BOUNDARY ORGANIZATIONS: AN EVALUATION OF THEIR IMPACT THROUGH A MULTI-AGENT SYSTEM

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ABSTRACT

Modern environmental issues imply that decision-makers consider simultaneously the various dimensions involved, such as science and economics. To take into account opinions from experts of different fields, they can rely on boundary organizations, institutions able to cross the gap between different domains and act beyond the boundaries while remaining accountable to each side. By encouraging a flow of useful information, they permit an exchange to take place while maintaining the authority of each side: they provide a better understanding of a situation characterized by uncertainty, increasing the efficiency of the decision-making process. Though never formally proved, this hypothesis is widely accepted based on the observation of existing institutions. In this paper, we observe the impact of boundary organizations through an agent-based model of continuous opinion dynamics over two dimensions where heterogeneous experts distinguished by credibility and uncertainty interact. We can conclude that boundary organizations significantly reduce the diversity of opinions expressed and increase the number of experts agreeing to emerging positions, which confirms theoretically the positive impact of boundary organizations on the efficiency of the decision-making process.

KEYWORDS

Boundary organization, Opinion diffusion, Decision-making, Agent-based model

Faced with modern environmental issues characterized by uncertainty and complexity, decision-makers must refer to experts from different areas of science, or even from different sciences, such as natural and social sciences, in order to consider all the aspects involved and take the most objective decision possible. Traditional decision-making provides independent advice from experts of the different dimensions involved, but these opinions may be conflicting when considered together. Boundary organizations have been designed to manage the meeting of distinct areas: by initiating and framing debates between experts, they provide decision-makers with a panel of opinions that integrate the various dimensions of an issue. The resulting eased and increased interaction between experts facilitates the decision-making process by encouraging the emergence of dominant opinions. Though this hypothesis is widely accepted, it has never been formally proved. Through an agent-based model of continuous opinion dynamics over two dimensions, it is possible to simulate a boundary organization and assess its impact on the positioning of experts: heterogeneous agents, differentiated by credibility and uncertainty, are separated in two distinct groups of experts and left free to modify their opinion through one-to-one interactions in their respective field. The boundary organization is introduced through agents open to trans-disciplinary discussion: able to cross the boundary between the two areas, they open possibilities of exchange on both dimensions between agents. This multi-agent system allows us to evaluate the impact of boundary organizations on the diversity of final opinions expressed and on the number of agents agreeing to each, testing the hypothesis supporting the existence of boundary organizations.

Scientific knowledge is essential to a sound decision-making process, but science is more than a simple reservoir of knowledge, competencies and people: it includes normative concepts such as objectivity, honesty, neutrality and truth that give it an institutional and ideological privileged status in the elaboration of public policy (Guston et al., 2000). Science includes in reality sciences, as it covers not only different areas of expertise, but also different approaches such as natural and social sciences, and decision-makers must consider all the dimensions involved in the issue considered. This implies the ability to cross the boundaries between different areas and types of sciences. The concept of boundary has been formalized by sciences in order to strengthen their differences with pseudo-sciences and scientific impostures. Boundaries protect organizations from the outside and maintain an internal order, while imposing the organization as a major actor through its relations with other organizations (Davenport & Leitch, 2005). They allow members to affirm their authority as experts over a field challenged by others, to maintain a monopoly by excluding others, and to protect the autonomy of the members while enforcing their cohesion. Boundaries can be of three types: physical, social and mental. Physical boundaries may be real objects or structures, but also rules and regulations that frame the exchanges within the organization or between the organization and its environment. These boundaries ensure a certain predictability, synonym of stability, while creating and enforcing an image of solidity toward the outside. Social boundaries are developed so that organizations may distinguish themselves from each other: they bring a notion of identity to members while giving the opportunity to identify what constitutes others, what is not part of the organization. Mental boundaries allow for distinctions and give individuals a meaning to the world that surrounds them (Davenport & Leitch, 2005). When two fields, under the authority of different experts, are involved in an issue and brought to interact, it is a natural reaction for each to reinforce the demarcation, in order to avoid confusion and to clarify the responsibilities. While boundaries play their role to protect an organization, they also set a barrier that limits or even prevents flows of information with the outside: their reinforcement results in a lack of communication between experts of the different aspects of an issue. The maintenance of a blurry boundary, rather than the clear and intentional distinction traditionally applied, can increase the productivity of policy-making (Jasanoff, 1990). Boundary organizations have been designed to manage the meeting of distinct areas of expertise and frame interactions in order to enhance the efficiency of the decision making process: by handling debates between experts, they ensure that science brings in a pertinent and useful information while maintaining its independence.

