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Do the number of origins and confidence thresholds in beliefs influence rumor diffusion dynamics? A theoretical approach using an agent-based model

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Abstract

Today, the actions of individuals who act, or fail to act, on the basis of a rumor can have major economic, political, and social implications. Following a review of the literature, this article proposes, firstly, a new sociological definition of rumor accounting for the concepts of uncertainty and suspicion of elite malevolence. Secondly, it examines how the variables number of rumor origins and people's confidence threshold in their own beliefs affect the dynamics of rumor diffusion. To this end, an agent-based model is built using the NetLogo program to carry out various simulations. The outcomes of the model are twofold. First, there is always total rumor diffusion. Second, the two variables studied affect the speed at which a rumor spreads, but not whether it spreads.

Keywords: opinion dynamics; information diffusion; confidence thresholds; social networks; social influence; social change; fake news; computational simulation; agentbased model; NetLogo

Resumen *¿Influyen el número de orígenes y los umbrales de confianza en las creencias en la dinámica de difusión de rumores? Una propuesta teórica desde un modelo basado en agentes*

Hoy en día, las acciones de los individuos, los cuales actúan o dejan de actuar movidos por un rumor, pueden tener grandes implicaciones económicas, políticas y sociales. Este artículo propone, en primer lugar, una nueva definición sociológica de rumor partiendo de una investigación bibliográfica y teniendo en cuenta los conceptos de incertidumbre y de la sospecha de la maldad de las élites. En segundo lugar, estudia cómo afectan a la dinámica de difusión de rumores las variables del número de orígenes de un rumor y del umbral de confianza que las personas tienen en las creencias propias. Mediante la construcción de un modelo basado en agentes con el programa NetLogo, se han realizado distintas simulaciones, y los resultados principales son dos. El primero es que siempre hay difusión total del rumor. El segundo es que las dos variables estudiadas afectan a la velocidad con la que se difunde un rumor, pero no al hecho de si este se difunde o no.

Palabras clave: dinámicas de opinión; difusión de información; umbrales de confianza; redes sociales; influencia social; cambio social; *fake news*; simulación computacional; modelo basado en agentes; NetLogo

Summary

1. Introduction

Rumors have been examined in several scientific disciplines, among them psychology, history, and sociology. The first studies on rumors date to the beginning of the 20th century and were conducted by Bernard Hart (1916). Among other factors, Hart analyzed the number of rumor origins and the process by which messages are distorted when disseminated. Individuals' interactions in the diffusion process (Shibutani, 1966) and factors related to the decision to spread a rumor (Bordia & Rosnow, 1998; DiFonzo & Bordia, 2007) have also been analyzed. Studies on the dynamics of rumor diffusion are more recent following the emergence of computational simulation. These include, for example, the essays by Kawachi et al. (2008), Liu and Chen (2011) and Xia and Huang (2007). The present paper attempts to contribute to the field of rumorology using computational simulation and combining two established facts: that both the number of rumor origins and individuals' threshold of confidence in their beliefs affect the spread of rumor diffusion.

Fake news illustrates the importance and consequences of the spread of rumors in the political and social sphere. For example, in 2013, a tweet claimed that the president of the United States, at that time Barack Obama, had been injured in an explosion. The information was false, but the tweet had an enormous repercussion, resulting in the loss of 130 billion US dollars in stock value (Huang et al., 2020).

The diffusion of rumor can also affect and hamper coexistence among citizens. Specifically, rumors that spread stereotypes about certain people or cultures can entrench prejudices toward certain groups. For this reason, state-level policies are currently being implemented to disprove rumor-based beliefs among the population. These anti-rumor policies have been designed due to the increase in xenophobic discourses that reinforce prejudices towards minorities, migrants, and refugees or one's own cultural diversity (Ayuntamiento de Getxo, 2019). However, as will be discussed in more detail in the theoretical framework, official denials of a rumor often contribute to its diffusion (Elster, 2007: 414). Therefore, anti-rumor policies may have the opposite effect to the one desired and further perpetuate certain prejudices.

For the above reasons, the study of rumorology is relevant to the field of sociology since the actions of individuals who act or fail to act moved by a rumor can have significant economic, political, and social implications.

This article presents a theoretical discussion on the dynamics of rumor diffusion from the perspective of analytical sociology. First, it proposes a definition of rumor as "a belief whose veracity is uncertain, at least in part of the population, that alludes to a person, object, or situation (or their interrelations) and which is frequently transmitted through an unofficial channel of information." Secondly, it examines how the number of a rumor's origins and the threshold of confidence that people have in their own beliefs affect the dynamics of rumor diffusion. The main hypothesis is that variables related to the number of origins of a rumor and individuals' confidence threshold in their own beliefs are necessary for rumors to spread among a population, and that changes in these variables will influence the emergence of this social phenomenon.

