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

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 $t \rightarrow t + 1$, 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.
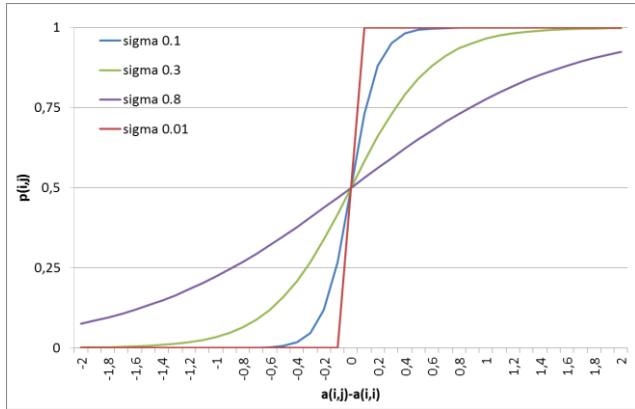

Figure 1. Examples of variations of the propagation coefficient $p_{i,j}$ when $a_{i,j}$ - $a_{i,i}$ varies, and for four values of the parameter σ. When σ decreases, this function tends towards a threshold function returning 0 for negative entries and 1 for positive entries.

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 :

$$p_{ij} = \frac{1}{1 + \exp\left(-\dfrac{a_{ij} - a_{ii}}{\sigma}\right)}$$

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 ≠ nil, z ≠ i, z ≠ j.
    If a_iz = nil,  a_iz ← 0
```
$$a_{iz} \leftarrow a_{iz} + \rho p_{ij}(a_{jz} - a_{iz} + \mathrm{Random}(-\delta, +\delta))$$

Random ($-\delta$, δ) returns a uniformly distributed random number between $-\delta$ and $+\delta$, 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 ← 0
        if a_ij = nil, a_ij ← 0
    a_ii ← a_ii + ρp_ij(a_ji − a_ii + Random(−δ,+δ))
    a_ij ← a_ij + ρp_ij(a_ji − a_ij + Random(−δ,+δ))
        + ω(a_ji − a_ii + Random(−δ,+δ))
```

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;
- ω 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.
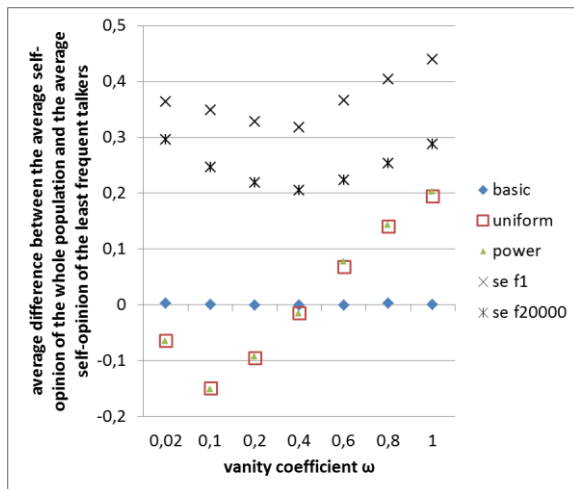

Figure 2. Average difference of self-opinion between average everyone's and the average value of the least frequent talkers for the various tested value of ω and for the basic model in which the probability to talk is the same for everyone (blue diamonds), a probability to talk picked out at random in 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 ω, we assume the dynamic behavioural pattern, defined by the value of ω 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.
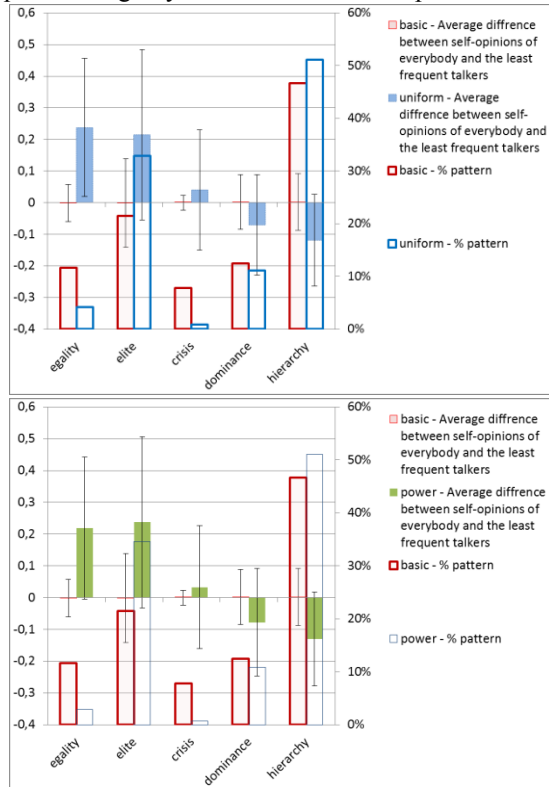

