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Attitude change in arbitrarily large organizations

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Abstract The alignment of collective goals and individual behavior has been extensively studied by economists under a principal-agent framework. Two main solutions have been presented: explicit incentive contracts and monitoring. These solutions correspond to changes in the objective situation faced by individuals. However, an extensive literature in social psychology provides evidence that behavior is influenced, not only by situational constraints, but also by attitudes. Therefore, an important aspect of organization is to choose the structures and procedures that best contribute to the dissemination of the desired attitudes throughout the organization. This paper studies how the initial configuration of attitudes and the size of the organization affect the optimal organizational structure and the timing of information flows when the objective is to align the members' attitudes. We identify and characterize three factors that affect the optimal organizational structures and procedures and the degree of alignment of attitudes: (1) clustering effects; (2) member cross-influence effects; and (3) leader cross-influence effects.

Keywords Organizational structure · Timing of information flows · Attitude change · Influence

1 Introduction

A fundamental issue of organization is the definition of the structures and procedures that deal efficiently with the problem of motivation, *i.e.*, that ensure that

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the different members willingly make their contribution to the cooperative activity. The motivation problem has been extensively studied in the economics literature under a principal-agent framework (*e.g.*, Ross 1973; Holmström 1982; Holmström and Milgrom 1994). The problem of aligning individual behavior and collective goals is not a trivial one, due to moral hazard. Moral hazard arises when actions which have efficiency implications are not easily observable and individuals may act in their own interest, not paying the due attention to the collective goals of the organization. Two main solutions to the motivation problem have been advanced by agency theorists. The first is an increase in the resources spent on monitoring and verification. The second consists of using explicit incentive contracts. Even if actions are not observable, contracts may be designed which are contingent upon observed outcomes, rewarding success and creating incentives for good behavior.

These two solutions have something in common. They correspond to changes in the objective situation faced by individuals and build on the idea that extrinsic incentives influence individual behavior. As explicitly recognized by several economists (*e.g.*, Radner 1992; Bernheim 1994; Kreps 1997; Gibbons 1998), behavior in organizations is determined, not only by economic incentives, but also by socio-psychological factors that affect individual preferences. These socio-psychological factors are *terra incognita* for standard microeconomics. In contrast, the concept of attitude has played a central role in the attempts of social psychologists to understand human behavior (*e.g.*, Fishbein and Ajzen 1974; Ajzen 1988; Pratkanis and Turner 1994; Kraus 1995). Attitudes are summary evaluations of persons, objects, ideas, or activities along a dimension ranging from positive to negative. As Fishbein and Ajzen point out, "there is general agreement that a person's attitude towards some object constitutes a predisposition on his part to respond to the object in a consistently favorable or unfavorable manner" (1974, p. 59).[1] To the extent that attitudes influence behavior, the objective of attaining collective goals translates into a problem of disseminating the attitudes that contribute to the attainment of those goals.

Individual attitudes are related in a systematic way to a number of things, including beliefs, values, personality and past behavior. However, members' attitudes are also affected by the attitudes of the organization members with whom they interact (*e.g.*, Weiss and Nowicki 1981; Griffin 1983). Thus, an important managerial issue is to choose the organizational structure and procedures that best contribute to the dissemination of the desired attitudes throughout the organization. In this paper, we assume that the top manager's objective is to align members' attitudes with his/her

[1] There is an extensive literature in the field of social psychology on the relationship between individual attitudes and behavior (*e.g.*, Fishbein and Ajzen 1974; Fazio 1986; Ajzen and Sexton 1999). Although some early studies, in particular the one conducted by LaPiere (1934), indicated that attitudes were largely irrelevant to the prediction of behavior, recent empirical research confirms that, in general, attitudes influence behavior (see, for an overview, Kraus 1995). However, the consistency of attitudes and behaviors has been found to depend on a number of factors, such as the level of effort required to perform a behavior (*e.g.*, Bagozzi et al. 1990), the accessibility of the attitude from memory (*e.g.*, Fazio et al. 1989), the extent to which individual behavior is susceptible to situational or interpersonal cues, as opposed to inner states or dispositions (*e.g.*, Ajzen et al. 1982), and the consistency between the affective and cognitive components of an attitude (*e.g.*, Norman 1975).

own. Clearly, there are real life situations where diversity of attitudes may be beneficial (*e.g.*, March 1996). Some degree of heterogeneity among individuals may facilitate creativity and innovation, improving the adaptive capacity of the organization. In this paper, we focus on those situations where conformity is beneficial and, as a result, the objective of the top manager is to align the members' attitudes with his/her own. For example, the top manager may be willing to disseminate a positive attitude towards customer-orientation, hard-working or social responsibility. Notice, however, that the general framework proposed in this paper can also be used to analyze the conditions under which diversity is produced. In fact, our model can be used to analyze the conditions under which the organization converges to any desired configuration of attitudes, given the initial conditions and the dynamic process of attitude change.

We do not model the impact of attitudes on behavior explicitly. Instead, we borrow from social psychology the idea that, at least under certain circumstances, attitudes influence behavior and study the impact of organization on the dynamic process of attitude change. More specifically, we take the perspective of a top manager whose objective is to choose the organizational structure and the timing of information flows that best contribute to align members' attitudes with his/her own.

We refer to *organizational structure* as the system of formal and informal communication channels that characterize an organization. Behind this notion is the recognition that important networks of informal communication often complement or bypass the systems of formal authority and the regulated channels. We identify two extreme types of organizational structures: the hierarchy and the network. Hierarchies and networks have been characterized in many ways in the literature (*e.g.*, Hummon and Fararo 1995; Carley and Lin 1997). In this paper, we use the words "hierarchy" and "network" in a very specific sense. We think of a *hierarchy* as a system in which the communication channels correspond to the links of authority that characterize the formal structure. The formal structure is composed of the set of positions in the organization, the way these positions are clustered, and the way the formal authority flows among them (*e.g.*, Mintzberg 1983). We define the *network* as an organizational structure where the communication channels corresponding to the formal links of authority are complemented by a complex system of informal relationships between organization members, so that all the members within the organization are linked. We also consider *all* the intermediate situations between these two extreme cases. A *hybrid* organization is *any* intermediate structure, where some informal relationships exist and others do not.

As pointed out by Friedkin (1993), the two components of social influence are interpersonal visibility and salience. Individual i's influence on individual j depends on j's knowledge of i's attitude. Invisible attitudes cannot be directly influential. In line with Friedkin (1993, p. 863), we assume that j knows i's attitude if i and j communicate with each other. Once j is aware of i's attitude, then i's influence on j depends on the salience or value of i's attitude for j. Irrelevant attitudes cannot directly influence j. Thus, by determining who communicates with whom, organizational structure may affect the process of attitude change within the organization. For example, in a network the top manager is able to exercise direct influence on subordinates in different levels of the organization; and the members' attitudes may reinforce each other. In contrast, in a hierarchy, the top manager contacts only his/her

direct subordinates; and the possibility of mutual reinforcement of attitudes is lessened. These two scenarios are likely to have very different implications for top managers trying to change attitudes. However, it is not clear which of these two extreme structures better facilitates change.[2]

The dynamic process of attitude change is modeled as follows. The attitude of each individual towards a given issue is assumed to be in one of two possible states: a "positive" attitude or a "negative" attitude. This assumption is justified by our focus on the alignment of attitudes. In fact, two attitudes are said to be aligned if they have the same sign, no matter their absolute values. This explains our binary characterization of attitudes. Consider an initial configuration of attitudes and a given set of interactions among organizational members. These interactions are fixed and not supposed to change over time. The attitude of each individual is affected by two different things: his/her personal values and the influence exercised by others over him/her. These two influences may reinforce each other, if aligned, or have the opposite effect. In the latter case, the stronger influence prevails. The system may or may not be in a stable situation. We say that the system is in a stable situation when the attitude of each individual is aligned with the combined impact of his/her personal values and the influence exercised by others over him/her. A model that describes how the system may evolve to a more stable configuration is the one developed in the seminal paper by Hopfield (1982) regarding the so-called *neural network*. In this paper, we use the simplest version of the neural network model to describe the dynamic process of attitude change.

The structure of the organization, as described above, defines who communicates with whom and, therefore, who influences whom. However, the evolution of attitudes within the organization also depends on the *timing of information flows*. By influencing who gets the new information first, top management may affect the order in which individuals revise their attitudes. As a consequence, attitudes do not necessarily change all at the same time. Thus, we consider two classes of dynamics of attitude change: the simultaneous dynamics and the sequential dynamics. In the simultaneous dynamics information flows quickly in the organization, so that all the members adjust their attitudes simultaneously. This scenario may be understood as corresponding to the situation where issues are discussed openly, with a high level of participation, so that attitudes change almost simultaneously. In the sequential dynamics, individuals adjust their attitudes sequentially, from the top of the organization to the bottom. This scenario may represent the situation where issues are discussed within subgroups, starting at the top of the organization.[3]

[2] We assume that all the influences are positive, meaning that all communications produce results consistent with the source attitudes. This means that when two individuals with the same attitude interact, their attitudes are reinforced. However, people have attitudes not only toward objects or ideas, but also relative to the people with whom they are communicating. According to Balance Theory (Heider 1946), at the extreme one may dislike something because a person he/she dislikes is advocating for it. Thus, influences may be negative. This issue is briefly discussed in the conclusion.

[3] Most likely, no real organization is correctly described by either of these two extreme specifications. In general, we would expect a combination of both dynamics, with some subgroups changing their attitudes simultaneously and others sequentially. However, since all the other possible dynamics are combinations of the two extreme cases, we believe that the discussion of these two cases captures the main features of the dynamics of attitude change in organizations.