To achieve these objectives, the rest of the article is organized as follows. First, an overview of the current sociological literature on rumors, their characteristics, the process of rumor diffusion, and the use of agent-based models to study this phenomenon are presented in the theoretical framework. Next, the relevance of studying rumor diffusion using an agent-based model and the importance of computational simulation for the social sciences are justified in the methodology section. An agent-based model created using the NetLogo computer simulation program is then described so that it can be replicated. The code created for the simulation is included in the Appendix. The simulation outcomes are then presented and analyzed. The final section concludes.

2. Theoretical framework

This section is divided into three parts. First, an overview of the existing sociological literature on rumors and their characteristics is presented and a new definition of rumor is proposed. The literature on the process of rumor diffusion is then presented. Next, a short review of studies using computational simulations with agent-based models to analyze the diffusion process between individuals is presented. This theoretical framework is largely based on Tapia-Tejada (2013).

2.1. Rumors: Definition and characteristics

The initial research in the field of rumorology dates to the early 20th century (Tapia-Tejada, 2013: 24). One of the first authors to define the concept of rumor was Bernard Hart, who understood rumor as the transmission of a report through a succession of testimonies (Hart, 1916: 13). Hart also addressed the distortion mechanisms that operate in the mental processes of the recipients of rumors, which often alter the content. He identified three distortion mechanisms: difficulties of perception, conservation of the transmission received, and reproduction of the information to be transmitted. Hart also states that rumors can have more than one origin.

In the same vein, Elster (2007: 414) argued that rumors can originate almost simultaneously but independently. To defend this position, he relies on Georges Lefebvre's study of the Great Fear of 1789. This rumor originated in seven different places in a coordinated manner during the harvesting season, and then travelled through most of France at an average speed of four kilometers per hour.

It is worth mentioning two authors that have also made important contributions to the field of rumorology: Gordon Allport and Leo Postman (1946; 1947). They proposed a law of rumor which states that the number of rumors that spread through a society is a multiplicative function between the importance that the rumor has for individuals and the information that the individuals themselves have about its content. If the rumor were of no interest to anyone or if individuals had full information about the subject of the rumor in question, it would never spread among a group of people.

As regards the transformation of rumors during their transmission, Peterson and Gist (1951) argued that, although it is true that certain details may be omitted in the transmission of a rumor, especially by those who are not very interested in the rumor content, the loss of detail does not affect the essential content. They also posited that individuals are eager to find an explanation in contexts where official explanations are lacking.

Tamotsu Shibutani (1966) highlighted the need to analyze individuals' interactions in the diffusion process. Contrary to the previous authors, Shibutani believed that the focus should not be placed on the distortion of messages, but rather on the interaction between individuals attempting to define an ambiguous situation. For Shibutani, an ambiguous situation is one that has not been reported by the official media and requires a solution. Shibutani defined rumor as a "recurrent form of communication through which men caught together in an ambiguous situation attempt to construct a meaningful interpretation of it by pooling their intellectual resources" (Shibutani, 1966: 17). To refer to rumors, he also used the term "improvised news" (Tapia-Tejada, 2013: 61). Thus, according to both Peterson and Gist and Shibutani, rumors emerge when official explanations are lacking.

On the other hand, Fine and Ellis define rumors as the "expression of a belief about a specific event that is supposed to have happened or is about to happen" (Fine & Ellis, 2010: 4). They argue that rumor diffusion is a short-lived process and, given its nature, is unassailable. In contrast, for Feria et al. (2019: 660), rumors are "informal information borne out of anxiety and uncertainty." This definition is particularly relevant because it suggests a very important characteristic for rumor diffusion to occur, contexts of uncertainty.

Coleman et al. (1957) were the first to provide evidence that social influence plays a very important role in contexts of uncertainty. If individuals do not have enough information, or enough time to seek more information or make a decision, they will be more influenced by what people in their social network do. This influence is stronger when, in contexts of uncertainty, people think that they may lose something. This would be a particular case of loss aversion (Kahneman & Tversky, 1979).

Along the same lines, Elster (2007: 417) affirmed that negative rumors spread more than positive ones, especially if their content refers to a negative action by the elites. This process occurs because of what he refers to as the suspected malevolence of the elites and minorities (Elster, 2007: 416). According to Elster, rumors based on the idea that elites and minorities are trying to cause harm and are inherently evil are more likely to be spread. This phenomenon is related to the notion of completeness and the innate tendency of people to identify causal patterns even where they do not exist (Kahneman, 2012). Similarly, for Knapp (1994: 30), a good rumor is one that is in harmony with the cultural traditions of the group in which it circulates, since in this way it will travel more and faster.

