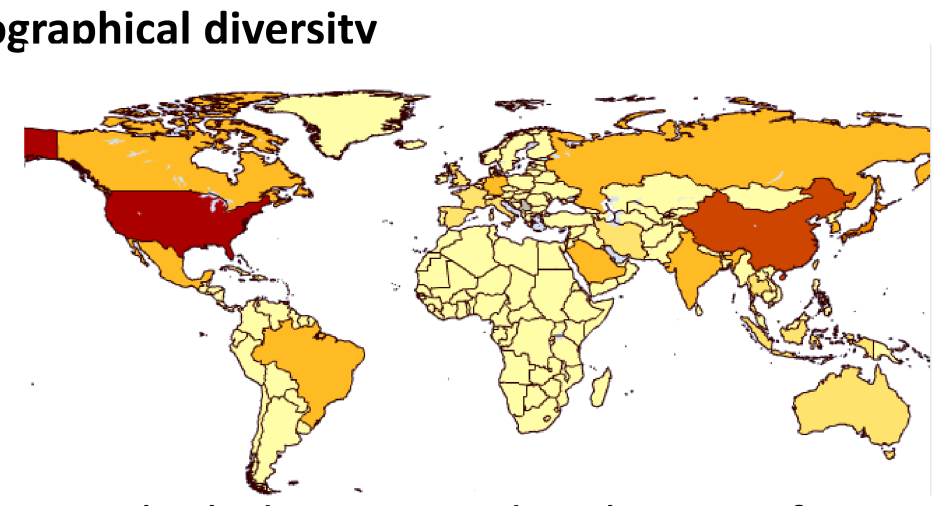
World Energy System Challenges

Peak in oil production

Production of energy from non-renewable resources is expected to peak due to finite size of the resources



Geographical diversity



There is high diversity in distribution of energy resources and pattern of energy consumption across the world

There is no universal control over the production, and consumption of energy due to political diversity of nations and regions across the world

Research Objective

To develop a model to explore the world energy system considering limitations of natural resources, and interactions among the geographical regions of the world

Theoretical Perspective

Biophysical Economics

B.E. is based on the biological and physical properties, structures and processes of economic systems. It enables us to consider limitations of natural resources in the economy.

Complex Adaptive Systems (CAS)

CAS perspective enables bottom-up modeling of the world energy system.

Theoretical Perspective	Biophysical Economics	CAS
Analysis View	Top-Down	Bottom-Up
Modeling Paradigm	System Dynamics	Agent-based Modeling

GEMBA

Global Energy Modeling – Biophysical Approach

A system dynamics model developed by M. Dale for exploring the global energy supply

GEMBA decomposes the world economy into "energy sector" and "the rest of economy"

Main parameters of the model are:
- Ultimate Recoverable Resources
- Technical Potential for renewable resources
- Capital intensity of the economy
- Parameters of the "Dynamic EROI function"

Multi-Region World Energy Model (MRWEM)