The evolution of attitudes in an organization depends not only on its structure and on the timing of information flows, but also on the *initial configuration of attitudes*. Two different types of initial configurations appear to be particularly interesting: the *supported leader case* and the *non-supported leader case*. The supported leader case corresponds to the situation where at least half of the members in each organizational level have a positive attitude. The non-supported leader corresponds to the situation where, in each organizational level, the number of individuals with a positive attitude is less than the number of individuals with a negative attitude. In the discussion of the non-supported leader case, we pay special attention to the case of an isolated leader, which corresponds to the situation where a leader tries to change the attitude of the rest of the organization, which is opposed to his/her own.[4] This captures important elements of the situation often faced by top managers when initiating a change process in their organizations.[5]

In all these cases, the problem faced by the top manager is to choose the organizational structure and the timing of information flows that favor the alignment of individuals' attitudes with his/her own. This paper studies this problem in the context of organizations with an arbitrarily large number of hierarchical levels and an arbitrarily large number of individuals per level. By doing so, we overcome the limitations, pointed out by Watts (1999), associated with models with a relatively small number of members. The consideration of arbitrarily large organizations is important to ensure an accurate understanding of the forces underlying the dynamic process of influence and attitude change in organizations.

We identify three factors that determine the optimal organizational structure and the extent to which the alignment of attitudes is achieved: (1) clustering effects, *i.e.*, the existence, in the formal structure, of clusters of individuals with a given attitude that only communicate with members with the same attitude; (2) member cross-influence effects, that result from direct peer contact and from all the direct diagonal relationships and override of authority chain contacts excluding the top manager; and (3) leader cross-influence effects, that result from all the direct diagonal relationships and override of authority chain contacts including the top manager. For each initial configuration of attitudes, the interplay of these factors determines the optimal organizational structure. We show that in the supported leader case, the network is an optimal structure where consensus is attained. In contrast, in the non-supported leader case, we identify conditions under which the hierarchy dominates the network. In the specific case of an isolated leader, we specify circumstances under which the

[4]Note that the isolated leader case does not correspond to a situation where the top manager is not influenced by its subordinates, but rather to the case where he/she has initially a different attitude from the rest of the organization. Independently of the initial configuration of attitudes, we consider throughout the paper both top-down and bottom-up influences.

[5]As mentioned by Kotter and Heskett (1992), effort toward major change is often initiated by leaders who "either came into their positions from outside their firms, came to their firms after an early career somewhere else, 'grew up' outside the core of their companies or were unconventional in some other way" (1992, page 89). As a result, these leaders tend to bring with them perspectives, personal values and attitudes that are different from the ones that are dominant within their organizations. Kotter and Heskett (1992) offer an interesting description and analysis of major change processes that occurred in several large organizations. Other important references on the topic of organizational change are Kanter et al. (1992) and Jick (1993).

hierarchy is optimal, leading to the desired consensus. When analyzing the relationship between the timing of information flows and attitude change in organizations, we identify two types of situations where the choice of dynamics is irrelevant. First, this may happen because, for the initial configuration of attitudes and organizational structure considered, the system converges to the desired equilibrium, independently of the dynamics. The dynamics may also be irrelevant because the two dynamics lead to the same final equilibrium where the leader is isolated. In addition, we specify conditions under which the choice of dynamics makes a difference. In particular, we show that the sequential dynamics may dominate, or be dominated, by the simultaneous dynamics.

The paper is organized as follows. Section 2 positions our contribution in the context of the existing literature. Section 3 describes the model used to analyze the impact of organizational structure and the timing of information flows on attitudes. Section 4 presents and discusses the results. Section 5 concludes.

2 Related literature

Our paper is closely related to the research on networks of interpersonal interaction. Subsequent to the important work by Lewin (*e.g.*, 1951), several psychologists studied social influence in groups (*e.g.*, Festinger et al. 1950; Newcomb 1961; Cartwright and Zander 1968). However, as pointed out by Eagly and Chaiken (1993, p. 660), research by psychologists has been predominantly focusing on the psychological processes that mediate influence. In contrast, there is an extensive literature, developed by sociologists, on social networks (*e.g.*, Marsden 1981; Friedkin 1993; see Stokman 2001, for an overview). Recognizing that much of the real work in organizations happens despite the formal organization, this literature pays attention to the networks of relationships that individuals form while interacting. In particular, our paper is closely related to the network theory of social influence developed by Friedkin and Johnsen (*e.g.*, Friedkin 1986, 1991, 1998; Friedkin and Johnsen 1990, 1997), which builds on the early work of French (1956) and Harary (1959). These authors propose a mathematical model of social influence, where interpersonal influences occur when individuals take into account the opinions of others in the formation of their own opinions on an issue. Individual opinions result from this endogenous process of opinion formation and a number of exogenous factors. This model describes how a network of interpersonal influences enters into a process of opinion formation, and how this opinion formation process results in either a stable pattern of disagreement or group consensus.

Our model differs from the one developed by Friedkin and Johnsen in several important dimensions. First, we explicitly assume that the top manager has some degree of choice over the pattern of interactions and the order by which individuals influence each other. In this context, we analyze how the top manager is able to affect the evolution of attitudes by influencing organizational structure and the timing of information flows. Assuming that the top manager's objective is to align members' attitudes with his/her own, we discuss how the optimal choices depend on the initial configuration of attitudes. To accomplish this, we propose a model that allows for

arbitrary initial configurations of attitudes, which are treated as independent of other exogenous variables. In contrast to our work, in the models mentioned above the initial configuration of attitudes is uniquely determined by a set of exogenous variables. Second, while in the existing models the rule governing the change of opinions is typically linear, in ours the rule is highly nonlinear. This results from our emphasis on the alignment of attitudes. We say that two attitudes are aligned with each other if and only if they have the same sign. To focus on the sign of attitudes, we use a binary model, *i.e.*, a model where attitudes may be either positive or negative. This naturally implies a highly nonlinear dynamics. Third, while in Friedkin and Johnsen's model individuals revise their positions by taking weighted averages of the influential positions of other members, meaning that the weights sum up to one, we do not have to impose this restriction to ensure the convergence of the change process.[6] Finally, our analysis differs from the one proposed by these authors by explicitly considering different dynamics. In spite of acknowledging the possibility that influences are exercised sequentially (*e.g.*, Friedkin and Johnsen 1990, p. 195, footnote 3), Friedkin and Johnsen focus on the simultaneous dynamics.

The analysis presented in this paper is also related to the extensive literature that uses computational contagion models to analyze the dissemination of relevant determinants of decisions in arbitrarily large networks. For example, Harrison and Carroll (1991, 2002) propose a model of cultural transmission in organizations, Carley (1991) and Hirshman et al. (2011) use a multi-agent dynamic-network simulation model to analyze group stability and tiering effects in networks, Carroll and Burton (2001) discuss the optimal amount of coordination needed to deal with organizational complexity, Valente (2005) models the process of information diffusion, and Mungovan et al. (2011) study norm evolution in social networks. A fundamental difference between our paper and this literature is that we explicitly consider the formal links of authority that characterize an organization. This allows us to study how organizational structure—defined by the set of the formal and informal communication channels—and the timing of information flows affect the dynamics of the system. This is the distinctive contribution of our paper.[7] In our model, individuals do not have equally strong ties to all other individuals. In contrast, the influence exercised by one organizational member on another one depends on their relative hierarchical position. Although some of the papers mentioned above (*e.g.*, Harrison and Carroll 2002; Hirshman *et al.*, 2011) allow individuals to influence each other differently, such differences are based, not on their relative hierarchical position, but on homophily—the principle that like seeks like. The consideration of different organizational structures also allows us to derive our conclusions in a mathematically closed-form way, without having to rely on simulation methods, thus avoiding the

[6] In Friedkin and Johnsen's model, the assumption that individuals revise their positions by taking weighted averages of the influential positions of other members allows for the convergence of the process of opinion change.

[7] Burton and Obel (1988) also contrast different organizational forms. There are, however, two main differences to our paper. First, they focus on a different issue—the effect of opportunistic behavior on the appropriate choice of economic organization. Second, they use a laboratory experiment and, consequently, the interpretation of their results has to recognize the particular laboratory setup.

validity issues often raised about the use of computational models in organization science (Burton and Obel 1995).

There have been other attempts to model the firm's internal organization as a communication network. For instance, one of the most influential approaches to the problem of organizational design developed by economists, the theory of teams (*e.g.*, Marschak and Radner 1972; and Radner 1992), studies the efficient use of information in an informationally decentralized organization. This theory focuses on the incomplete and heterogeneous dissemination of information among the several decision makers, on the characterization of decision functions that are optimal given that decentralization and, finally, on the comparison of alternative (decentralized) information structures under the assumption that each one will be used efficiently. A related perspective on the problem of organizational design is proposed by Sah and Stiglitz (1985 and 1986). These authors look at certain aspects of an organization which they refer to as *architecture*. The architecture "describes how the constituent decision-making units are arranged together in a system, how the decision-making authority and ability is distributed within a system, who gathers what information, and who communicates what with whom" (1986, p. 716). Sah and Stiglitz compare different architectures according to the quality of decision making and conclude that the architecture affects the errors made by individuals within the system, as well as how these errors are aggregated. While these approaches to the problem of organizational design view linkages among individuals as channels through which information flows and focus on the efficient use of information or on the quality of decision making, we conceive such linkages as channels through which individuals influence each others' attitudes. Therefore, this paper provides a complementary criterion to compare different organizational forms.