Figures 3. Link between the nature of the correlation between self-esteem and the probability to talk given by the average difference of self-opinion between average everyone's and the average value of the least frequent talkers, and the dynamic behavioural pattern for, from the top to the bottom right, 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.
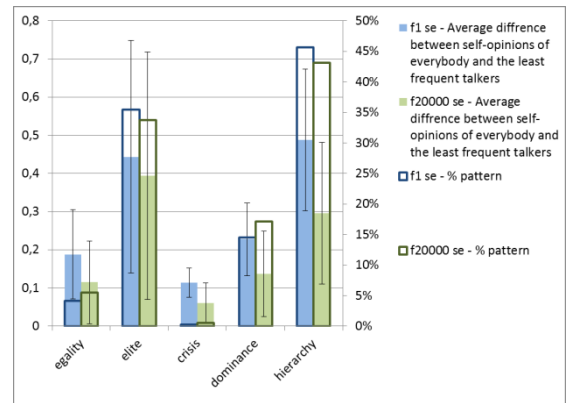
Figure 4. Link between the nature of the correlation between self-esteem and the probability to talk given by the average difference of self-opinion between average everyone's and the average value of the least frequent talkers, and the dynamic behavioural pattern for, a probability to talk depending 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.
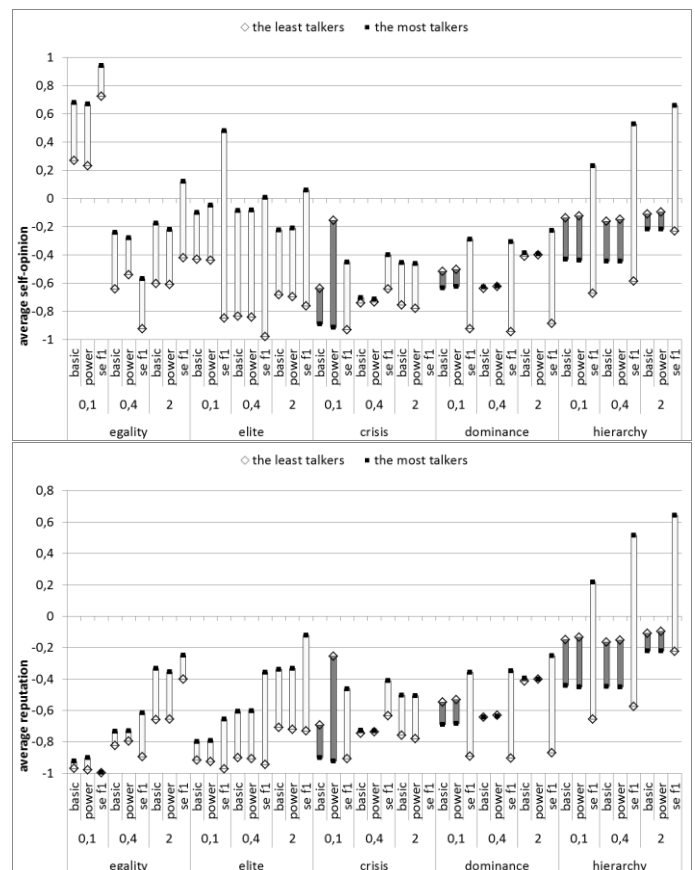
Figures 5. Variation of the average self-opinion (at the top) and the average reputation (at the bottom) for the dynamic behavioural patterns and the various hypotheses (presented at the bottom of the figures) for the two extreme groups of talkers (the least frequent (diamonds), the most frequent (black 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 NxN 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.
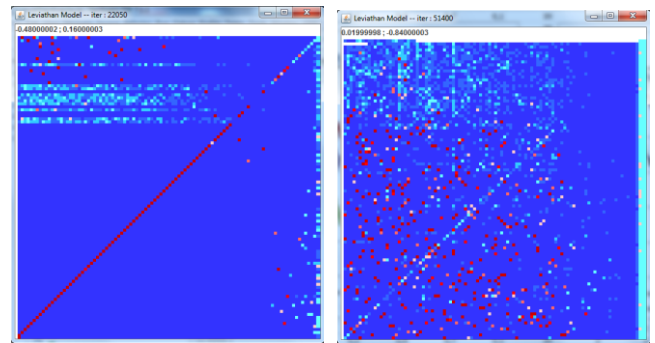
Figures 6. Mixed dynamic behavioural pattern egality/elite: on the left k=5, δ=0.2, N=100, σ=0.1, ρ=0.1, ω=0.4, and on the right right k=4, δ=0.2, N=100, σ=0.4, ρ=0.3, ω=0.8. The agents' frequency of talk decreases from the left to the right; the least frequent talker is the last agent on the right