The Hybrid Agent-based – System Dynamics Model

11 geographical regions

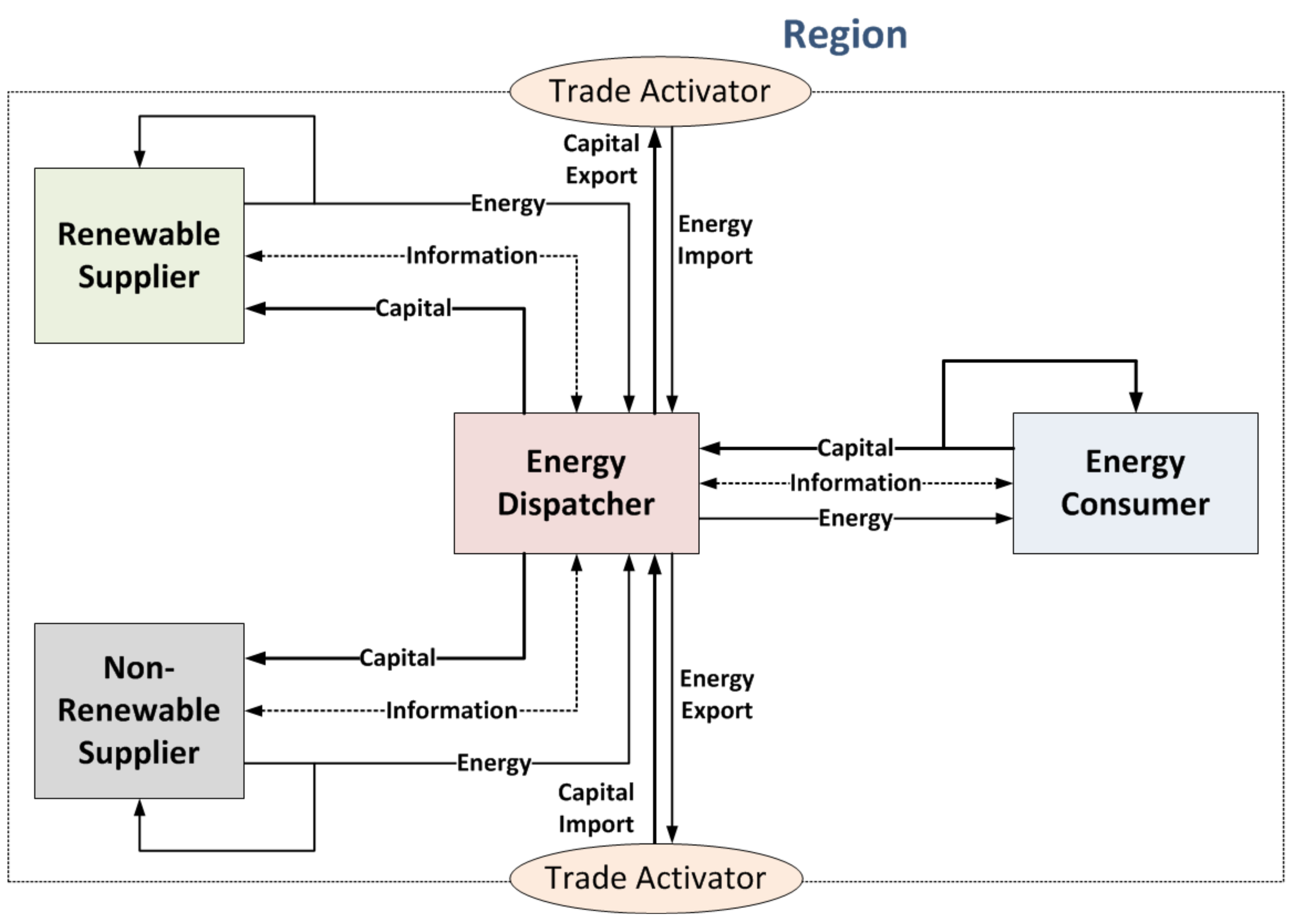
Each region is composed of 5 agents

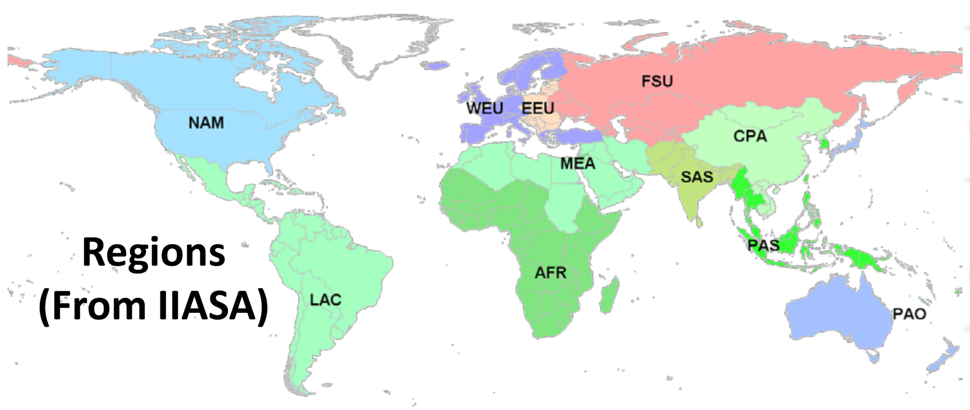
Four agents (*Renewable Supplier*, *Non-Renewable Supplier*, *Energy Consumer*, *Energy dispatcher*) operate using System Dynamics paradigm as proposed in GEMBA

Energy Dispatchers make strategic decisions e.g. investments in energy resources

Energy Dispatchers make strategic decisions e.g. investments in energy resources

Interactions among regions are done through Trade Activators





Regions (From IIASA)

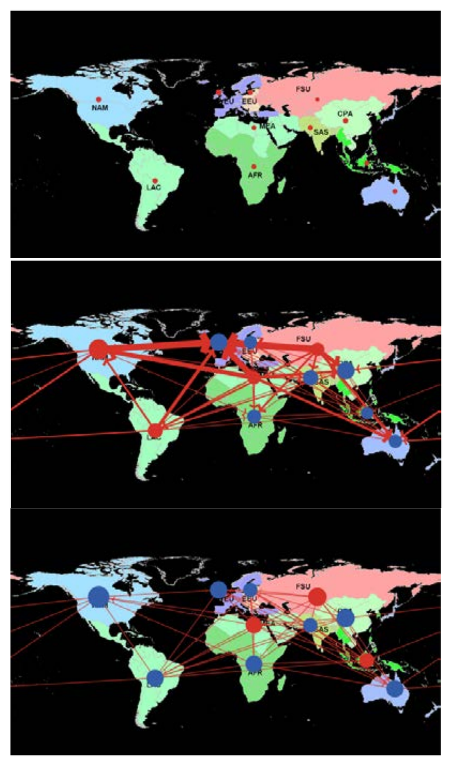
Energy-Return-on-Investment (EROI) is an important variables in biophysical economics

EROI of energy resources within each region measured using the Dynamic EROI function Developed by M. Dale.