Boundary organizations are institutions that cross the gap between different fields: they are able to act beyond the boundaries while remaining accountable to each side (Guston, 2001). They encourage and manage a blurring of the boundaries, permitting an exchange to take place while maintaining the authority of experts (Cash et al., 2003; Clark et al., 2002). By integrating the demarcation, they allow for communication instead of division: each side can express its reactions to the other's expectations, leading to cooperation around common interests (Davenport & Leitch, 2005). Miller defines boundary organizations as “organizations that sit in the territory between science and politics, serving as a bridge or an interface between scientific research, political decision and public action” (Miller, 2000), and Guston defines them as “institutions that internalize the provisional and ambiguous character of the apparent boundary between science and politics” (Guston, 2000). Boundary organizations are similar to an interface established and influenced by both sides, but independent. It may look like they face a reductive double set of constraints, but groups of experts seen as independent or even opposed distinct social organizations, are more similar than it seems (Miller, 2000), at least in their structure and behavior. The double responsibility of boundary organizations makes them in fact stronger, as if their structure was held on both sides, giving it a unique support that guarantees impartiality (Guston et al., 2000): this dependence of boundary organizations on each side is as important as their independence (Guston, 2001). A boundary is not an established limit between two different areas of authority, but an intermediary zone of variable size: the boundary is permanently defined, criticized, challenged, defended and adjusted. Boundary organizations are not fighting against a strong solid demarcation, but in reality helping to stabilize or even create the boundary. They do not limit themselves to the zone between two areas, but extend inside each side, widening the boundary zone in order to internalize the possible areas of ambiguity. The goal is to involve both sides in the construction of a common boundary that is favorable to each perspective, while setting the limits to potential intrusion of one sphere into the other: the boundary organization must allow and encourage the interactions by increasing the permeability of the separation, while guaranteeing that they don't mix irresponsibly by limiting the porosity (Socci, 2001). Unlike most organizations, their goal is not their personal benefit but that of both sides of the boundary: they do not aim at ensuring their survival, but at offering a complete and honest vision of a situation by encouraging the production and sharing of knowledge in order to guarantee a decision-making process as objective and efficient as possible. Therefore they must remain impartial and neutral in the debates they frame. The boundary organization is judged on criteria of credibility, pertinence and legitimacy, similarly to the expert members and the global decision-making process. The problem of the evaluation of the efficiency of a boundary organization comes from the fact that many parameters, external to the organization and on which it has no control, may affect positively or negatively the results, such as the historical context or the characteristics of the evaluation process. Efficient boundary organizations are those remain stable despite external pressures and an internal instability of the boundary. Boundary organizations may in fact be applied to numerous cases of boundaries: between science and non-science, like historically done, between science and politics, like currently done, but also between different fields of science or different types of sciences such as natural and social sciences like modern global environmental issues may benefit from. Boundary organizations are not a new concept, but modern successful applications, such as the Health Effects Institute, the Office of Technological Assessment, the Agricultural Extension or the International Research Institute for Climate Prediction, demonstrate the diversity and utility of such institutions (Guston et al., 2000). Boundary organizations lead to a decision-making structure able to integrate knowledge from different dimensions into a single analysis. Decision-making with respect to technological choices that enhance the well-being of society by modifying the man-environment relationship, associated with risk and uncertainty, requires to take into consideration norms and practices from natural sciences and economics. Boundary organizations appear as a solution to integrate the interactions between the different sources of information involved in environmental issues. At this date, no boundary organization has taken on this exact role, but it has been suggested as a possible evolution of existing organizations, such as the European Environment Agency (Scott, 2000). As the current level of globalization increases the temporal and spatial scopes of risks, boundary organization could be an interesting solution for decision-making related to environmental issues, especially if their theoretical efficiency can be fully established.