Most authors generally recognize two features as being characteristic of rumors. The first is the lack of evidence or proof accompanying the rumor when it is transmitted and prevents it from being ratified or denied (Allport & Postman, 1946; Buckner, 1965; DiFonzo et al., 1994). The second feature is that rumors are in constant circulation (Walker & Blaine, 1991).

At this point, it is important to distinguish rumors from two very similar phenomena, gossip and urban legend, which share the two main features of rumors. All three are usually spread through unofficial information channels, such as by word of mouth or digital social networks and lack elements to determine their veracity (Tapia-Tejada, 2013: 63).

Nonetheless, there are certain differences that allow us to distinguish them. For example, rumors and urban legends generally spread more than gossip, which is usually spread only among people who share a specific space, such as a work environment or a classroom (Tapia-Tejada, 2013: 63). Urban legends, unlike rumors, are usually narrative in nature and are long stories with many compositional elements that refer to cultural aspects of a collective group (Cortázar Rodríguez, 2008).

Finally, Tapia-Tejada, building on the previous definitions of DiFonzo and Bordia (2007), Fine and Ellis (2010), Buckner (1965) and Tai and Sun

(2011), proposed a new definition according to which rumor is "an ambiguous belief, which has neither been confirmed nor disproved by official sources, which alludes to a person, object or situation (or their interrelations) and which is frequently transmitted through an unofficial information channel" (Tapia-Tejada, 2013: 62).

However, this definition does not account for the effect of popular beliefs about the malevolence of the elite introduced by Elster (2007: 416) and discussed above. Consequently, the fact that the belief has neither been confirmed nor disproved by official sources cannot be an element of the definition. As Elster argued, given popular beliefs about the malevolence of the elite, confirmation and disproof by official sources may reinforce the rumor. As an example, people may think, "The elites want me to believe *a*, but, since they are evil, I will believe *b*, which is the right thing to do."

Likewise, official denials about the substance of a rumor often serve to feed it (Elster, 2007: 414). On the one hand, people who had not heard the rumor before will now do so. On the other hand, people who had given no importance to the rumor will do so when official sources give it enough importance to confirm or deny it.

As regards the notion that a rumor is an ambiguous belief, it is argued that rumors are rather a precise belief whose veracity or falsity is uncertain. In turn, this uncertainty may exist objectively, or it may affect certain individuals who are less well-informed and dubious by nature. Thus, in this article I propose a definition of rumor as "a belief for which there is uncertain veracity, at least in part of the population, that alludes to a person, object or situation (or their interrelations) and is frequently transmitted through an unofficial channel of information."

2.2. Rumor diffusion process

The phenomenon of rumor diffusion raises two major issues: the distortion of the content of the message during the diffusion process and factors related to the transmission of rumors between individuals.

2.2.1. Distortion during rumor diffusion

Most authors claim that rumors will become distorted during the diffusion process, that is, the content of the rumor will be altered as it spreads. This argument is called *information perversion* and has been described by many authors (Allport & Postman, 1947; Esposito & Rosnow, 1984; Hart, 1916; Scanlon, 1977).

Specifically, Hart (1916) argued that as rumors spread, they become distorted since individuals reproduce and deform them through mechanisms such as the "self-assertion" group or phantasy. Likewise, Allport and Postman (1946) also understand the distortion of rumor content as a fundamental characteristic of the rumor diffusion process. For these authors, each time an individual receives a message, its content is altered with respect to the initial content in the subsequent transmission. Not only is the content of the rumor distorted, but according to Elster (2007: 414), it also tends to be amplified in multiple and successive retellings. In contrast, other authors argue that the content of the rumor remains essentially the same, because when we speak of rumors we speak of simple propositions and not of great argumentative stories such as urban legends, and the reiterative nature of the diffusion makes the message more precise (Anthony, 1973; Peterson & Gist, 1951).

2.2.2. The transmission of rumors

Some authors, such as Allport and Postman (1946), have suggested that rumors are transmitted in a linear manner. This was contested by Buckner (1965), who argued that linear transmission is an unrealistic assumption, since diffusion processes are not linear. He also criticized Allport and Postman's designs for other unrealistic assumptions because rumors can be heard by receivers more than once and because the people who receive them are not passive actors but take an active role with certain reaction levels.

According to Buckner (1965), it is necessary to distinguish between closed groups, which are characterized by being small and having a high degree of in-group interactions, and open groups, which function in the opposite manner. According to Buckner (1965), in closed groups with a high interest in the rumor content, the level of diffusion of the rumor will be high, but in open groups with little interest in the rumor content, the level of diffusion will be low (Tapia-Tejada, 2013: 29).