EROI of energy trade in MRWEM is calculated using the formula for EROI of imported fuel developed by Hall et.

Model Results

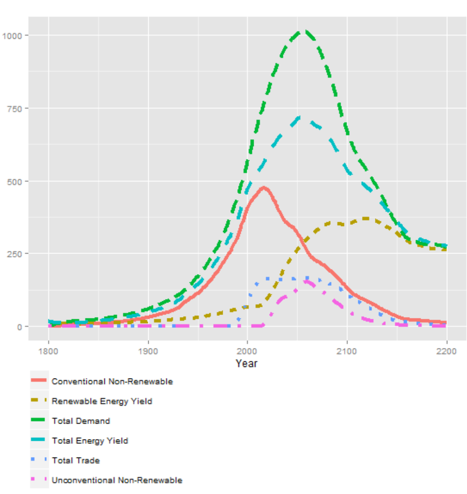
1950
2050
2150



The total non-renewable production and the total energy trade will experience peak and decline

The total renewable production will experience peak and plateau

Advantages of MRWEM over GEMBA:
- It provides insights on the inter-regions energy movements and trade
- Provides flexibility in analysis as changes in the model; and can be done at the level of regions



Methodological Insights

- In MRWEM, SD becomes the rule-base of agents ABM. This combination is different from so-called multi-paradigm
- When the level of abstraction is very high, the differences between the top-down view and the bottom-up view decreases which enables the hybrid use of ABM and SD
- There is no hard boundary between SD and ABM as long as they can be programmed in programming languages without being trapped in regularities of software applications.

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Making city in the "Non-City": the integration of irregular settlements in Andalusia. A case study

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Abstract—**The problems associated with numerous irregular buildings existing in Andalucia today, demands a new approach. In order to deepen the definition of strategies of urbano-territorial integration of these settlements, we present a case study in which, at the end of its implementation in agent-based simulation models, we summarize the ODD Protocol which will form the basis of the simulation, indicating the determining factors to consider for an effective and participatory planning, that minimize the progressive estrangement between the normative framework and the reality that is tried to order..**