The hypothesis that supports the existence of boundary organizations is that the resulting eased and increased interaction facilitates the attainment of dominant opinions among experts of different fields. Though never formally proved, this is accepted based on the observation of existing boundary organizations (Guston et al., 2000). Through an agent-based model, we can assess the impact of a boundary organization on the diffusion of opinions and final positioning of experts of similar and different domains. The methodology is based on simulations of opinion diffusion where experts of different fields positioned on a continuous model of opinion interact and modify their positions through series of one-to-one discussions; once the system is stabilized, we observe the number of opinions expressed, and the ratio of experts agreeing to each. A boundary organization of increasing importance is simulated to see the impact on those indicators. The model relies on a multi-agent system where autonomous heterogeneous agents interact: replicated series of experimentations over ranges of parameters allow us to observe an emerging recurrent macroscopic behavior resulting from microscopic interactions that could not be deduced by simply aggregating the properties of the agents (Axelrod & Tesfatsion, 2006). Since opinions can be more or less positive or negative, they are modeled using a continuum going from an absolute negative to an absolute positive, rather than through a binary approach. For example, positive unconditional opinions are rare as they will generally be accompanied with constraints or restrictions and be in fact more or less positive.

Opinions may also change over the entire spectrum along the process. Negative positions can be definitive, or simply temporary: they can be reviewed if new information becomes available, such as through the application of the precautionary principle, and even become positive. The model is based on work done on a single dimensional model of continuous opinion dynamics (Deffuant & al., 2001) extended over two dimensions, representing two independent fields of expertise such as natural science and economics. Agents are positioned at random over a two-dimensional graph, where each axis represents the range of possible opinions, from -100% to 100%, in each field of expertise involved. Agents a_i have a state vector X_i (opinion attributes with respect to the axes of the graph) and a state transition function f_i at a given time unit: they are identified by their coordinates x(a) and y(a) reflecting their position over the different dimensions, and are left free to interact through one-to-one exchanges at each time unit, modifying this position as a result. The choice is to rely on a model without desire, intention, or motivational function for agents, but with a belief that evolves through time with respect to interactions with other experts. Agents are reactive, with a perception-action relation and no representational function of their environment: they only show a reflex behavior with respect to their encounters, as tropic agents. They are heterogeneous agents differentiated by credibility (c) and uncertainty (u). The credibility of an agent represents how much other agents may be influenced by this agent, with respect to their own credibility. It is used as a factor, ranging from 0 to 100%, applied to the change of position, so that the sum of the credibility factor of an agent and that of its interlocutor equals 1. If we consider an agent a and its interlocutor a', the credibility effect of the agent a' over the change of position of the agent a is:

$$\left[\frac{c(a') - c(a)}{200} + 0.5\right] \quad (1)$$

The uncertainty of an agent reflects the range of accepted opinions of potential interlocutors. It acts as the maximum distance between the position of an agent a and that of its interlocutor a' so that:

$$| x(a) - x(a') | \leq u(a) \text{ for interactions over the x-axis}$$
$$\text{and} \quad | y(a) - y(a') | \leq u(a) \text{ for interactions over the y-axis} \quad (2)$$

It is also used to influence the change of opinion, based on the uncertainty of an agent over the total uncertainty of both interlocutors, so that more uncertain agents will have a greater change of position than less uncertain agents. The uncertainty effect of the agent a' over the change of position of the agent a is:

$$\left[\frac{u(a)}{u(a) + u(a')}\right] \quad (3)$$

Time units represent series of one-to-one interactions where each agent chooses an interlocutor to engage into discussion and modifies its position as a result. The maximum potential change of position is based on the capacity for an agent to adopt the position of its interlocutor. It is affected by a factor inversely proportional to the overlap between the distance separating an agent from its interlocutor and its uncertainty, so that the further away agents are, the smaller the change of position.