3 The model

Consider an organization composed of N individuals.[8] The attitude of each individual may be described by one of two possible states, a "positive" or a "negative" attitude, depending on how the agent feels about a certain issue. The state of this organization of N individuals at a given time t is described by the vector of attitudes $(s_1(t), s_2(t), \ldots, s_N(t))$, where each $s_i = \pm 1$, $i = 1, 2, \ldots, N$ represents the attitude of an individual.[9]

Without loss of generality, we assume that the top manager's initial attitude is positive, *i.e.*, $s_1 = +1$. The initial set of attitudes is not necessarily stable: attitudes evolve over time as individuals are influenced by other members. The dynamics through

[8] A similar model has been used by Almeida Costa and Amaro de Matos (2002), focusing on very small organizations with a limited number of hierarchical levels and individuals. In the present paper, by focusing on arbitrarily large organizations we are able to provide a more complete characterization of the forces underlying the dynamic process of attitude change.

[9] Alternatively, attitudes could be modeled as continuous variables, rather than binary ones. Although such a representation of attitudes may seem more natural, it would significantly complicate the analysis. With continuous attitudes, there would be an infinite number of configurations of attitudes to be compared. As mentioned in the Introduction, our binary approach is justified by our focus on the alignment of attitudes.

which attitudes in organizations evolve depends on the pattern of interactions among individuals. The interaction between pairs of individuals is described by an $N \times N$ matrix J, where each element J_{ij} describes the influence of individual i over individual j. A positive value of J_{ij} means that a given attitude of i tends to influence j's attitude in the same direction. Conversely, a negative value of J_{ij} means that a given attitude of i tends to influence j's attitude in the opposite direction. The intensity of the influence of i over j is given by the absolute value of J_{ij}. We assume that influences are reciprocal, in the sense that if individual i influences individual j, then j also influences i.[10] In other words, $J_{ij} = 0 \Leftrightarrow J_{ji} = 0$.[11]

Consider a sequence of points in time, $t = 1, 2, 3, \ldots$. For a given set of attitudes at time t, the j-th attitude is updated at time $t + 1$ based on three factors: the attitudes of the other members at time t, the influence of each of them on j, and the strength of j's personal beliefs, values and personality. This last factor is represented by a variable α_j. The sign of this variable gives the attitude of j in the absence of influence by any of the other members. Its magnitude allows us to compare the impact of j's personal beliefs, values and personality with the strength of the influence of the others over him/her. The change of j-th attitude is assumed to occur according to the rule

$$s_j(t+1) = \text{sign}\left(\sum_i J_{ij} s_i(t) + \alpha_j\right). \tag{1}$$

Notice that s_j tends to align with the personal values α_j and with the attitudes of those who have a positive influence over j ($J_{ij} > 0$). In addition, it tends to align negatively (or disalign) with the attitudes of those who have a negative influence over j ($J_{ij} < 0$).

The rule in (1) defines how the attitude of a given member changes. It describes how the attitude of an individual at time $t+1$ is influenced by the attitudes of the other individuals at time t. We still have to specify whether the above equation applies to all individuals at the same time, or whether they update their attitudes sequentially. We consider both the simultaneous and the sequential dynamics. Under the simultaneous dynamics, everybody revises his/her attitude simultaneously. Under the sequential dynamics, attitudes are revised sequentially, according to a pre-specified order.

A set of attitudes is said to be in *equilibrium* when the configuration attains a fixed point under the specified dynamics. The relevant issue in this model is to characterize the equilibrium configuration under different conditions.

In our model, the top manager is seen as a change agent that tries to disseminate his/her attitude through the organization. In this context, it makes sense to assume

[10] Note that this assumption does not imply that the influence of i over j has the same intensity as the influence of j over i.

[11] There is an extensive literature in social psychology that analyzes influence in dyadic relationships between an influencing agent and a target (see, for an overview, Eagly and Chaiken 1993, Chap. 13, pp. 634–642). This research largely focuses on the identification of the factors that determine the power the influencing agent has to influence the target (*e.g.*, French 1956; Raven 1965; Kelman 1958, 1974; Cialdini 1988). In other words, this literature discusses the factors that determine the value of a given J_{ij}. Our focus in this paper is different. We take each J_{ij} as given, and discuss the conditions under which the dynamic system of social influence in organizations evolves to a consensus.

that the top manager's personal values and beliefs, given by α_1, are so strong that his/her attitude does not change when he/she is subject to the influence of the rest of the organization.

Under the assumption that the top manager's objective is to align members' attitudes with his/her own, we say that the optimal organizational structure is the one that maximizes the number of individuals that share the top manager's attitude, assumed to be positive. Clearly, the ideal organizational structures are those where the entire organization converts to a positive attitude. And the worst possible structures are those leading to an equilibrium where all individuals reach a negative attitude. When the system reaches an equilibrium where some individuals have a positive attitude and others have a negative attitude, the larger the number of individuals with a positive attitude, the better.[12]

The evolution of attitudes depends on the matrix of interactions, the nature of the dynamics, and the initial configuration of attitudes. We now specify each element of the model used to analyze attitude change in organizations.

3.1 Organizational structures

We consider an organization with the following formal structure. Let $l = 1, 2, \ldots, K$ label the different levels of authority. In each level l there are, say, n_l elements ordered as $i = 1, 2, \ldots, n_l$. Let $n_1 = 1$. Each individual is formally subordinated by an authority link to one individual in the next upper level $l - 1$, except, of course, when $l = 1$. Also, the i-th individual of level l is the direct superior of q_{il} individuals in the next lower level $l + 1$, except, obviously, when $l = K$. Thus, $n_{l+1} = \sum_{i=1}^{n_l} q_{il}$ for all $l \geq 1$.

The formal structure does not incorporate the informal relationships that often complement the regulated system of authority. Therefore, it may or may not correspond to the structure of communication channels within the organization. The two extreme organizational structures, the *hierarchy* and the *network*, are characterized as follows. In the hierarchy, the communication channels correspond to the formal links of authority. In particular, we define the matrix of influences J^h, where J^h_{ij} represents the intensity of the influence of individual i over individual j, as follows

$$J^h_{ij} = \begin{cases} u & \text{if } i \text{ is a direct superior of } j, \\ d & \text{if } i \text{ is a direct subordinate of } j, \\ 0 & \text{otherwise.} \end{cases}$$

As mentioned above, individual i's ability to influence individual j depends, not only on his/her interpersonal visibility, but also on the salience or value of i's attitude for

[12] When comparing the different organizational structures and the different dynamics, we just look at the final configuration, ignoring the length of the adjustment period. The sequential dynamics typically requires a larger number of interactions than the simultaneous dynamics. However, this does not imply that the length of the adjustment period in the sequential dynamics is larger. The reason is that one step of the simultaneous dynamics may take longer than one step of the sequential dynamics. In fact, in real life situations discussions involving many people at the same time may take longer than a number of discussions in small groups.

j (*e.g.*, Friedkin 1993). Irrelevant attitudes cannot directly influence j. We consider that the salience of i's attitude for j depends on their relative hierarchical position. More specifically, we assume that each element influences his or her subordinates equally, with intensity $u > 0$. For instance, the influence of the top manager on individuals in level 2 is expressed by $J^h_{1j} = u$, for $j = 1, \ldots, q_{11}$. It is also assumed that subordinates influence their direct superiors equally, with intensity $d > 0$ and $d < u$. For example, the top manager is influenced by the individuals in level 2, but with less intensity. This is expressed by $J^h_{i1} = d$, with $u > d > 0$ for $i = 1, \ldots, q_{11}$.[13]

In the network, the communication channels corresponding to the formal links of authority are complemented by a system of informal relationships. In these informal channels, individuals bypass the formal authority system in order to communicate directly. The network structure is characterized by the existence of channels of communication between *every* pair of elements, independently of the hierarchical role of these elements within the organization. This corresponds to assume three types of informal relationships: direct peer contact—individuals in the same level communicate directly rather than through their superiors; direct diagonal contact—an individual at one level of the formal structure communicates directly with the subordinates of a peer; and override of authority chain—managers are bypassed as their superior communicates directly with their subordinates. In particular, we define the matrix of influences J^n, where J^n_{ij} represents the intensity of the influence of individual i over individual j, as

$$J^n_{ij} = \begin{cases} u & \text{if } i \text{ is a superior of } j, \\ d & \text{if } i \text{ is a subordinate of } j, \\ e & \text{if } i \text{ is at the same level as } j, \\ 0 & \text{otherwise.} \end{cases}$$

Again, we assume that each element influences all the elements in lower levels equally, with intensity $u > 0$. This is expressed by $J^n_{1j} = u$ for all j. It is also assumed that every element influences all individuals in upper levels equally, with intensity $d > 0$ and $d < u$. Finally, since all relationships are considered, we include the influence among individuals within the same hierarchical level. Whatever the considered level, their reciprocal influence is assumed to be given by $e > 0$ with $e < u$.

A *hybrid structure* is any intermediate case, where some informal relationships exist and others do not. In a hybrid structure the communication channels corresponding to the formal links of authority are complemented by an *incomplete* network of informal communications. Any hybrid structure is characterized by an influence matrix J as follows. If J_{ij} is different from zero in the hierarchy, then it has the same value in any hybrid structure. At least one of the other off-diagonal elements of the J ma-

[13] The assumption that $u > d$ can also be justified by the fact that managers control several factors that may affect values, beliefs and attitudes of their subordinates (Harrison and Carroll 1991). In the same vein, the influence exercised by superiors over subordinates encompasses not only an element of conformity, whereby an agent simply follows the behavior of another agent, but also an element of obedience, which results from enforcement by an authority (Elsenbroich and Xenitidou 2012).

trix of the hybrid organization is positive, and at least one is zero. Furthermore, all non-zero elements of this matrix have the same value as in matrix J^n.[14]

3.2 Simultaneous and sequential dynamics

In this section, we describe the implementation of the different dynamics. We assume that personal values and beliefs are relatively weak, so that influences play a relevant role. Obviously, if personal values and beliefs are relatively strong, individual attitudes do not change. More specifically, we assume that $\alpha_j = 0$ for all $j > 1$. As already mentioned, we also assume that α_1 is sufficiently large for the top manager's attitude not to change.