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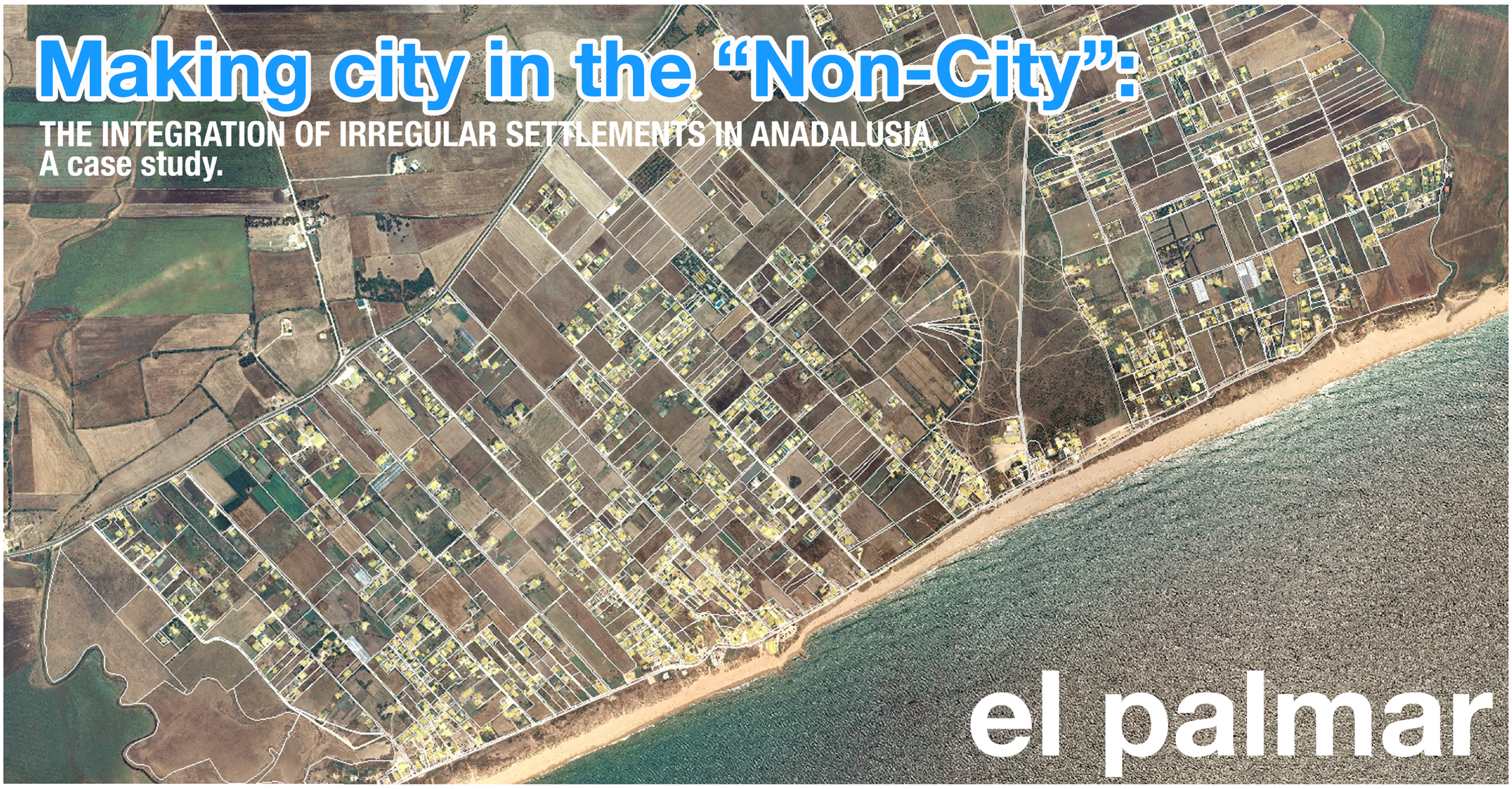
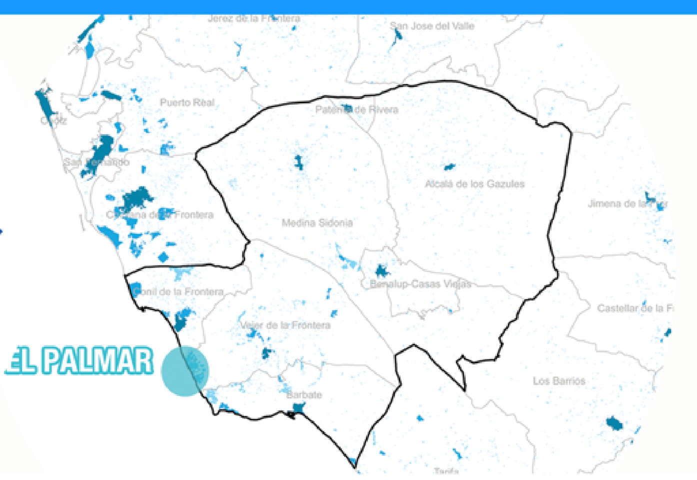
Making city in the "Non-City":

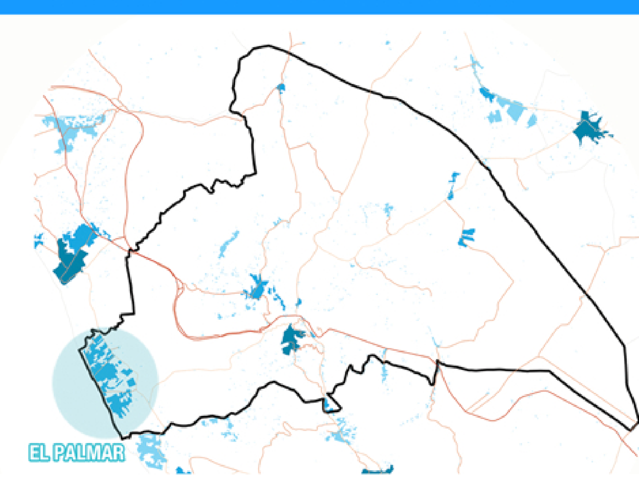
THE INTEGRATION OF IRREGULAR SETTLEMENTS IN ANADALUSIA. A case study.