Shibutani (1966) identified six types of roles adopted by people who interact in the diffusion of rumors. These include the messenger, who brings the rumor to the group; the interpreter, who contextualizes the rumor, evaluates it, and speculates about future implications; the skeptic, who expresses doubt and demands proof; the auditor, who listens and says nothing; the agitator, who urges others to believe it; and the decision-maker, who takes the lead in deciding whether to believe the rumor or not (Tapia-Tejada, 2013: 30).

Prashant Bordia and Ralph Rosnow argued that belief in rumors does not affect their diffusion, nor does the trust individuals have in the rumor or its source, but that to be disseminated, rumors must simply make sense (1998: 347). These authors frame their theory of rumors in a market situation, in the same way as Merton (1948). They also observed that rumors that cause fear spread more than those that express a desire. Bordia and Rosnow also claim that rumors spread more among people of the same sex. Recent research has found evidence supporting the relationship between rumor diffusion and social network structure (Tapia-Tejada, 2013: 60).

Likewise, Granovetter (1973) argued that people have different confidence thresholds in their beliefs. Some people will quickly change their beliefs if those around them believe something different. Yet other people who are very confident in their beliefs, even if no one around them believes the same thing, will never change their beliefs. That is, some people will be more susceptible to social influence than others. For this reason, explanations of rumor diffusion processes must account for the fact that diffusion will differ depending on individuals' threshold of confidence in their beliefs.

In relation to Granovetter's threshold theory, Centola (2018) proposed a distinction between simple contagions and complex contagions similar to the spread of a disease. People are either inactivated, which means they are susceptible to contagion, or activated, which means they are infected and can transmit contagion to others. Simple infections can be transmitted by a single contact, whereas in complex infections people need multiple sources of activation. Most information is transmitted through simple contagions, but some behaviors are not spread in this way, as they require legitimacy, credibility, or complementarity to be adopted (Centola, 2018: 35). Important information, such as changes in weather conditions or upcoming events, is easily spread from one person to another, as is the most banal information, such as the result of a sports competition. In contrast, when it comes to social movements, social norms, or healthrelated behaviors, people depend on the decisions of others to adopt or not adopt a behavior. It is here where the difference arises between being exposed to a behavior (i.e., a simple contagion) or adopting it (i.e., a complex contagion). This difference between simple and complex contagions is of particular importance, as we cannot generalize the results of the diffusion of simple contagions to the diffusion of complex contagions.

2.3. Studies using agent-based models or computational simulation

Many studies on the process of rumor diffusion have used agent-based models to replicate epidemiological models. This is because the way an infectious disease spreads is similar to the spread of information (Wang et al., 2018). Kawachi et al. (2008) proposed an example of this type of epidemiological model. To analyze interaction processes in rumor transmission, the authors developed a simulation model with three types of agents: one who is likely to believe the rumor; one who spreads the rumor; and the stifler, who is the person who denies it or is not interested in it. The authors concluded that stiflers play an important role in stopping the rumor from spreading.

Hu et al. (2018) also reproduced an epidemiological model of rumor diffusion. In their model, they considered different attitudes that people might have toward rumors which affect their spread. Agents could exhibit one of three attitudes toward rumors: hesitant, susceptible, or resistant. The results show that agents with a hesitant attitude are key in spreading rumors, much more so than susceptible or resistant agents.

In the same vein, Zhang et al. (2019) noted that most current studies on rumor diffusion are based on the epidemiological model or the threshold model, also called the decision model. Both models tend to focus on diverse attributes of the actors spreading the rumor. The authors argued that the diversity of behavior patterns in rumor-spreading agents is equally important. They concluded that the reliability of the agent who decides whether to spread a rumor greatly affects overall rumor diffusion and determined that the saying "Rumors stop at the wise man" is true.

Xia and Huang (2007) criticized the use of epidemiological models to represent rumor diffusion dynamics because they are unable to capture the evolution of individual beliefs or the generation of anti-rumors. They used an agent-based model to simulate a rumor-spreading dynamic that was configured as follows. There are three types of agents: agents who spread the rumor or anti-rumor, agents who spread the rumor if they believe it, and agents who never say anything. The agents move randomly through a plot. The probability that an agent will believe the rumor (or not) is determined by the percentage of neighbors who believe it (or not). The authors concluded that it is more difficult for anti-rumors to emerge once the rumor has already spread among the agents.