3.2.1 Simultaneous dynamics

From (1), the total influence over element j at time t is given by

$$h_j(t) = \sum_{i=1}^{N} J_{ij} s_i(t).$$

If $h_i(t)$ is positive, the j-th element will have a positive attitude at time $t+1$; if $h_j(t)$ is negative, the j-th element will have a negative attitude at time $t+1$.

In the simultaneous dynamics all individuals revise their attitudes at the same time. Hence, at time $t+1$, $s_j(t+1) = \text{sign}\, h_j(t)$. The equilibrium configuration of attitudes at time t is given by $s_j(t)h_j(t) > 0$, for all j.

3.2.2 Sequential dynamics

In the sequential dynamics, attitudes are revised starting from the top of the formal structure to the bottom, in repeated cycles until an equilibrium is reached. We assume that, in each cycle, the sequence of attitude change in each level follows the numbering given to the individuals in that level. Let $j = t + 1 - N[\frac{t}{N}]$, where $[a]$ denotes the integer part of the real number a. For an initial configuration $\{s_1(0), s_2(0), \ldots, s_N(0)\}$, this dynamics implies that the configuration of attitudes at any future time t is given by $s_j(t) = \text{sign}\, h_j(t-1)$ and $s_i(t) = s_i(t-1), \forall i \neq j$. Equilibrium is reached at the first time t such that $s_i(t)h_i(t) > 0$, for all i. At this point in time, the attained configuration becomes invariant, by construction.

3.3 Initial configurations of attitudes

A leader who is interested in changing the configuration of attitudes prevailing in the organization may face very different situations. Two initial situations are considered: the *supported leader case* and the *non-supported leader case*. The supported

[14] These specifications can be generalized in several different ways. For example, some parameters could be negative, and different u's, d's and e's could have different values. The number of alternative scenarios is unbounded. For simplicity, we limit our analysis to the above mentioned cases.

leader case corresponds to the situation where at least half of the members in each organizational level have a positive attitude. The non-supported leader corresponds to the situation where, in each organizational level, the number of individuals with a positive attitude is less than the number of individuals with a negative attitude. In the discussion of the non-supported leader case, we pay special attention to the particular case of an isolated leader. In the isolated leader case $s_i = -1$ for $i \neq 1$ at time zero.

4 Results

We now characterize the equilibrium configuration of attitudes under different scenarios.

4.1 Supported leader

Consider first the supported leader case. In the hierarchy, for any dynamics the ability of the top manager to disseminate his/her attitude depends on the influence exercised by superiors over subordinates. In contrast, in the network the attitude of the top manager prevails independently of the dynamics and of the influence exercised by superiors over subordinates. Hence, the network is an optimal organizational structure, (weakly) dominating not only the hierarchy, but also all hybrid structures.

Proposition 4.1 *In the supported leader case, the network is an optimal structure and leads, under both dynamics, to an equilibrium where all individuals have the same attitude as the top manager.*

Proof See the Appendix. □

In the supported leader case, the informal relationships that characterize the network help the top manager in imposing his/her initial attitude. In the hierarchy, there are typically clusters of individuals with a negative attitude that do not interact with individuals having the opposite attitude. This *clustering effect* makes attitude change more difficult. In the network and in hybrid organizations, there is another effect, the *cross-influence effect*, that may help overcome this problem. This effect results from the informal relationships that characterize these organizational structures. In the network, since at least half of the members in each level have a positive attitude, the cross-influence effect leads to the diffusion of the top-manger's attitude.

It follows from this proposition that, under the optimal organizational structure, the network, the ability of the top manager to impose his/her initial attitude does not depend upon the dynamics under consideration.

Corollary 4.1 *In the supported leader case, under the network the dynamics is irrelevant.*

Proof See the Appendix. □

The key difference between the sequential dynamics and the simultaneous dynamics is that in the former individuals in upper levels revise their attitudes before exercising their influence over individuals in lower levels. In the supported leader case, under a network the order by which individuals in different levels revise their attitudes is irrelevant. Independently of the dynamics, the field felt by each individual is positive because, in each level, the number of individuals with a positive attitude is greater or equal than the number of individuals with a negative attitude and everybody communicates with everybody.

It also follows from Proposition 4.1 that, under the network, the ability of the leader to impose his/her attitude does not depend on the value of u.

Corollary 4.2 *In the supported leader case, under the network the strength of the influence exercised by superiors over subordinates is not relevant to the attainment of an equilibrium where all individuals have the same attitude as the top manager.*

Proof See the Appendix. □

To see the intuition behind this result, consider the extreme situation where the number of individuals with positive and negative attitudes is the same in each level. Since in the network everybody communicates with everybody, even in this extreme case the leader's influence always makes the difference. Therefore, the attitude of a supported top manager prevails independently of the degree of influence exercised by superiors over subordinates.

4.2 Non-supported leader

The characterization of the optimal organization in the case of a non-supported leader is more problematic. In this section, after deriving some results for the general case, we concentrate on the particular case of an isolated leader.

4.2.1 General case

In contrast with the supported leader case, here the network is not necessarily an optimal structure, leading to an equilibrium where all individuals have a positive attitude. We first identify conditions under which in equilibrium the network leads to an isolated leader.

Proposition 4.2 *In the non-supported leader case, if the influence exercised by superiors over subordinates is not sufficiently large, the network leads, under both dynamics, to an equilibrium where the leader is isolated.*

Proof See the Appendix. □

To understand the intuition for this result, we distinguish two types of cross-influence effects. The *leader cross-influence effect* corresponds to the informal relationships *including* the top manager. This encompasses all the direct diagonal relationships and override of authority chain contacts involving the top manager. The

member cross-influence effect corresponds to the informal relationships *excluding* the top manager. This includes direct peer contacts and all the direct diagonal relationships and override of authority chain contacts excluding the top manager. The informal relationships including the top manager facilitate the dissemination of his/her attitude. In contrast, since most individuals have a negative attitude, in the network the informal relationships excluding the top manager can only make attitude change more difficult. If the influence exercised by superiors over subordinates is sufficiently small, under the network the member cross-influence effect dominates the leader cross-influence effect and, as a result, the system converges to the isolated leader case.

We now establish sufficient conditions for the hierarchy to be preferred to the network. In particular, for a two-level organization, *i.e.* $K = 2$, the result is trivial. Under the assumed initial conditions of a non-supported leader, the hierarchy will always lead to a final configuration where all individuals attain a positive attitude, whereas the result in a network depends on the relative value of u/d and on the number of individuals with positive attitude in the second level. Hence, for $K = 2$ the network is the worst solution, always dominated by the hierarchy. The following Proposition establishes a sufficient condition for the hierarchy to dominate the network as a function of the number of organizational levels.

Proposition 4.3 *In the non-supported leader case, a sufficient condition for the hierarchy to be preferred to the network is that the number of levels in the organization is large enough.*

Proof See the Appendix. □

In the hierarchy, there are typically clusters of individuals with a negative attitude that do not interact with individuals having the opposite attitude. As we saw, this clustering effect makes attitude change more difficult. In the non-supported leader case, the cross-influence effect associated with the network may reinforce this problem. This happens if the combined impact of the negative informal influences each individual suffers dominates the combined impact of the positive informal influences. The larger the number of organizational levels, the stronger these negative informal influences under the network. Thus, if the number of levels is sufficiently large, the hierarchy dominates the network.

4.2.2 Isolated leader

In the isolated leader case it is possible to establish sufficient conditions under which the hierarchy is optimal. For that purpose it is convenient to derive some intermediate results. We first identify sufficient conditions for the equilibrium configuration to coincide with the initial configuration.

Lemma 4.1 *In the isolated leader case, under both dynamics a sufficient condition for any organizational structure to lead to an equilibrium with the initial configuration is that any agent in the second level has a sufficiently large span of control.*

Proof See the Appendix. □

If individuals in the second level have a sufficiently large number of subordinates, their combined influence dominates the influence exercised by the top manager. In this case, under the hierarchy the initial configuration prevails in equilibrium because the leader does not have sufficient influence to trigger attitude change in the second level in the organization. Furthermore, the cross-influence effects associated with the network or a hybrid organization do not induce attitude change. The leader cross-influence effect does not induce change because each individual below level two has a superior with a negative attitude, whose influence cancels that of the top manager. The member cross-influence effect leads to the mutual reinforcement of the initial negative attitude of the members involved.

We are now in position to establish sufficient conditions under which the hierarchy is optimal, independently of the initial configuration of attitudes.

Proposition 4.4 *If all agents have a sufficiently small span of control, then the hierarchy is at least as good as the network under both considered dynamics and for all initial configurations, leading to an equilibrium where all individuals have a positive attitude.*

Proof See the Appendix. □

The intuition is straightforward. If the maximum number of subordinates of any member is sufficiently small, the adverse clustering effect associated with the hierarchy is not an obstacle to the dissemination of the top manager's attitude. In such cases, the cross-influence effect associated with the network or a hybrid organization can only lead to the mutual reinforcement of the members' initial attitudes, making change more difficult.

We may now state the following result concerning the optimal organizational structure in the isolated leader case.

Proposition 4.5 *In the isolated leader case, the hierarchy is an optimal structure under both dynamics if all agents in the second level have the same number of subordinates and if no other agent has as many subordinates.*

Proof See the Appendix. □

Since all individuals, with the exception of the top manager, have an initial negative attitude, the member cross-influence effect makes attitude change more problematic. To understand the role of the leader cross-influence effect, it is convenient to distinguish two situations. If the level of influence exercised by superiors over subordinates is sufficiently large, the adverse clustering effect is not a problem and, as a result, the leader cross-influence effect, although strong, is unnecessary. If the influence of superiors over subordinates is sufficiently small, the leader cross-influence effect is too week to make a difference. Thus, under the conditions specified in this proposition, the hierarchy is an optimal structure.