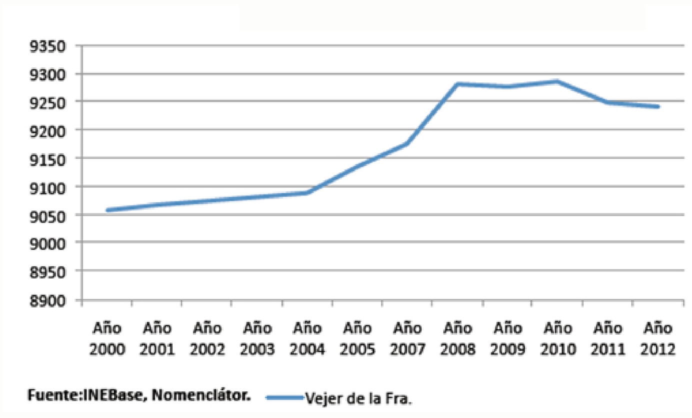


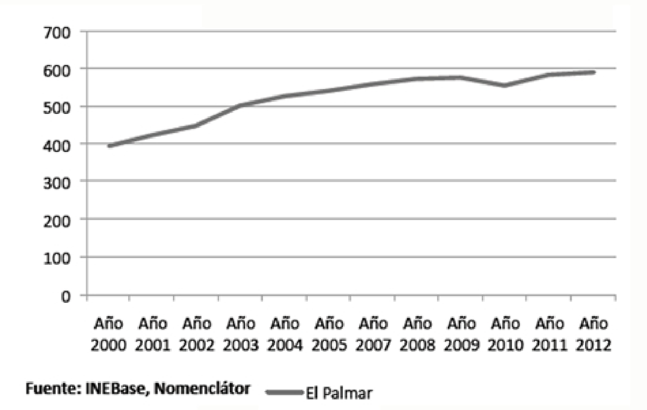
el palmar

ANDALUCÍA	TERRITORIAL UNIT LA JANDA	MUNICIPALITY VEJER DE LA FRONTERA	POPULATION IN THE MUNICIPALITY VEJER DE LA FRONTERA	POPULATION IN THE CASE STUDY EL PALMAR