Another example of a study in this line is Liu and Chen (2011). These authors studied the propagation of rumors in cyberspace, specifically in a scale-free network like Twitter. These networks are characterized by being asymmetric, that is, the fact that information circulates from A to B does not imply that information circulates from B to A, since reciprocity between the followed and the followers is not mandatory in many digital social networks. The results of their research show that the evolution of the ratio of people who come to believe a rumor in scale-free networks is higher than in other types of networks (by up to 70%) and that the number of people who had not heard a rumor was lower (20%). Consequently, they concluded that rumors spread much more in scale-free networks than in other types of networks.

Feria et al. (2019) expanded on the work of Liu et al. (2018). Their model considers two types of spreaders: rumor spreaders and truth spreaders. Their model also includes interaction by both types of spreaders with ignorant individuals. The authors also introduced another type of agent they call "exposed spreaders." That is, they add interaction with agents who have been exposed to one or both types of spreaders, but who are still verifying the information received. The authors conclude that, for the rumor to spread more widely, the rumor spreaders must infect the maximum number of agents in the first rounds.

However, the model of Feria et al. (2019) has a problem in terms of its approach. The authors base their study on the premise that all rumors are false when they could in fact be true. Moreover, people do not always know the truth concerning the rumor, and even if they do know it and share it, those who are ignorant of the truth may decide not to believe them or trust their information as much as the rumor. Thus, a person could have heard the truth and still believe the rumor.

In a more recent study, Lai et al. (2020) investigated the relationship between the Big Five personality traits (extraversion, agreeableness, conscientiousness, neuroticism and openness) and individuals' belief in false rumors circulating on the Internet. They found that people who exhibit high levels of neuroticism and extraversion are the most vulnerable to believing false rumors.

The authors also established a relationship between lower educational level and more belief in false rumors.

As a final example, Zhang and Li (2019) designed a model to identify whether and which individuals are more influential in spreading a rumor. They concluded that individuals in the nodes in the highest layers of a social network are the most influential spreaders, whether they started the rumor or heard it. That is, individuals who are more educated, those of higher social status, and those with greater media presence etc. are the key agents in rumor diffusion. These conclusions are in line with Elster's approach, according to which official denials about the content of a rumor often serve to feed it (Elster, 2007: 414). That is, whether they confirm or deny it, they are making it reach more people.

3. Methodology

To study the influence of the two variables (i.e., the number of rumor origins and confidence threshold people have in their own beliefs), we use an agent-based model, which is a form of computational simulation (Gilbert, 2008: xi) and a tool that satisfies the generative standard (Epstein, 2006: xii).

Formally, agent-based modelling is a computational method that allows researchers to create, analyze, and experiment with models composed of agents interacting in an environment (Gilbert, 2008: 2). Agent-based simulation enables modeling individual heterogeneity, explicitly representing the rules by which agents make decisions, and situating agents in a geographical or another type of space. It allows modelers to represent in a natural way multiple scales of analysis, the emergence of macro-level structures from individual action, and various types of adaptation and learning, which is not easy to do using other methodological approaches (Gilbert, 2008: 1).

An agent is "a computer system that is capable of independent action on behalf of its user or owner" (Woolridge, 2009, cited in Manzo, 2014: 30). A multiagent model is "one that consists of a number of agents, which interact with one another, typically by exchanging messages through some computer network infrastructure" (Woolridge, 2009, cited in Manzo, 2014: 30). Agent-based models are characterized by autonomous, heterogeneous agents guided by some kind of bounded rationality and also involve explicit space, local interactions, and non-equilibrium dynamics (Epstein, 2006: xvi). Although agents must be thoughtful, they do not always have to be brilliant (Miller & Page, 2007: 3). The environment is the virtual space in which agents act and can be entirely neutral, with little or no effect on the agents, or in other models can be as carefully designed as the agents themselves (Gilbert, 2008: 6).

Even in the most sophisticated models, interaction between agents almost always occurs through the transmission of a non-mediated message directly from agent to agent. As Gilbert (2008: 72) stated, this is quite different from the human form of communication "in which our thoughts and intentions have to be conveyed through an external neutral language that is inevitably ambiguous and whose meaning has to be learned." In other words, communication is not innate in agent-based models.

In modeling artificial societies, social structures emerge, demonstrating that certain micro specifications are sufficient to generate the macro phenomenon of interest (Epstein, 2006: xi), in this case, the spread of rumors. Abstract models show patterns at the macro level that are expected and interpretable based on plausible rules of agent behavior at the micro level. The aim of these abstract models is to demonstrate some basic social process that may occur in many spheres of social life (Gilbert, 2008: 41).

The simulation of an agent-based model involves iterating the rules that define the objects, updating the attributes of the objects, and allowing the objects to communicate and influence each other during the simulated time. Thus, by simulating an agent-based model, the process potentially contained in the artificial mechanism is activated *in silico.* This process generates precisely what analytical sociology seeks: evidence that a given representation of an interconnected set of entities/properties/activities, that is, the generative model is capable of generating a set of high-level associations (Manzo, 2014: 31). The results obtained from an agent-based model will only be of interest if the model behaves in the same way as the human system (Gilbert, 2008: 3).