It follows from Proposition 4.5 that, for the specified conditions, under the optimal structure the dynamics is irrelevant.

Corollary 4.3 *In the isolated leader case, if all agents in the second level have the same number of subordinates and if no other agent has as many subordinates under the hierarchy the dynamics is irrelevant.*

To understand the intuition for this result, consider the following. In the isolated leader case, under the hierarchy, if no other agent has as many subordinates as those in level two, a necessary condition for the top manager's attitude to prevail is that, in the first time individuals in level two revise their attitudes, they assume a positive attitude. In other words, either the top manager is able to change the attitude of the individuals in level 2, or it is not possible for the top manager's attitude to prevail in the organization. Furthermore, if the top manager is able to change the attitudes of all managers in level two and no other agent has as many subordinates as those in level two, the attitude of individuals in lower levels will also change, independently of the order by which individuals in different levels revise their attitudes. As a result, the dynamics is irrelevant.

In general, the ability of the top manager to change the members' attitudes depends on the level of influence exercised by superiors over subordinates. The following corollary establishes necessary and sufficient conditions for the top manager's attitude to prevail.

Corollary 4.4 *In the isolated leader case, under any organizational structure, a necessary condition for the leader to change the prevailing attitude in the organization is that the number of subordinates of individuals in the second level is sufficiently low; under the hierarchy, this is a sufficient condition. The larger the influence exercised by superiors over subordinates, the larger the required span of control for which this result holds.*

Proof See the Appendix. □

The necessary condition results from the fact that the leader has to convince at least the second-level manager who has less subordinates (all with negative attitudes). The sufficient condition under the hierarchy corresponds to the situation where any positive-attitude superior converts his/her direct subordinates, since the influence from above is larger than the aggregate influence from below.

Table 1 summarizes the main results above.

4.3 Optimal dynamics

Our results for the supported leader and isolated leader cases seem to indicate that the dynamics is irrelevant. However, depending on the initial configuration of attitudes, this may not hold. In this section, we identify conditions under which the dynamics is relevant and irrelevant, both for the network and the hierarchy.

Table 1 Optimal structure and irrelevance of dynamics

	Organizational structure	Dynamics
Supported leader	Network	Irrelevant
Non-supported leader	Hierarchy[a]	Irrelevant

[a]This result holds under the conditions specified in the proof of Proposition 4.3. In particular, it holds if the number of levels is sufficiently large

4.3.1 Relevance of the dynamics: network

In the first part of this section we identify sufficient conditions for the dynamics to be irrelevant under a network and use these conditions to explain the results in the former sections.

The results about the relevance or irrelevance of the dynamics are crucially determined by the comparison of the attitude of each individual with $H_l(t)$, a measure of the influence exercised by all organizational members over a member in a level l of the organization under a network. More specifically, we define the variable $H_l(t) = [h_{il}(t) + es_{il}(t)]/e$, where $h_{il}(t)$ is the field felt at time t by individual i in level l, and the term $es_{il}(t)$ is added to ensure that the final variable does not depend on the considered individual i. We now show that $H_l(t)$ is the same for all individuals in a given level at each point in time.

Lemma 4.2 *The measure of influence $H_l(t)$ is the same for all individuals in a given level at each point in time.*

Proof See the Appendix. □

We are now in position to derive sufficient conditions for the dynamics to be irrelevant.

Proposition 4.6 *Under a network structure, a sufficient condition for an equilibrium where all individuals have a positive attitude to arise under any dynamics is that $H_l(t) > +1$. In addition, a sufficient condition for an equilibrium where all individuals have a negative attitude to arise under any dynamics is that $H_l(t) < -1$.*

Proof See the Appendix. □

This proposition reflects the natural idea that whenever the influence exercised over all organizational members is strong, *i.e.*, either very positive or very negative, the dynamics is not relevant as it does not influence the final configuration of attitudes. The proposition also helps us to understand the results presented in Corollary 4.1, Proposition 4.2 and Lemma 4.1 about the irrelevance of the dynamics. Any supported leader configuration satisfies condition (4) in the Appendix, reflecting the first sufficient condition in the Proposition above. Also, any non-supported leader configuration satisfies condition (5) in the Appendix, reflecting the second sufficient

condition. Thus, both in Corollary 4.1 and Proposition 4.2 the dynamics is irrelevant. In particular, notice that Corollary 4.1 is a special case of Proposition 4.6. Moreover, under quite general conditions, the isolated leader configuration satisfies condition (5). This implies that also in Lemma 4.1 the dynamics is irrelevant.

We now identify a sufficient condition under which the dynamics is relevant.

Proposition 4.7 *Under a network structure, if* $H_l \in]-1, 1[$ *for all individuals in at least one level* l*, then* (*i*) *the sequential dynamics is optimal if, in each level, the first individual to revise his/her attitude has a negative attitude, and* (*ii*) *the simultaneous dynamics is optimal if, in each level, the first individual to revise his/her attitude has a positive attitude.*

Proof See the Appendix. □

In the network, any individual in level l such that the aggregate influence exercised over him/her is relatively weak, *i.e.*, $H_l \in]-1, 1[$, changes his/her attitude during the process of revision of attitude. Consider first the case where the initial attitude of individual i in level l is negative, or $s_{il}(t) = -1$. Since $H_l(t) = [h_{il}(t) + es_{il}(t)]/e$, it follows that $h_{il}(t) > 0$ and individual i will revise his/her attitude to become positive. As a result, H_l will become larger than $+1$ and the field felt by any other individual in that level will be positive. In this case, the first individual to revise his/her attitude is a "positive trigger", as he/she triggers the dissemination of a positive attitude. In a similar way, if the initial attitude is positive, *i.e.*, $s_{il}(t) = +1$, then $h_{il}(t) < 0$ and individual i will revise his/her attitude to become negative. As a result, H_l will become smaller than -1 and the field felt by any other individual in that level will be negative. In this case, the first individual to revise his/her attitude is a "negative trigger", as he/she triggers the dissemination of a negative attitude. Thus, if under a sequential dynamics the first individual to revise his/her attitude is a positive trigger, the sequential dynamics dominates the simultaneous dynamics, where all individuals revise their attitudes at the same time. In contrast, if under a sequential dynamics the first individual to revise his/her attitude is a negative trigger, the simultaneous dynamics dominates the sequential dynamics since under the simultaneous dynamics some attitudes may become positive. These results reflect the idea that the sequential dynamics is preferable if the top manager is able to induce individuals at different levels of the organization to change their attitudes in the desired direction and use them as change agents.

Table 2 summarizes our results for the dynamics under the network.

Table 2 When the dynamics is relevant under the network

	Weak aggregate influence	Strong aggregate influence
Positive trigger	Sequential	Irrelevant
Negative trigger	Simultaneous	Irrelevant

4.3.2 Relevance of the dynamics: hierarchy

We now consider the case of the hierarchy. We start by characterizing sufficient conditions under which the dynamics is irrelevant.

Proposition 4.8 *Under the hierarchy, if the maximum number of subordinates of any agent is sufficiently low, then the dynamics is irrelevant.*

Proof See the Appendix. □

This proposition proves that if the maximum span of control in the organization is sufficiently low the dynamics is irrelevant, because all final attitudes become positive independently of the dynamics.[15] We now show that the dynamics may also be irrelevant even if there are individuals in the organization with a larger span of control, provided that some additional conditions are satisfied.

Proposition 4.9 *Under the hierarchy, if the number of subordinates of any agent is large, the dynamics is irrelevant provided that each individual has a sufficiently large number of subordinates with a negative attitude.*

Proof See the Appendix. □

This proposition shows that, if some individuals in the organization have a large span of control, a sufficiently large number of subordinates with a negative attitude ensures that all final attitudes become negative independently of the dynamics.

There are situations where the dynamics may not be indifferent, i.e., situations where we cannot guarantee that the attitudes under the simultaneous and the sequential dynamics will be the same. The next proposition identifies conditions under which the choice of dynamics makes a difference. In particular, it specifies conditions under which, independently of the initial configuration of attitudes, under the sequential dynamics all individuals end up with a positive attitude, while under the simultaneous dynamics this is not necessarily the case.

Proposition 4.10 *Under the hierarchy, if the number of subordinates of any agent is large, the dynamics is relevant provided that each individual has a sufficiently small number of subordinates with a negative attitude.*

Proof See the Appendix. □

Under the sequential dynamics, the positive attitude of the top manager guarantees the dissemination of his/her attitude throughout the organization. In the first step of the dynamics the top manager induces a positive attitude on all his/her direct subordinates, since the number of subordinates with a negative attitude is limited. In the

[15] Note that the sufficient conditions in Lemma 4.1 and Proposition 4.4 coincide with the sufficient condition in this proposition. This explains why those results do not depend on the dynamics.

Table 3 When the dynamics is relevant under the hierarchy

	Large span of control	Low span of control
Large relative n° neg. subordinates	Irrelevant	Irrelevant
Low relative n° neg. subordinates	Relevant dynamics	Irrelevant

second step each of those subordinates induces a positive attitude on all of his/her own subordinates, and so on. Under the simultaneous dynamics, although the second level of the organization will convert entirely to the positive attitude (as in the sequential dynamics), not all elements in the third level will necessarily be contaminated by that positive attitude. The reason is that the first step of the simultaneous dynamics may increase significantly the number of fourth-level agents with negative attitudes.

Table 3 summarizes our results for the dynamics under the hierarchy.