The resulting basic change over the x-axis for an agent a with an interlocutor a' is:

$$\left[x(a')_t - x(a)_t\right] \times \left[1 - \frac{|x(a)_t - x(a')_t|}{u(a)_t}\right] \quad (4)$$

The actual change is in fact the basic change possible, affected by the credibility and the uncertainty effects. For an interaction over the x-axis, the change of position of an agent a with an interlocutor a' would be done according to the following formula:

$$x(a)_{t+1} = x(a)_t + \left[x(a')_t - x(a)_t\right] \times \left[1 - \frac{|x(a)_t - x(a')_t|}{u(a)_t}\right] \times \left[\frac{u(a)_t}{u(a)_t + u(a')_t}\right] \times \left[\frac{c(a') - c(a)}{200} + 0.5\right] \quad (5)$$

A change over the y-axis would follow a similar formula. Due to the heterogeneity of agents, the change of position is not reciprocal, and the interaction does not imply that both agents modify their positions, since only one may lie in the zone of uncertainty of the other. In addition, the more interactions an agent has, the smaller his uncertainty becomes, so that it tends to zero, hence the stabilization of the system. The uncertainty of an agent, after it has changed its position, is modified as follows:

$$u(a)_{t+1} = u(a)_t \times \left[1 - \frac{|x(a)_{t+1} - x(a)_t|}{2 \times u(a)_t}\right] \quad (6)$$

The goal of this model is to observe the final positioning of agents representing experts interacting over an issue, and to see how it is affected by the introduction of a boundary organization. The simulation relies on NetLogo, a programmable modeling platform developed specifically for simulating both natural and social phenomena over time, making it a logical choice for a model of interaction between natural and social sciences. In addition, the Logo language relies on mobile agents called turtles who move over a grid, by modifying their direction and choosing a length of displacement, a well suited concept for simulating experts who decide to modify their position (displacement) after identifying an interlocutor (direction). Considering that NetLogo is also free of use and cross-platform, including the possibility to be embedded in web pages, it seemed the best choice, and its weaknesses with respect to the simulation capacity were not a limit for our model. The simulation involves 200 agents equally spread over two fields of expertise and is left running over 1000 time units, each time unit giving the opportunity for each agent to choose to enter into interaction with an other agent. First, only two kinds of agents (scientists and economists) are left free to interact through one-to-one exchanges in their respective field represented by each of the axes. At each time unit, each agent chooses an interlocutor of the same kind and modifies its position and uncertainty according to the equations (5) and (6). These reference results show that the two-dimensional projection is in accordance with the single-dimensional continuous opinion model used as a basis. The boundary organization is then introduced through agents called borgs: open to trans-disciplinary discussion, they are able to cross the boundary between the two axes, creating possibilities of exchange on both dimensions, while other agents remain limited to interactions within their field of expertise with similar agents. Borgs are regular agents who gain a new property, no matter what their initial position is, mainstream or minor, extreme or average, since the boundary organization must remain impartial and neutral in the debate and allow for all opinions to be expressed to maintain a high level of legitimacy. Boundary organizations could therefore not be modeled as a spatial zone, since it would reduce the diversity of opinions that could be expressed within the organization. The ratio of borgs among the total population of agents is increased from 0 to 50%, by steps of 1% from 0 to 10% and by steps of 5% beyond 10%, with ten simulations at each value. The position of experts is recorded every 10 units of time. The results are analyzed in terms of the number of opinions expressed by a group of experts representing at least 1% of the total number of agents (i.e. at least 2 agents sharing the same opinion), and the ratio of experts agreeing to each of these opinions once the positions are stabilized.

Considering the number of distinct final opinions expressed, the impact of a boundary organization of increasing importance is significant. The total number of opinions representing each at least 1% of all experts is reduced by 11% when 5% of agents are borgs; 10% of borgs represent a reduction by 22% and 30% lead to a decrease of 32%, with no variation beyond this level. The following graph shows this impact through a logarithmic regression:

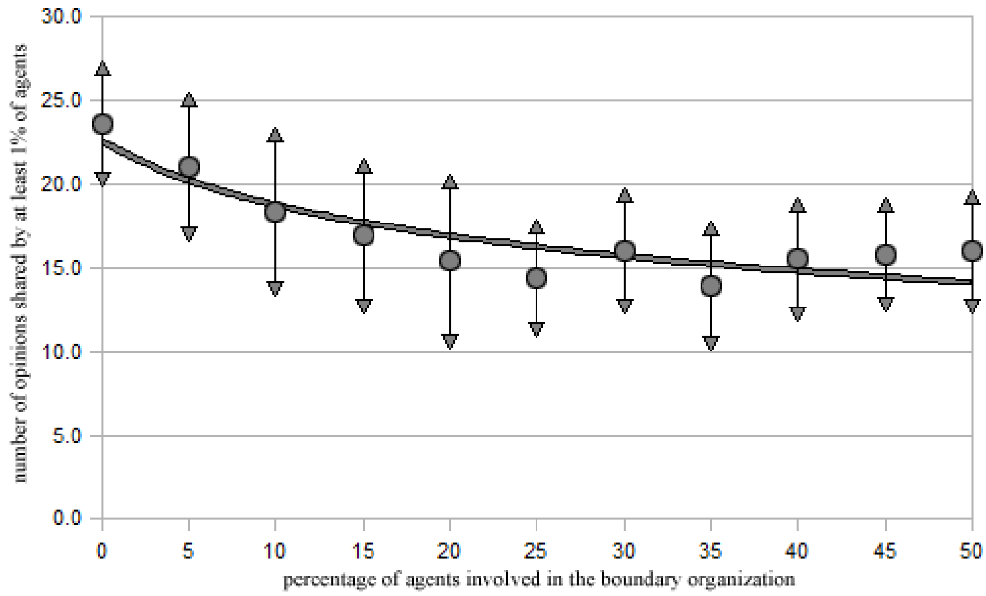

Figure 1 – Average number, standard deviation and logarithmic regression of final opinions expressed shared by at least 1% of all agents with respect to the size of the boundary organization

This global reduction of final opinions expressed is really due to a decrease of the minor opinions, i.e. distinct opinions that represent at least 1% but no more than 2% of all experts. Their number is reduced by 11% with 5% of borgs, by 31% with 10% of borgs, to reach a maximum decrease of 58%, which is represented by a logarithmic regression of greater slope on the following graph:

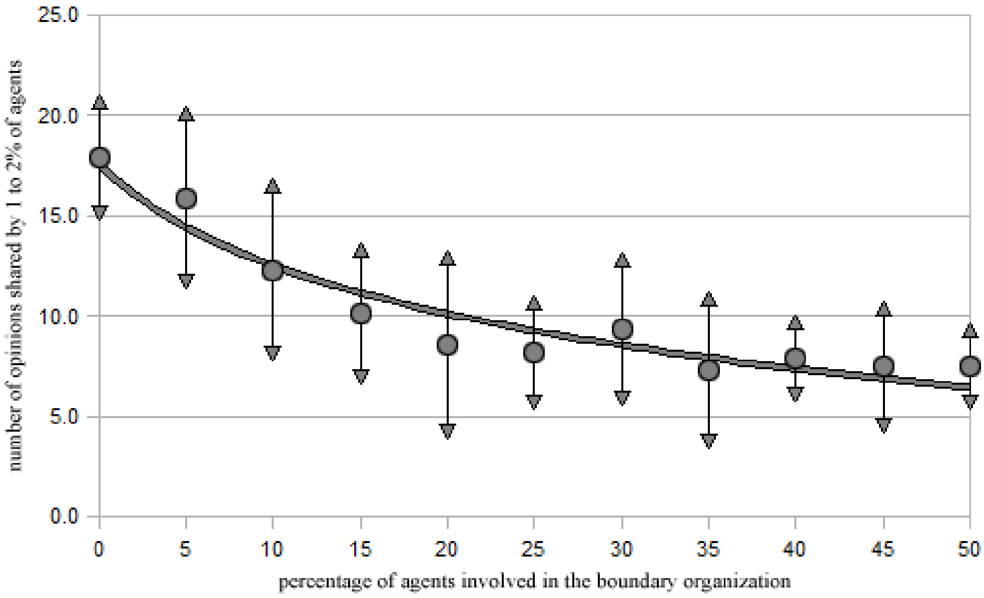

Figure 2 – Average number, standard deviation and logarithmic regression of final opinions expressed shared by 1 to 2% of all agents with respect to the size of the boundary organization

If we consider the distinct final opinions representing each at least 5% of all agents, the impact of the boundary organization is completely inverse: their number is slightly positively affected, with a linear relationship to the size of the boundary organization.