Every realization of an agent-based model is a strict deduction (Epstein, 2006: xvi). However, most social simulations contain some element of randomness (Gilbert, 2008: 43). Currently, the most popular program for agent-based simulation is NetLogo (Gilbert, 2008: 48), which has been used to create the simulation in this research.

4. Description of the model

In what follows, we present the characteristics of the agent-based model programmed with NetLogo to study the dynamics of rumor diffusion. First, the simulation contains a total of 450 randomly distributed agents. It should be noted that the environment does not affect interaction between agents. To make the simulation more realistic, only one agent may occupy a square, since people occupy a certain physical space, and no two people can be in the same place at the same time. The agents can move randomly throughout the environment, that is, they are not fixed in a particular place. In each round, the agents can move to an empty place around them, provided there is one; otherwise, they remain where they are.

As far as the rumor-related features of the model are concerned, on the one hand, like Hart (1916), we established that the rumor could have more than one origin. Consequently, the percentage of agents who start the rumor in the simulation can be selected. Agents who believe the rumor change from yellow (they do not believe the rumor) to brown (they believe the rumor).

On the other hand, this form of diffusion follows a threshold model, in the sense that agents update their beliefs according to a threshold of confidence in their own belief. This threshold is established in relation to the beliefs of the individuals around them. According to Granovetter (1973), people have different thresholds of confidence in their beliefs. Some people will change their belief if the majority of people around them believe something different. For simplicity's sake, however, the thresholds in this model are viewed as being uniform across agents. For example, if a threshold of 30% is set, it will be the same for all agents.

For this reason, in each round agents evaluate the beliefs of the agents around them. Agents will change or maintain their belief according to the established confidence threshold. This threshold refers to agents' confidence when they have a minority belief among the agents around them. For instance, if we select a threshold of 30%, an agent will only change its belief, or will believe the rumor, if more than 30% of the agents around it believe the rumor. If less than 30% of the agents around the agent believe the rumor, the agent in question will maintain its belief. Since the agents in our simulation can move, the agents around them change in each round.

Importantly, the simulation also follows an epidemiological model in line with Wang et al. (2018), who posited that the way an infectious disease spreads is similar to the way information spreads. In our model, this is represented by the fact that when an agent believes the rumor, it never stops believing it, even if it is in the minority. Finally, during the simulation, the model shows us the evolution of the number of agents who do not believe the rumor and the number of agents who do believe it. The simulation stops at 1,500 rounds when the model indicates that the spread of rumors has reached an equilibrium.

To conclude this point, the code used in the simulation is of our own creation, although we have partially relied on two existing codes for its elaboration. The part of the code concerning agents' evaluation of their own belief is based on the code of the Schelling segregation model, as it appears in the NetLogo database. The to-go-if-empty-nearby part of the code, which allows agents to move to an empty box around them, was taken from an Internet forum for resolving NetLogo queries.[1] The code used to create the simulation can be found in the Appendix.

4.1. Simulated parameters

We hypothesize that rumor diffusion dynamics largely depend on the fact that rumors have more than one origin (Hart, 1916) and on people's confidence threshold in their own beliefs (Granovetter, 1973). Therefore, different parameters in the rumor origin and confidence threshold should result in different patterns of rumor diffusion behavior.

To test this hypothesis, the threshold of confidence in one's own beliefs and number of rumor origins are set at the beginning of each simulation so that we can explore the two variables. In the simulation, the number of rumor

1. Available at <https://github.com/NetLogo/models/blob/master/Code%20Examples/One%20Turtle%20Per%20Patch%20Example.nlogo>.

origins can have a value ranging from zero to one hundred percent of the agents. Depending on the percent of agents that are chosen, the simulation will start so that this percent of agents initiate the rumor. The specific agents that initiate the rumor are determined randomly.

Although the simulation enables studying from zero to one hundred percent of rumor origins, it is considered useful and objective to use only one to five percent. At a higher figure, the rumor may already have spread among the population, and it would not be relevant to study. Thus, this simulation can start in five states, with a number of rumor origins (RO) from one to five percent of the population.

As noted, there is empirical evidence of the important role confidence thresholds play in one's own beliefs (Granovetter, 1973) in information diffusion. The confidence threshold also has a value from zero to one hundred. However, similar to what occurs with the number of rumor origins, the confidence threshold cannot have a value of zero or one hundred percent. The idea that all people in a group are extremely confident in their beliefs and would never change their beliefs in the face of new information is an unrealistic assumption. Likewise, the other extreme is also an unrealistic assumption. It is very difficult to conceive of a world where all people in a group have no confidence in their own beliefs and will always change their beliefs. For these reasons, it is relevant to study confidence thresholds from ten to fifty percent.