5 Conclusion

In this paper, we use a formal model to analyze the dynamic process of attitude transmission and change in organizations. As suggested by Harrison and Carroll (1991: 554), there are important managerial reasons to study the processes of influence in organizations, since managers have some degree of control over their main determinants (see also Schein 1985; O'Reilly 1989). In particular, we focus on the problem faced by top management of choosing the organizational structure and the timing of information flows that favor the dissemination of the desired attitudes throughout the organization. We identify three underlying factors that determine the optimal organizational structure and the extent to which the alignment of attitudes is achieved: (1) clustering effects, *i.e.*, the existence, in the formal structure, of clusters of individuals with a given attitude that only communicate with members with the same attitude; (2) member cross-influence effects, that result from direct peer contact and from all the direct diagonal relationships and override of authority chain contacts excluding the top manager; and (3) leader cross-influence effects, that result from all the direct diagonal relationships and override of authority chain contacts including the top manager. For each initial configuration of attitudes, the interplay of these factors determines the optimal organizational structure.

More specifically, we show that in the supported leader case, the network is an optimal structure where consensus is attained. While in the hierarchy clustering effects typically make attitude change more difficult, the leader and member cross-influence effects associated with the network help overcome this problem, because at least half of the members in each level have a positive attitude. This result is consistent with the idea that the socialization process can be managed to intensify the dissemination of a given corporate culture throughout the organization (e.g., Schein 1985; O'Reilly 1989; Harrison and Carroll 1991). In contrast, in the non-supported leader case, we identify conditions under which the hierarchy dominates the network. In this case, since the number of individuals with a negative attitude is at least the same as the number of individuals with a positive attitude, the cross-influence effects associated with the network may reinforce the problems due to the clustering effect. This

happens if the member cross-influence effect dominates the leader cross-influence effect. Furthermore, in the specific case of an isolated leader, we identify conditions under which the hierarchy is optimal, leading to the desired consensus. When all individuals, with the exception of the top manager, have an initial negative attitude, the member cross-influence effect makes attitude change more problematic. To understand the role of the leader cross-influence effect, it is convenient to distinguish two situations. If the influence exercised by the top manager, when interacting with subordinates, is sufficiently large, the adverse clustering effect is not a problem and, as a result, the leader cross-influence effect, although strong, is unnecessary. If the influence exercised by the top manager is sufficiently small, the leader cross-influence effect is irrelevant.

Carroll and Burton (2001) find that structures that are highly connected (analogous to what is here defined as networks) may perform much worse than those with a lower level of connection (analogous to what is here defined as hierarchies) when undertaking complex task assignments. While Carroll and Burton focus on the impact of complexity in the choice of the optimal organizational structure, we study how the dynamic process of attitude dissemination affects this choice. Interestingly, in our model the hierarchy does not necessarily dominate the network. As mentioned above, the higher level of socialization associated with the network may facilitate the dissemination of the desired attitude throughout the organization. A similar result is obtained by Mungovan et al. (2011) using a different dynamic model of norm evolution in social networks. These authors also find that increasing the frequency of interactions results in higher levels of convergence.

We also analyze the relationship between the timing of information flows and attitude change in organizations. We identify two types of situations where the choice of dynamics is irrelevant. First, this may happen because, for the initial configuration of attitudes and organizational structure considered, the system converges to the desired equilibrium, independently of the dynamics. The dynamics may also be irrelevant because the two dynamics lead to the same final equilibrium where the leader is isolated. In addition, we specify conditions under which the choice of dynamics makes a difference. By influencing the degree of participation and the order by which individuals revise their attitudes, the top manager may influence the equilibrium configuration of attitudes. In particular, we show that, depending on the order by which individuals in a given level revise their attitudes, the sequential dynamics may dominate, or be dominated, by the simultaneous dynamics. This means that the choice of dynamics is a non-trivial problem deserving careful attention. Our results may have interesting implications for the network theory of social influence developed by Friedkin and Johnsen (*e.g.*, Friedkin 1986, 1991, 1998; Friedkin and Johnsen 1990, 1997). In spite of acknowledging the possibility that influences are exercised sequentially, these authors focus on the simultaneous dynamics. Although our model and the one proposed by Friedkin and Johnsen are different, our results about the relevance of the dynamics seem to suggest that further work is required to analyze the implications of different dynamics, also in the context of their network theory of social influence.

This paper complements the extensive literature that uses computational contagion models to analyze the dissemination of relevant determinants of decisions in arbitrarily large networks (Carley 1991; Harrison and Carroll, 1991, 2002; Carroll

and Burton 2001; Valente 2005; Hirshman et al. 2011; and Mungovan et al. 2011). There are two main differences between our paper and this literature. First, we explicitly model the formal links of authority that characterize an organization. This allows us to study how organizational structure and the timing of information flows affect the dynamics of the attitude change. In our model, individuals do not have equally strong ties to all other individuals. In contrast, the influence exercised by one organizational member on another one depends on their relative hierarchical position. Second, in the vein of the network theory of social influence developed by Friedkin and Johnsen (*e.g.*, Friedkin 1986, 1991, 1998; Friedkin and Johnsen 1990, 1997), we derive our conclusions in a mathematically closed-form way, without having to rely on simulation methods. Our methodology not only avoids the validity issues often raised about the use of computational models in organization science (Burton and Obel 1995), but also allows us to identify—through the analysis of the mechanisms of the proofs of the different results—the underlying factors that determine the optimal organizational structure.

The model considered in this paper may be extended in several ways. One possibility is to consider a model where, in addition to the top manager, some other members do not change their initial attitude during the dynamic process, regardless of the influences exercised over them. In fact, in many change processes in real life, some organizational members have such strong convictions that it does not seem reasonable to expect their attitudes to change by the influence of other members. In our model this would correspond to a situation where some individuals have strong personal values and beliefs or, in other words, a large value for α. The relevant questions are under what conditions it is beneficial to have some members with 'strong personalities' and where they should be 'located' (near the top, spread around the organization, etc.).

Another possible extension is to consider some negative influences in the organization. In this paper, we assume that all the influences are positive, meaning that when two individuals with equal attitudes interact, their attitudes are reinforced. If negative influences are considered, then the opposite effect is produced: when two individuals with equal attitudes interact, their attitudes tend to disalign. This negative influence may arise in real organizations from the existence of competition, distrust, animosity or sense of separate identity between pairs of individuals. In our model this situation corresponds to making some parameters J_{ij} negative.

This paper may also be extended by assuming that attitude change is not deterministic. In our model, we assume that the change of j-th attitude occurs according to the rule given in (1) with certainty. Alternatively, one may consider that influences create nothing more than a predisposition for attitude maintenance or change, so that attitudes may or may not evolve according to the rule given by (1). Non-deterministic behavior is caused by noise originated, for example, by misunderstandings. This situation may be modeled by assigning a probability $p > 1/2$ to the attitude given by the rule in (1) and $1 - p$ to the opposite attitude. It may also be interesting to study the situation where, *ex-ante*, each individual in the organization (except the top manager) has an equal probability of having either a negative or a positive attitude. This would force a discussion of the optimality of the various structures and dynamics when the precise "location" of attitudes is not known ex-ante.

An additional extension would be to consider that individuals influence each other strategically. When there are executives and managers with authority to make discretionary decisions, affected employees may try to influence their decisions. Several authors have studied the ways in which careful organizational choices can, at least partially, control the direct costs of influence activities (*e.g.*, Holmström and Ricart i Costa 1986; Milgrom 1988). A related question is how the attempt to influence the organization's decisions affects the dynamic process of social influence and attitude change. Building on the social exchange model proposed by Coleman (1972, 1973), Marsden (1981) proposes a model where individuals may influence each other strategically, in the pursuit of their individual goals. However, his model does not incorporate a dynamic process of influence. In fact, he assumes that individuals influence each other only once, and does not study how the repeated interplay of the influence process leads to an equilibrium configuration of interests. For simplicity, we ignore this kind of strategic behavior, assuming that any chosen organizational structure determines the matrix J. Notice, however, that much observed behavior in organizations is not truly strategic. Attitudes often change simply because individuals understand and are influenced by how others *really* evaluate a given object. In this perspective, this paper studies how this kind of influence depends on the system of communication channels and on the timing of information flows that characterize an organization.

Appendix

In this appendix, we present the proofs of our results.

Proof of Proposition 4.1 In the network, the i-th individual of level l is under a field

$$\begin{aligned} h_{il} &= u\sum_{k<l}\left(n_k^+ - n_k^-\right) + e\left(n_l^+ - n_l^- - s_{il}\right) + d\sum_{k>l}\left(n_k^+ - n_k^-\right) \\ &= (u - es_{il}) + u\sum_{1<k<l}\left(n_k^+ - n_k^-\right) + e\left(n_l^+ - n_l^-\right) + d\sum_{k>l}\left(n_k^+ - n_k^-\right), \end{aligned} \tag{2}$$

where n_k^+ and n_k^- denote the number of individuals at level k starting with a positive and negative attitude, respectively. Since $u > e$, the assumption that $n_i^+ > n_i^-$ for all i ensures that $h_{il} > 0$ for all i and l. Thus, no matter what dynamics is used, the number of positive attitudes increases until all individuals assume a positive attitude. □

Proof of Corollary 4.1 Follows from the proof of Proposition 4.1. □

Proof of Corollary 4.2 Follows from the proof of Proposition 4.1. □

Proof of Proposition 4.2 For $K > 2$, from (2), it follows that $h_{il} < 0$ under the assumed conditions, since $n_k^+ - n_k^- < 0$ for all $k > 1$. For $l = 2$, the field reads $h_{i2}^n = (u - es_{i2}) + e(n_2^+ - n_2^-) + d\sum_{k>2}^{K}(n_k^+ - n_k^-)$ and, if $u < (K-2)d$, the result follows no matter what dynamics is used. □