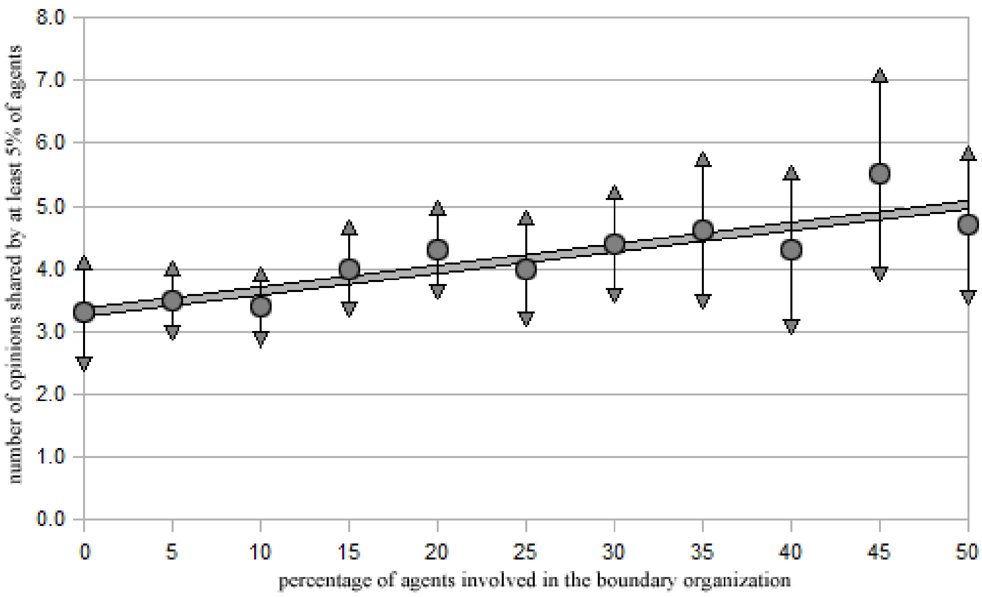

Figure 3 – Average number, standard deviation and linear regression of final opinions expressed shared by at least 5% of all agents with respect to the size of the boundary organization

The situation is similar for opinions supported by at least 10% of agents: they become slightly more numerous with a boundary organization of increasing importance.

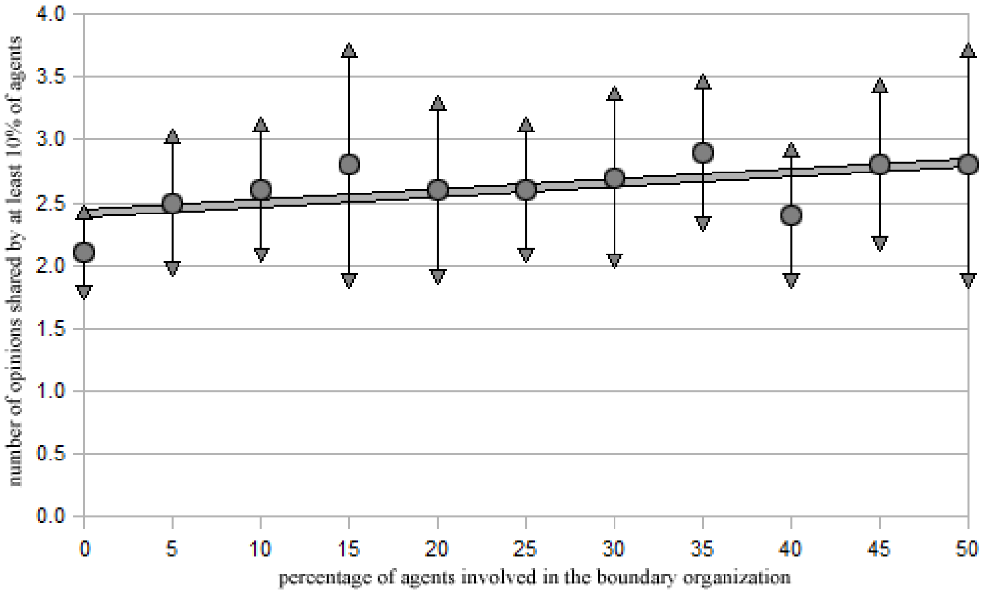

Figure 4 – Average number, standard deviation and linear regression of final opinions expressed shared by at least 10% of all agents with respect to the size of the boundary organization

The greatest positive impact is on opinions gathering at least 20% of the agents, since they can be multiplied by up to 3.