For example, a 10% confidence threshold in one's own beliefs means that an agent will make the following assessment: "I only need 10% of the people around me to have the same belief as me and I will maintain my belief; if more than 90% of the people around me have a different belief than mine, I will change my belief."

5. Results and analysis

The analysis of the rumor diffusion model has two objectives. First, the results obtained for each combination of parameters are presented to determine what steady state is achieved in rumor diffusion (if in fact some mechanism is achieved). Second, the generative process, or the process that leads to these steady states, is explained. This is because agent-based models can only lead to explanations without black boxes when we explain the chain of events at the micro level that lead to the emergence of regularities at the macro level (León-Medina, 2017a; 2017b)

5.1. Simulation outcomes

This section presents the most relevant outcomes of the simulations performed. In the simulation there is always a total diffusion of the rumor, that is, when the simulation stabilizes, all the agents believe the rumor. A table with the mean number of rounds in which the simulation stabilizes is shown below. The mean is calculated for each parameter setting between the number of

Table 1. Mean number of rounds in which the simulation stabilizes, repeated 200 times

50	291	211	179	157	147
40	325	241	200	181	164
30	442	328	296	269	237
20	524	395	378	347	323
10	556	471	390	360	344
SW/RO	1	2	3	4	5

Source: Own elaboration.

rumor origins (RO) and the threshold of confidence in one's own beliefs (SW) repeated 200 times.

As the above results suggest, and as can be seen in Table 1, the only thing that changes depending on the parameter settings is the speed at which the rumor is completely spread. This fact is intuitively plausible in that the more people initiate the rumor and the less confidence people have in their own belief, the faster the rumor will spread.

The parameter of the threshold of confidence in own beliefs affects the speed with which the rumor spreads, but it always ends up spreading completely. That is, the threshold of confidence that people have in their beliefs does not determine whether the rumor will spread or not, but rather the speed at which it will spread. Just as the threshold of confidence in one's beliefs affects the speed at which the rumor spreads, so does the number of rumor origins. Even with 1% of rumor origins, the rumor always ends up spreading to all agents in the simulation. Consequently, it can be stated that Hart's (1916) thesis that rumors always have more than one origin does not hold true. According to the model, rumors do not always have to have more than one origin, it is sufficient for a single agent to start a rumor for it to emerge.

For this reason, when the two variables are combined, the higher they are, the faster the rumor spreads; and the lower they are, the less rapidly the rumor spreads. Consequently, when the parameters are set to 5% for the number of rumor origins and 50% for the threshold of confidence in one's own beliefs, the rumor spreads more rapidly, and when the parameters are set to 1% for the number of rumor origins and 10% for the threshold of confidence in one's own beliefs, the rumor spreads more slowly.

5.2. Generative process

The agent-based model of rumor diffusion presented above generates a single scenario, a steady state, which is the total diffusion of the rumor. During the first few rounds of the simulations, the agents spreading the rumor can be seen to move through the environment with no change in any agent's beliefs. When an agent who does not believe the rumor is left alone with one or more agents who believe the rumor, the agent changes its belief. Thus, exponentially, when agents who do not believe the rumor find themselves surrounded by agents who believe the rumor, they update their minority belief to believe the rumor and adapt to the majority. That is, if an agent who does not believe the rumor were never left alone with one or more agents who believe the rumor, there would never be rumor diffusion.

Therefore, it could be concluded that, if no other variable could be influencing the process of rumor diffusion, the present model demonstrates that rumors will always spread throughout the population. In a certain way, the model yields conclusions like those of epidemiological models: rumors will spread exponentially until they *infect* the entire population.

6. Conclusions

Firstly, as stated in the theoretical framework, we propose a modification of Tapia-Tejada's (2013) definition of rumor. Based on Elster's (2007) concept of suspicion of elite malevolence, we argue that a rumor can be confirmed or denied by official sources and continue to exist. According to Elster's contributions, it is argued that not only can a rumor continue to exist, but the fact that official sources make claims regarding the rumor can have the opposite effect of what they seek. People believe that the elites may be evil and, therefore, make the following reflection: "The elites want me to believe *a*, but, since they are evil, I will believe *b*, which is the right thing to do."