Proof of Proposition 4.3 Under the hierarchy

$$h_{il}^{h}(t) = us_{p,l-1}(t) + d\sum_{k=\eta_{il}+1}^{\eta_{il}+q_{il}} s_{k,l+1}(t) \tag{3}$$

with $\eta_{il} = \sum_{k=1}^{i-1} q_{kl}$ and p denoting the superior of i. Notice that, by construction, for $l > 2$, we have $h_{il}^{h}(t) > -u - dq_{il}$. For $l = 2$, we have $h_{i2}^{h}(t) > u - dq_{i2}$. Under the network, we have from expression (2)

$$h_{il}^{n} = u\sum_{k<l}\left(n_k^+ - n_k^-\right) + e\left(n_l^+ - n_l^- - s_{il}\right) + d\sum_{k>l}\left(n_k^+ - n_k^-\right).$$

For $l > 2$, we have $\sum_{k<l}(n_k^+ - n_k^-) \leq 3 - l$, $(n_l^+ - n_l^- - s_{il}) \leq 0$ and $\sum_{k>l}(n_k^+ - n_k^-) \leq -(K - l)$. Hence $h_{il}^{n} \leq -d(K-3) - (u-d)(l-3)$. For $l = 2$, the field reads

$$h_{i2}^{n} = (u - es_{i2}) + e\left(n_2^+ - n_2^-\right) + d\sum_{k>2}^{K}\left(n_k^+ - n_k^-\right) \leq u - d(K-2).$$

A sufficient condition for $h_{il}^{h}(t) \geq h_{il}^{n}$ is that

$$q_{i2} \leq K - 2,$$

and for $l > 2$,

$$q_{il} \leq -\frac{u}{d} + (K-3).$$

If both conditions above are satisfied, the hierarchy is preferred to the network. From the result above, we know that a sufficient condition is that $q_{il} \leq \max[K-2, -\frac{u}{d} + (K-3)]$. Since $K - 2 > -\frac{u}{d} + (K-3) > K - 4$, it follows that the hierarchy is preferred to the network if $K > q^* + 4$, where q^* denotes the maximum number of subordinates of any agent in the organization. □

Proof of Lemma 4.1 In the network, we know from (2) that

$$h_{il}^{n} = (u - es_{il}) + u\sum_{1<k<l}\left(n_k^+ - n_k^-\right) + e\left(n_l^+ - n_l^-\right) + d\sum_{i>l}\left(n_k^+ - n_k^-\right).$$

Since in this case $n_k^+ = 0$ and $n_k^- = n$ and $s_{il} = -1$ for all $i > 1$, we have

$$\begin{aligned} h_{il}^{n} &= (u+e) - u\sum_{1<k<l} n_k - en_l - d\sum_{k>l} n_k \\ &= u\left(1 - \sum_{1<k<l} n_k\right) + e(1-n_l) - d\sum_{k>l} n_k. \end{aligned}$$

Since $1 - \sum_{1<k<l} n_k < 0$ for $l > 2$ and $n_l \geq 1$, we have $h_{il} < 0$ for all $l > 2$. For $l = 2$,

$$h_{i2}^n = u + e(1 - n_2) - d \sum_{k>2} n_k.$$

Let $q_l^m = \min_i q_{il}$ denote the minimum number of subordinates of any agent in level l. Since $\sum_{k>2} n_k \geq q_2^m$ and $n_2 > 1$, we have $h_{i2}^n < 0$, leading to our result. In the hierarchy, (3) and $u \leq q_2^m d$ imply negative fields for all individuals. A hybrid organization can be seen as a hierarchy plus some informal links. For the case of an arbitrary individual in the second level, the initial field under the hierarchy is $h_{i2}^h(0) = u - dq_{i2}$. Under a hybrid structure it is $h_{i2}^{hyb}(0) = u - dq_{i2} - dn_{i2}$, where $n_{i2} \geq 0$ denotes the number of informal links associated with that particular individual. Thus, for $u \leq q_2^m d$, no individual in the second level changes attitude. Similarly, no individual in lower levels will change attitude, since

$$h_{il}^{hyb}(0) = -u - dq_{il} - dn_{il}^d - en_{il}^e - un_{il}^u + u\delta_{il},$$

where $n_{il}^d \geq 0$ denotes the number of informal links with individuals in lower levels, $n_{il}^e \geq 0$ denotes the number of informal links with individuals in the same level, $n_{il}^u \geq 0$ denotes the number of informal links with individuals in higher levels (except the top manager), and δ_{il} is equal to 1 if there is a direct link to the top manager and zero otherwise. This concludes the proof. □

Proof of Proposition 4.4 Define $q^* = \max_l q_l^*$ as the maximum number of subordinates of any individual in the organization. Under the hierarchy, the field felt by any individual is given by (3). Notice that, by construction,

$$\sum_{k=\eta_{il}+1}^{\eta_{il}+q_{il}} s_{k,l+1}(t) \geq -q_{il} \geq -q^* \quad \Longrightarrow \quad h_{il}(t) \geq u s_{p,l-1}(t) - q^* d.$$

Since $s_{11} = +1$, $u > q^* d$ implies $h_{i2}(t) > 0$ for all $i = 1, \ldots, n_2$ and for all $t \geq 0$. Consider first the sequential dynamics starting at $t = 0$. For $t \geq n_2$, we have $s_{i2}(t) = +1, \forall i$, leading to $h_{i3}(t) > 0$ for all $i = 1, \ldots, n_3$. In general, if $t \geq \sum_{k=2}^{\nu} n_k$, we have $s_{ik}(t) = +1, \forall i$, for all $k \leq \nu$. Hence, at $t = N$ the system attains the fixed point configuration where all individuals have positive attitudes. In the simultaneous dynamics, all individuals in $l = 2$ become positive at $t = 1$. For the same reason, in the next step of the dynamics all individuals in $l = 3$ become positive. The process goes on until all individuals become positive at $t = K$. □

Proof of Proposition 4.5 If $u > q^* d$, from Proposition 4.4 the hierarchy is optimal under both considered dynamics, leading to an equilibrium where all individuals have a positive attitude. If $u \leq q_2^m d$, we know from Lemma 4.1 that, under both dynamics, the equilibrium configuration will be the one where the leader is isolated, independently of the organizational structure. Since by assumption $q_2^m = q^*$, this concludes the proof of our statement for all values of u. □

Proof of Corollary 4.4 Follows from Lemma 4.1 and from Proposition 4.4. □

Proof of Lemma 4.2 Under the network, the field felt by individual i in level l is given by

$$h_{il}(t) = u\sum_{k<l}\left[n_k^+(t) - n_k^-(t)\right] + e\left[n_l^+(t) - n_l^-(t) - s_{il}(t)\right] + d\sum_{k>l}\left[n_k^+(t) - n_k^-(t)\right].$$

Let $\Delta_k(t) = n_k^+(t) - n_k^-(t)$ and note that

$$h_{il}(t) > 0 \iff s_{il} < \frac{u}{e}\sum_{k<l}\Delta_k(t) + \Delta_l(t) + \frac{d}{e}\sum_{k>l}\Delta_k(t),$$

$$h_{il}(t) < 0 \iff s_{il} > \frac{u}{e}\sum_{k<l}\Delta_k(t) + \Delta_l(t) + \frac{d}{e}\sum_{k>l}\Delta_k(t).$$

For simplicity, we introduce the following notation

$$\Delta(t) = \sum_k \Delta_k(t); \qquad \hat{\Delta}_l(t) = \sum_{k<l}\Delta_k(t); \qquad \check{\Delta}_l(t) = \sum_{k>l}\Delta_k(t).$$

Furthermore, assume $\alpha \equiv u/e$ and, for simplicity, $\gamma \equiv d/e \geq 1$. Under this specification, the two conditions above simplify to

$$h_{il}(t) \geq 0 \iff s_{il}(t) \leq H_l(t),$$

$$h_{il}(t) \leq 0 \iff s_{il}(t) \geq H_l(t),$$

where

$$H_l(t) = (\alpha - 1)\hat{\Delta}_l(t) + (\gamma - 1)\check{\Delta}_l(t) + \Delta(t),$$

and by construction does not depend on i. □

Proof of Proposition 4.6 The sufficient conditions in this proposition are

$$H_l(t) \geq +1, \quad \forall l > 1 \tag{4}$$

for the first part and

$$H_l(t) \leq -1, \quad \forall l > 1 \tag{5}$$

for the second part. Since $s_{il}(t) \in \{-1, +1\}$, we have that if $H_l(t) \geq +1$ for a given level l, then $h_{il} \geq 0$ for all individuals in that level. Similarly, if $H_l(t) \leq -1$ for a given level l, then $h_{il} \leq 0$ for all individuals in that level. Under condition (4) it follows that $h_{il} \geq 0, \forall l$, and any dynamics implies $\Delta(t+1) \geq \Delta(t)$, leading to an equilibrium where all individuals have a positive attitude. From condition (5) it

follows that $h_{il} \leq 0, \forall l$, and any dynamics implies $\Delta(t+1) \leq \Delta(t)$, leading to an equilibrium where the leader is isolated. □

Proof of Proposition 4.7 Consider an arbitrary level l. Under the simultaneous dynamics, we have the following three possibilities

$$\begin{aligned} H_l \geq +1 \quad &\Longrightarrow \quad n_l^+(t+1) = n_l^+(t) + n_l^-(t) \equiv n_l, \\ H_l \in \,]-1,1[\quad &\Longrightarrow \quad n_l^+(t+1) = n_l^-(t), \\ H_l \leq -1 \quad &\Longrightarrow \quad n_l^+(t+1) = 0. \end{aligned}$$

Under the sequential dynamics, starting with an individual with a positive attitude, we get for $n_l \geq \tau > 0$

$$\begin{aligned} H_l \geq +1 \quad &\Longrightarrow \quad n_l^+(t+\tau) = n_l^+(t) + \max\{\tau - n_l^+(t), 0\} \to n_l, \\ H_l \in \,]-1,1[\quad &\Longrightarrow \quad n_l^+(t+\tau) = \max\{0, n_l^+(t+\tau-1) - 1\} \to 0, \\ H_l \leq -1 \quad &\Longrightarrow \quad n_l^+(t+\tau) = \max\{0, n_l^+(t+\tau-1) - 1\} \to 0. \end{aligned}$$

Under the sequential dynamics, starting with an individual with a negative attitude, we get for $n_l \geq \tau > 0$

$$\begin{aligned} H_l \geq +1 \quad &\Longrightarrow \quad n_l^+(t+\tau) = n_l^+(t) + \max\{\tau - n_l^+(t), 0\} \to n_l, \\ H_l \in \,]-1,1[\quad &\Longrightarrow \quad n_l^+(t+\tau) = \min\{n_l, n_l^+(t+\tau-1) + 1\} \to n_l, \\ H_l \leq -1 \quad &\Longrightarrow \quad n_l^+(t+\tau) = \max\{0, n_l^+(t+\tau-1) - 1\} \to 0. \end{aligned}$$

Therefore, due to the levels where $H_l \in \,]-1,1[$, the sequential dynamics starting with an individual with a negative attitude is preferred to the simultaneous dynamics, which, in turn, is preferred to the sequential dynamics starting with an individual with a positive attitude. □

Proof of Proposition 4.8 It is convenient to start by characterizing what happens with the attitude of an arbitrary individual under both dynamics.