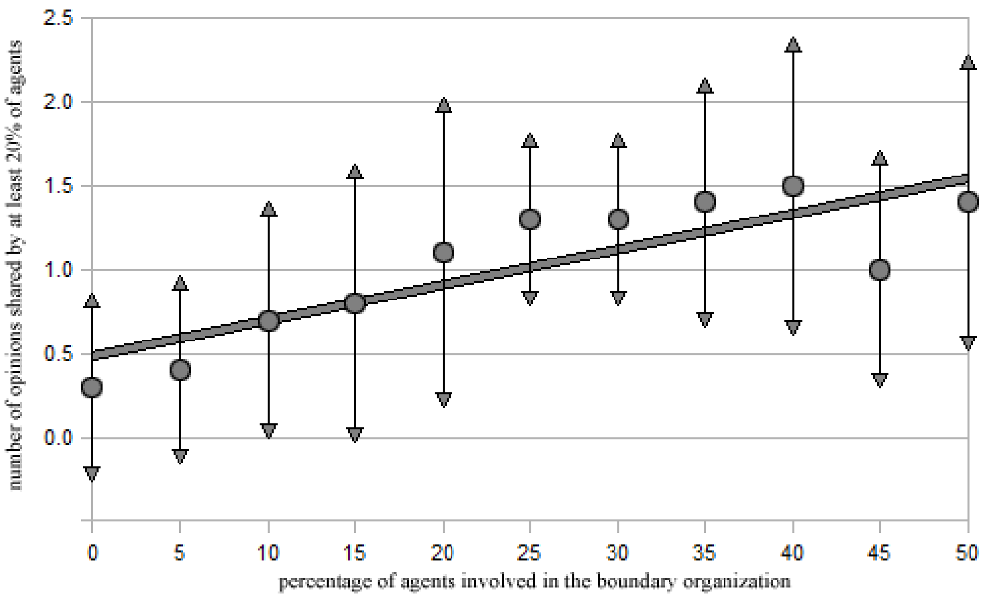

Figure 5 – Average number, standard deviation and linear regression of final opinions expressed shared by at least 20% of all agents with respect to the size of the boundary organization

The impact of a boundary organization of greater importance on the reduction of the number of final distinct opinions expressed is significant and not linear, with the stabilization of the impact at a certain level. At low realistic levels of 10 to 20% of agents involved in the boundary organization, the impact is immediate on the reduction of the number of different minor opinions expressed and on the increase of the number of opinions gathering the largest shares of experts, while average opinions are not greatly affected: the global reduction of the diversity of opinions is an apparent transfer from minor to dominant opinions. When we consider the ratio of agents agreeing to each of the final opinions expressed, the impact is significant. If we consider the dominant final opinion, 5% of borgs are sufficient to increase the number of agents agreeing by 19% to reach a maximum increase of 25%. If we consider the sum of agents agreeing to the two main opinions, the increase is reduced to 17% at 5% of borgs but reaches 23% at 10%, for a maximum of 43%. A similar situation is observed for the five main opinions with an increase of 20% at 5% of borgs and a maximum of 41%. The sum of the ten main opinions increases by 15% with 5% of borgs, by 20% with 10%, and by 35% with 20% to reach a maximum of 45%. The following graph shows the total share of agents agreeing to the 1, 2, 5 and 10 dominant opinions with respect to the size of the boundary organization.