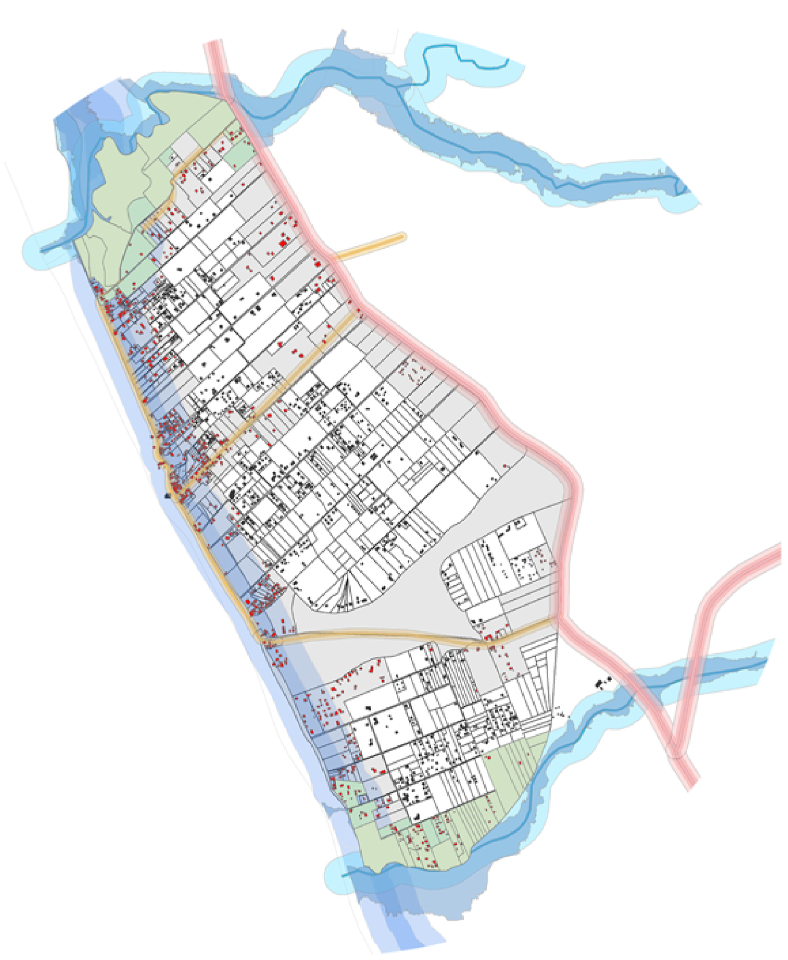


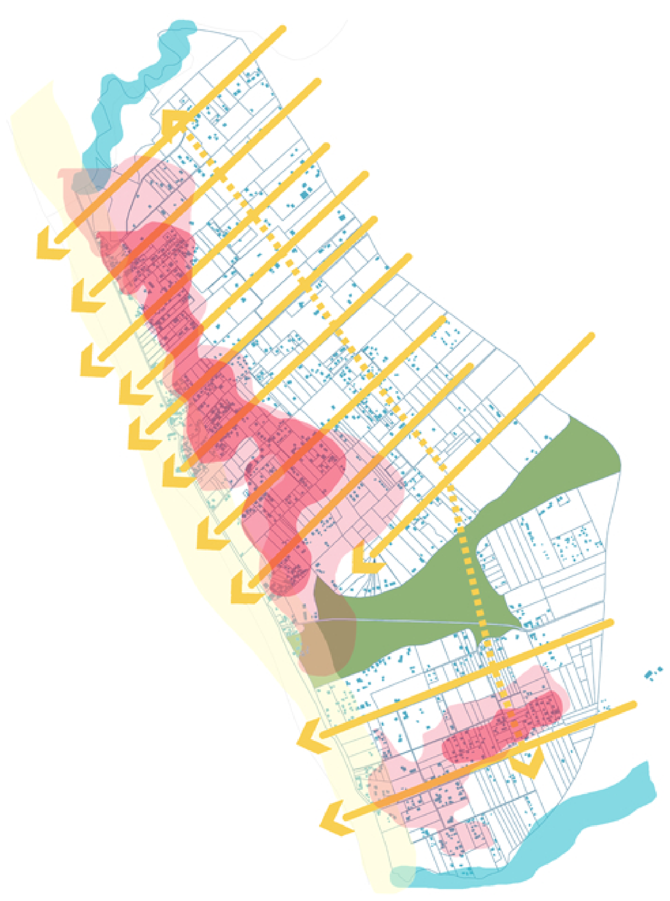


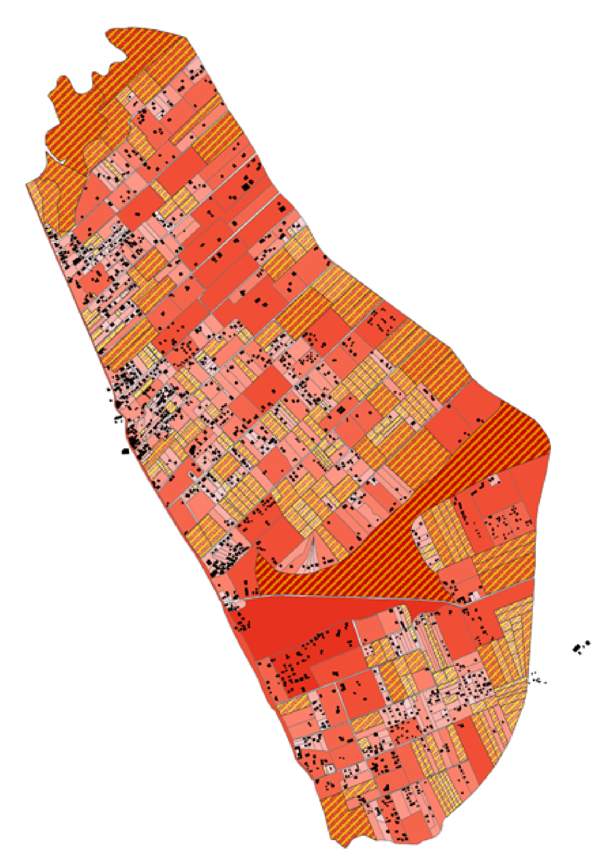




EXISTING ENVIRONMENTAL IMPACT	EXISTING FUNCTIONALITY	EXISTING URBAN CLASSIFICATION	EXISTING OCCUPATION	EXISTING STRUCTURE







protocol

Abstract—The problems associated with numerous irregular buildings existing in Andalucia today, demands a new approach. In order to deepen the definition of strategies of urbano-territorial integration of these settlements, we present a case study in which, at the end of its implementation in agent-based simulation models, we summarize the ODD Protocol which will form the basis of the simulation, indicating the determining factors to consider for an effective and participatory planning, that minimize the progressive estrangement between the normative framework and the reality that is tried to order.

HIGH DENSITY

Associated to the vision of the nucleus of El Palmar like space of growth of the municipality of Vejer of the Frontier. This scenario would generate a great density of housings for hectare, and throughout the time we could foresee it would be an extreme position. In spite of it, the economic impact would be the lowest, and we don't know if it could end up compensating the impact of ecological print or landscape. Also the social impact it's predicted like an answer of negative tendencies.

MEDIUM DENSITY

Result of a hybridization among low and high density. That is to say, alternation of low and high density, in a heterogeneous way in the environment, or a half density in a homogeneous way. This would suppose an urban model associated to a diversity in ways of occupying the parcels, generating an economic balance. The environmental impact would be only negative in the landscape aspect, generating possibilities of unexpected results, since it will depend on the variability of the situation of the spaces of more density. The social impact is one of the objectives of this programming, since right now we understand that it could be foreseen negative, but when existing multiple solutions, we could obtain unexpected results.