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.
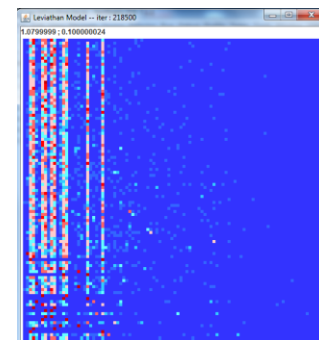
Figure 7. Pure dynamic behavioural pattern elite for k=5, δ=0.2, N=100, σ=0.3, ρ=0.3, ω=0.7. The agents' frequency of talk decreases from the left to the right; the least frequent talker is the last agent on the right

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.
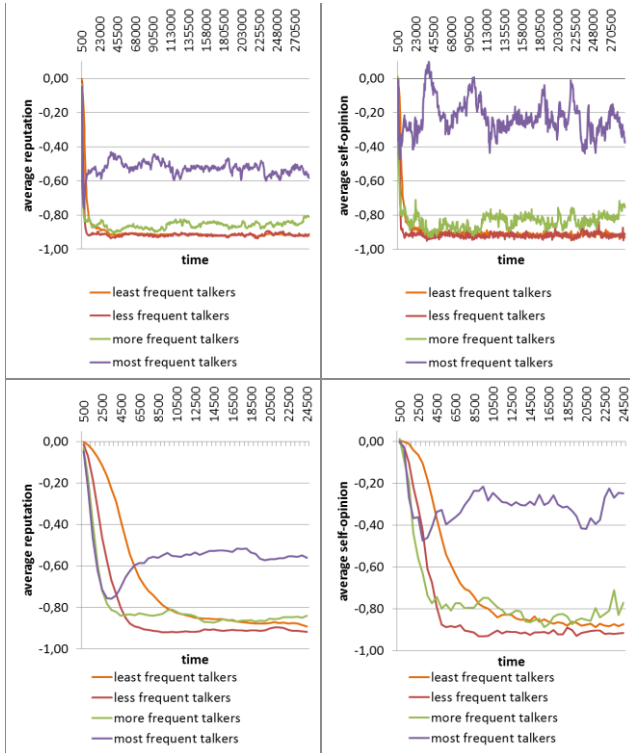

Figures 8. Temporal trajectory of the dynamic behavioural pattern elite for a replica of a simulation with parameters $k=5$, $\delta=0.2$, $N=100$, $\sigma=0.3$, $\rho=0.3$, $\omega=0.7$. Average reputation on the left, average self-opinion on the right with at the top the total trajectory, at the bottom 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.
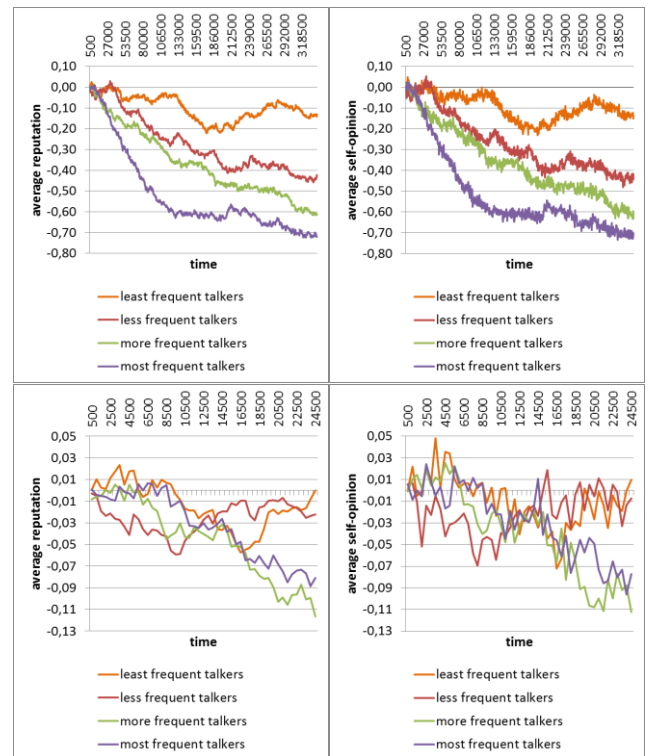
Hierarchy

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.
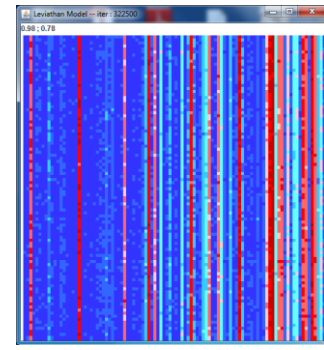
Figure 9. Pure dynamic behavioural pattern hierarchy $k=15$, $\delta=0.2$, $N=100$, $\sigma=0.4$, $\rho=0.7$, $\omega=0.2$. The agents' frequency of talk decreases from the left to the right; the least frequent talker is the last agent on the right.

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 $k=15$, $\delta=0.2$, $N=100$, $\sigma=0.4$, $\rho=0.7$, $\omega=0.2$. 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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