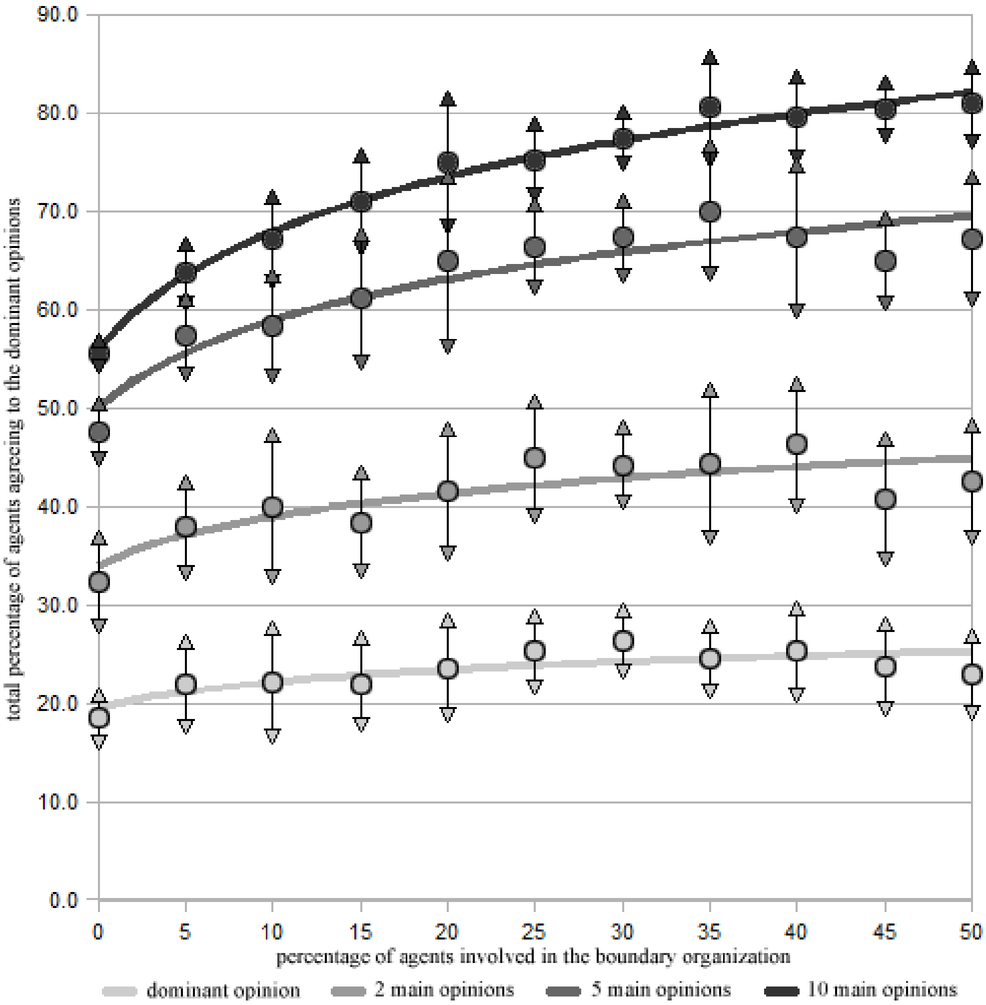

Figure 6 – Average value, standard deviation and logarithmic regression of the ratio of agents agreeing to the 1, 2, 5 and 10 main final opinions expressed with respect to the size of the boundary organization

We can confirm the impact of the boundary organization on the share of agents supporting dominant opinions by looking at the number of different opinions necessary to represent at least 50% of all agents. Without a boundary organization, we need to aggregate the 7 main opinions to represent 50% of the experts, when it requires 6 with 1% of borgs, 5 with 3%, 4 with 5% and only 3 with 15%, with no variation beyond this level. The concentration of agents around dominant opinions is significantly increased by the existence of a boundary organization.

The rising interest for boundary organizations, supported by observed successful cases, is confirmed by our agent-based model: boundary organizations do not require the involvement of a large share of experts to show a significant impact on the reduction of the diversity of final different opinions expressed and on the increase of the concentration of experts around dominant opinions, resulting in an apparent transfer from minor to major opinions. It is then easier for decision-makers to analyze the different aspects of an issue altogether: they face less opinions to consider, and are presented with more affirmed dominant opinions among the experts consulted. Boundary organizations seem to be able to increase the scale of confrontation between groups of opinion: their agents do not emerge as opinion leaders, but encourage the exchanges between experts by easing and increasing the transfer of information from one sphere to the other, which results in more affirmed positions of experts over the different dimensions of an issue.

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