LOW DENSITY

That is to say, maintenance of the current situation. This will bear a regularization with an economic great impact due to the great extension of the busy territory for population so little mass. The environmental impact could be negative, although the landscape impact can come out positive, because the environmental impact and of ecological print they would be negative. The social impact can be positive, since, under the current conditions, the local residents only want the incorporation of the basic infrastructures and that they don't change the morphological conditions of the place, although neither they are willing to pay very expensive infrastructures. For what we can foresee that the impact would be for the most part negative and, therefore, to conclude that the maintenance of the current tendency of the drop density doesn't produce a sustainable territory.

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User Profiling in Multiplayer Serious Games

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Abstract—**Designing multiplayer serious games that support collaborative learning has become a promising area of education techniques. Player should play a game with a proper level of ability and skills. Current approaches to adapt game make it possible for different elements to adjust to the player. However most of these approaches can adapt one single player; so we need to find ways to aggregate all users input and history into some potential information that can be used for the adaptation mechanism, we believe that user's profiling respond to these need by providing a detail analysis of player's performance. The goal of our research is to provide a novel approach for game adaptation correlated to a user's profile that guided by two concerns: player skill levels and social interaction between players. To achieve this, we present a conceptual user's profile.**

Keywords: **user's profiling, collaborative learning, multiplayer serious game,**

I. Introduction

Nowadays, due to the New Technologies advance, learning forms have changed in classroom and become more effective and enjoyable, one of most widely used approaches is collaborative game. Game-Based Learning (GBL) is used as a learning strategy through game play. Various researches [1] have shown that Collaborative serious game enhances social competencies such as collaborative decision-making, negotiation and communication. The essence of serious game is to be adapted according to the level skill of each user. This user is defined and coded in the game: all serious game include a profile of the user. In one single player games, it presents a classification of the target players and a memory of player's actions in the game. In multiplayer games the model contains social parameters and behaviours, and it can also be a cognitive model.

With Serious game technology and Collaborative learning, users-centred design is required now more than ever to provide an adaptable and personal content (level); Due to the lack of concepts for multiplayer serious games, only a limited number of Serious Games have been designed with multiplayer support. Multiplayer Serious Game used with collaborative learning purposes should be adaptable to each player; so we need to find ways to aggregate all users input and history into some potential information that can be used for the adaptation mechanism. We believe that user's profiling respond to these need by providing a detail analysis of player's performance.

We aim to provide an approach for game adaptation correlated to a user's profile. It will supply response to each player's individual needs. The goal of our research is to define a profile of users able to define the strategy of adaptation to all players and support the collaborative learning principals in multiplayer serious game.

In this paper we give a brief survey of the current researches on user's profile for game adaptation next we introduce a possible structure of user's profile and. In the end, the conclusion and future work are given.

II. Related Works

The user profile represents user properties such as knowledge, behaviour, and goals. It contains evaluations of the physical situation, psychological and social parameters deduced from existing cognitive and sociological models [2]. In multiplayer game, players have individual engagement and social engagement: personal engagement refers to the perceived competence and skills level, social engagement refers to the types of interaction between players.

User profiling is the most studied area in current Technology Enhanced Learning systems, which is a necessary feature to meet the effectiveness requirement for each adaptive game. Several research areas on user profile have conducted, there are two distinct ways of implementing user profile: user-controlled and computer-controlled [3], the first one tries to adapt game according to a feedback given by the user, the second personalize game according to user's needs and preferences.

Picard [4] has based on emotional communication (frustration, confusion, disliking, interest…) to design user profile. According to Bartle [5], in role-playing, players that have same preference can be grouped into same category: achiever, explorer, socializer and killer. These types are generated from the analysis of a multi-user dungeon (MUDs). The user's profile proposed in [6] considered three possible levels: "user modeling, which includes a profile of an individual user, user clustering, which is based on similarities between user profiles and forming a user cluster using some form of automated technique, and community modeling, which includes a profile about the social group as a whole, not as the sum or the average of its individual member's profiles". These levels can be used simultaneously to personalize social and individual preference in multiplayer serious game. Many applications in internet training system [2] have used an user profile based on three levels: generic model which includes general information about the player (age, gender…), in addition to general information, localized model represents knowledge of the user's location and personalized model is based on complex state variables about each user. [7] proposed a user's profile called group model, it based on communication and action between players. User's profile proposed by most these works still utilisable in specific domain and not generalized. All of these methods use the user's profile to optimize the playability factor of the game and few works have exploited the adaption in game according to the user's profile.