Secondly, our model has provided valid results and allowed us to study how the number of rumor origins and the threshold of confidence that people have in their own beliefs affect the dynamics of rumor diffusion. The main hypothesis was that the variables number of rumor origins and people's threshold of confidence in their own beliefs are necessary for rumors to spread among a population, and that changes in these beliefs will affect the emergence of the rumor. It has been shown that this is not the case. Regarding the number of rumor origins, according our model and contrary to Hart's (1916) approach, rumors do not necessarily have to have more than one origin, and that the number of people who start a rumor will only affect the speed at which it spreads. Similarly, it has been observed that Granovetter's (1973) confidence thresholds also explain the speed at which a rumor spreads, but do not affect whether the rumor spreads or not. Thus, it can be concluded that, according to this model, both the number of rumor origins and the threshold of confidence that people have in their own beliefs affect the speed at which a rumor will spread, but do not whether it spreads through a population.

The model presented in this article is a first version that can be developed in multiple directions to make it more realistic and applicable. As far as the realism of the assumptions is concerned, there are two avenues for improvement: the characteristics of the agents and the interaction structure. As regards the first aspect, there are some intuitive changes that could improve the model. These possibilities have already been mentioned in the text. For example, heterogeneous thresholds could be introduced, or agents could stop believing the rumor. A more ambitious step would be to calibrate the model using empirical data from laboratory experiments, for example.

As regards the interaction structure of the model, agents could be situated in more complete and realistic structures, such as scale free networks. These are also of interest, given that digital social networks such as Twitter are based on a scale free networks topology. The study of rumor diffusion in a space such as digital social networks is relevant, since rumors were spread by word of mouth, through the media, and so on prior to the existence of these networks. The rumor needed some time to spread and had a limited reach in physical space. Today, however, rumors are mainly transmitted through digital social networks (Huang et al., 2020). In the absence of physical constraints, digital social networks largely facilitate the diffusion of rumors and increase the speed at which they are spread. In terms of applicability, the model could benefit from identifying real cases to test its predictions. For example, rumors regarding vaccination against COVID could be studied, a topic that is currently of great interest.

However, the simplicity of our model and the fact that we did not use an excessive number of parameters allowed us to identify how the variables affected the model outcome. Consequently, this model illustrates in a clear and simple way the evolution of the rumor diffusion process taking into account the parameters number of rumor origins and the thresholds of confidence in one's own beliefs. Unlike overly complicated models, which may introduce black boxes, if the modeler cannot understand how the model works or what changes in the parameters have caused the generated outcome (Macy & Flache, cited in Hedström & Bearman, 2009: 263), the model's simplicity provide a clear picture of how the two variables affect the rumor diffusion process without introducing black boxes.

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Appendix 1. Simulation code

```
globals [
  percent-similar-belief ;on the average, what percent of a turtle's friends have
  the same belief as that turtle?
  percent-confidence-belief ;what percent of the turtles have confidence in their
  belief
]

turtles-own [
  confidence-belief? ;for each turtle, indicate whether at least %-similar-be-
  liefs-wanted percent of that turtle's friends have the same belief as the turtle
  similar-nearby ;how many neighboring patches have a turtle with my belief?
  other-nearby ;how many have a turtle of another belief?
  total-nearby ;sum of previous two variables
]

to setup
  clear-all
  ask patches [
    set pcolor white ]
  create-turtles 400 [ setxy random-pxcor random-pycor ]
  ask turtles [
    set color 45
    set size 1
  ]
  start-rumor
  update-turtles
  update-globals
  reset-ticks
end

to go
```

```
  if ticks = 1500 [ stop ]
  update-belief
  update-turtles
  update-globals
  go-if-empty-nearby
  tick
end

to start-rumor
  ask n-of %-rumor-origin turtles [ set color 40 ]
end

to update-belief
  ask turtles with [ not confidence-belief? ]
  [ change-belief ]
end

to change-belief
  if color = 40 [ set color 45 ]
  if color = 45 [ set color 40 ]
end

to update-turtles
  ask turtles [
    set similar-nearby count (turtles-on neighbors) with [ color = [ color ] of
    myself ]
    set other-nearby count (turtles-on neighbors) with [ color != [ color ] of
    myself ]
    set total-nearby similar-nearby + other-nearby
    set confidence-belief? similar-nearby >= (%-similar-beliefs-wanted *
    total-nearby / 100)
  ]
end

to update-globals
  let similar-neighbors sum [ similar-nearby ] of turtles
  let total-neighbors sum [ total-nearby ] of turtles
  set percent-similar-belief (similar-neighbors / total-neighbors) * 100
  set percent-confidence-belief (count turtles with [ not confidence-belief? ])
  / (count turtles) * 100
end


to go-if-empty-nearby
  ask turtles [
```

```
    let empty-patches neighbors with [not any? turtles-here]
    if any? empty-patches
    [ let target one-of empty-patches
      face target
      move-to target ]
  ]
  tick
end
```