III. Multiplayer game in collaborative learning

The use of serious games with group activities in which the primary activity for the trainee is the action of playing, the knowledge and cognitive skills development are the result of this process. Our main research goal is based on the collaborative learning which offers group trainees to achieve common goals while they are learning. Collaborative learning fosters development of interpersonal competencies and social connectivism such as collaborative decision making, negotiation and creative solution. In multiplayer serious games each trainee depend on others, they help and provide advises to others.

Johnson and Johnson (1994) propose five essential components which enhance collaborative work [8]:

A. Positive interdependence

A group success or failure represents individual success or failure, each player cannot succeed alone.

B. Individual accountability

The results of each individual performance evaluation are given back to both the group and the individual.

C. Face to face promotive interaction

Promoting behavior, each trainee encourages others to success by helping, sharing their knowledge during learning process.

D. Social skills

Group skills, interpersonal competencies and communication are essential to enhance the collaborative work.

E. Group processing

The group evaluates itself to estimate their work.

IV. Structure of user's profile

Collaborative learning has also combined in educational videogame. As we showed in section 3, there are several requirements which need to be met in order to facilitate the incorporation of collaborative learning in serious games. In our context, we are based on these guidelines (see Johnson and Johnson 1994) to propose the conceptual user's profile.

The user's profile is based on two levels: knowledge and competence model, social model.

A. Knowledge and competence model

Which collects data about the player, it includes possible estimation of the skill levels and competence of the player, this information can be obtained through deliberate answer investigation or induced in real time from actions and behavior of the player.

TABLE I.
KNOWLEDGE AND COMPETENCE MODEL

Attribute	description
Identifier	Identification
Name	Trainee name
Age	Trainee current age
Sex	Trainee gender
Score (skill level)	Marks obtained
Proposed goals	List of proposed goals to be learning
Faced goals	List of goals that the trainee has started, tasks completed.
Achieved goals	List of goals that the trainee has achieved
Proposed tasks	List of proposed tasks to be performed
Faced tasks	List of tasks that the trainee has started,
Achieved tasks	List of tasks that the trainee has achieved
Best task	Ordered list of tasks which this trainee obtains the best results
Worst task	Ordered list of tasks which this trainee obtains the worst results

TABLE II.
SOCIAL MODEL

Attribute	description
Trainees	Number of trainees that must participate in this task
Type task	When this task is for a group, defines the way in which the trainees must address it
Difficulty task	Difficulty of task
Most connected trainee	Group member who receives the most messages (help, advices)
Most influential trainee	Group member who sends the most messages
Communication network	Number of contacts made by group
Levels	Describe task level and rules to calculate score
General score	Score for all group member

The proposed knowledge and competence model (table 1) is composed of three categories: personal, goal and task. Personal attributes contains general information about the trainee and his/her score (competences), the next categories are related to trainee achievements and contains information about goals and tasks that a trainee must address, has started or has achieved. The attributes related to these categories are initially empty, and they are updated when the trainee is playing. The list of goals must be specified before starting game because they must have a common goal for all group members. When a faced goals accomplished (proportion of tasks completed), then the achieved goals list is updated because all tasks associated with this goal have been completed. The attributes related to tasks work similarly to those just explained. Attributes (Best task and worst task) are intended to adapt the game to avoid the difficulties. In this way, the system has more information to propose the trainee who can help others.

B. *Social Model*

The goal of the social model is to deduce preferences and level of each player from social interaction, it allow changing player's level. The Social model must be able to gather social skills and generate feedback related to the interaction between players.

The social model is also composed of three categories: tasks (game play), interaction and evaluation. The first contains the number of trainees needed to solve the proposed task, and if more than one, it describes how trainees must address the task (type task). The attribute difficulty task is related to general difficulty of this task. The second category contains information about the general features of the group, three attributes are included: Most connected trainee, most influential trainee, and interaction network. The last category defines task levels and describes the rules (formulae) to calculate the general score.

V. CONCLUSION AND FUTURE WORKS

User's profiling is an important research area in adaptive multiplayer serious games, however only a limited number of games have been designed according to the user's profile.

This paper has proposed a conceptual user's profile to analyze collaborative learning in serious games. Two levels have been presented. The first is indented to describe knowledge and competence of each trainee, common goals, and an individual evaluation. The second has been defined with three specifications: tasks included in the game play, interaction between trainees and the group evaluation. The user's profile proposed is especially important the adaption because it contains information about what trainees have learned, how they have collaborated and the difficulties encountered. We are in the process to define a platform to integrate this model with a set of others models to aggregate all users input and history into some potential information to carry out an adaptive multiplayer serious game. In this manner, it is possible to adjust the difficulty to each trainee.

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