The field felt by individual i in level l, given by (3), can be rewritten as

$$h_{il}(t) = u s_{p,l-1}(t) + d \sum^{i,l} s_{k,l+1}(t),$$

where $\sum^{i,l}$ denotes the sum over all subordinates of individual i at level l, and p denotes his/her superior. Let q_{il} denote the total number of direct subordinates, $n_{il}^+(t)$ denote the number of subordinates with a positive attitude at time t, and $n_{il}^-(t)$ denote the number of subordinates with a negative attitude. Then,

$$n_{il}^+(t) + n_{il}^-(t) = q_{il}$$

and the field above can be rewritten as

$$h_{il}(t) = u s_{p,l-1}(t) + d\big[n_{il}^+(t) - n_{il}^-(t)\big].$$

Also, let q^* denote the maximum number of subordinates that any agent has in the organization, *i.e.*,

$$q^* = \max_l q_l^* = \max_l \Big\{ \max_i q_{il} \Big\}.$$

We first characterize what happens with an arbitrary individual in a hierarchy under the sequential dynamics. Since there are no same-level peer interactions in a hierarchy, we assume, without loss of generality, a dynamics that revises the attitudes of all individuals in each level at the same time. Assume that individual i in level l revises his/her attitude at $t+1$. Then,

$$\begin{aligned} s_{il}^{seq}(t+2) &= \operatorname{sign}\Big[us_{p,l-1}(t) + d \sum^{i,l} s_{k,l+1}(t) \Big] \\ &= \operatorname{sign}\big\{ us_{p,l-1}(t) + d\big[n_{il}^+(t) - n_{il}^-(t) \big] \big\}. \end{aligned} \tag{6}$$

Consider now the simultaneous dynamics. For an arbitrary individual i in an arbitrary level l, we have in the second step of the dynamics

$$\begin{aligned} s_{il}^{sim}(t+2) &= \operatorname{sign}\left[us_{pl-1}(t+1) + d \sum^{i,l} s_{kl+1}(t+1) \right] \\ &= \operatorname{sign}\left[u \operatorname{sign} h_{pl-1}(t) + d \sum^{i,l} \operatorname{sign} h_{kl+1}(t) \right]. \end{aligned} \tag{7}$$

The result of the proposition follows from the comparison of these two equations.

Consider an individual i in level l, whose superior has a positive attitude and does not change it, *i.e.*, $s_{p,l-1}(t) = s_{p,l-1}(t+1) = +1$. Under the assumption that $q_{il} \le q^* < u/d$, it follows from (6) and (7) that $s_{i,l}(t+2) = +1$ under both dynamics. Each of its subordinates will then have a superior with a positive attitude in the next step of the dynamics and the argument applies again until all agents under the initial superior attains a positive attitude. Since the head of the organization (the individual in $l = 1$) has a positive attitude at time $t = 0$ that does not change by design, the argument may apply initially to each of the individuals in level $l = 2$ and then for all other levels. Since the argument does not depend on the dynamics, the result follows.

In the case where $q^* = u/d$, the above argument follows obviously for every individual i in level l such that $q_{il} < q^*$. Let us focus on the first individual such that $q_{il} = q^* = u/d$. Knowing that his/her superior has attained a positive attitude at some point under either dynamics, we consider three cases.

- If at least one of his subordinates has a positive attitude. It follows that $n_{il}^+(t) > 0 \Rightarrow h_{il}(t) > 0$ and the above argument still holds for both dynamics, leading to $s_{il}(t+1) = +1$. This clearly implies that $s_{il}(t+2) = +1$ under both dynamics, since the worst that may happen is that in the simultaneous dynamics all his/her subordinates have changed into negative attitudes at $t+1$, leading to a null resulting field and $s_{il}^{sim}(t+2) = s_{il}^{seq}(t+2) = +1$. However, we are left to show that if $n_{il}^+ = 0$, his/her final attitude does not depend on the dynamics. This leads to the two following cases.

- If the focal individual has a positive attitude $s_{i,l}(t) = +1$ and all his/her subordinates have a negative attitude, then $n_{il}^{+}(t) = 0 \Rightarrow h_{il}(t) = 0 \Rightarrow s_{il}(t+1) = +1$ under both dynamics, by the argument just described.
- If the focal individual has a negative attitude $s_{i,l}(t) = -1$ and all his/her subordinates have a negative attitude, then for the sequential dynamics $n_{il}^{+}(t) = 0 \Rightarrow s_{il}^{seq}(t+2) = -1$. Notice that in the sequential dynamics all the subordinates of the focal individual will remain with negative attitudes in subsequent times since they have *at most* q^* subordinates themselves (by definition of q^*) and even if all these have a positive attitude, the fact that $u = q^* d$ constrains change. This same argument applies in the case of the simultaneous dynamics. Here, either $\text{sign} h_{kl+1}(t) = s_{k,l+1}(t+1) = -1$ for all the subordinates of the focal individual and $s_{il}^{sim}(t+2) = s_{il}^{seq}(t+2)$ from (7) and (6), or $h_{kl+1}(t) = 0$ for some subordinate, leaving its attitude $s_{k,l+1}(t+1) = -1$ negative and sustaining $s_{il}^{sim}(t+2) = s_{il}^{seq}(t+2)$.

This concludes our proof. □

Proof of Proposition 4.9 We show that under the hierarchy if the number of subordinates of any agent is larger than u/d and the maximum span q^* is strictly larger than u/d, a sufficient condition for the dynamics to be irrelevant is that, for all agents, the number of subordinates with a negative attitude is larger than half of the sum of u/d with the number of subordinates, i.e., $n_{il}^{-} > \frac{1}{2}(q_{i,l} + u/d)$ for all i, l. The condition $q_{il} \geq u/d$ ensures that $\frac{1}{2}(q_{i,l} + u/d) \leq q_{i,l}$. Under the condition $n_{il}^{-} > \frac{1}{2}(q_{i,l} + u/d)$ we then have

$$\begin{aligned} h_{il} &= u s_{p,l-1}(t) + d\big[n_{il}^{+}(t) - n_{il}^{-}(t)\big] \\ &= u s_{p,l-1}(t) + d\big[q_{il}(t) - 2n_{il}^{-}(t)\big] \\ &< u s_{p,l-1}(t) - u \leq 0. \end{aligned}$$

From (6), we have that under the sequential dynamics

$$s_{il}^{seq}(t+2) = -1.$$

Under the simultaneous dynamics, the argument above holds for $l > 2$ leading to

$$s_{pl-1}(t+1) = \text{ sign } h_{pl-1}(t) = -1$$

and

$$s_{kl+1}(t+1) = \text{ sign } h_{kl+1}(t) = -1.$$

From (7) we conclude that for $l \geq 2$

$$s_{il}^{sim}(t+2) = -1$$

thus concluding our proof. □

Proof of Proposition 4.10 We show that under the hierarchy if the number of subordinates of any agent is larger than u/d and the maximum span q^* is strictly larger

than u/d, a sufficient condition for the dynamics to be relevant is that, for all agents, the number of subordinates with a negative attitude is less than half of the sum of u/d with the number of subordinates, i.e., $n_{il}^{-} < \frac{1}{2}(q_{i,l} + u/d)$ for all i, l. Under the condition $n_{il}^{-} < \frac{1}{2}(q_{i,l} + u/d)$ we then have

$$\begin{aligned} h_{il} &= us_{p,l-1}(t) + d\big[n_{il}^{+}(t) - n_{il}^{-}(t)\big] \\ &= us_{p,l-1}(t) + d\big[q_{il}(t) - 2n_{il}^{-}(t)\big] \\ &> us_{p,l-1}(t) - u \leq 0. \end{aligned}$$

If the superior of a given agent i in level l has a positive attitude, the agent's field will be positive. From (6), we have that under the sequential dynamics

$$s_{il}^{seq}(t+2) = +1.$$

Since the top manager has a positive attitude, we conclude that the above conditions ensure the diffusion of that positive attitude, under the sequential dynamics, throughout the whole organization. Under the simultaneous dynamics, individuals whose initial attitude are positive and whose superiors do not have initially a positive attitude, will feel a field $h_{il} > -2u$ that may be negative, changing in that case their attitudes into negative, and increasing the number of negative subordinates (and superiors) in the system, possibly invalidating the condition $n_{il}^{-} < \frac{1}{2}(q_{i,l} + u/d)$. In the second step of the dynamics a subordinate of one such individual will feel a field that may be negative for the very same reason, increasing the number of negative subordinates in the system. This shows that, under the conditions of this proposition, the sequential dynamics is preferred, thus concluding our proof. □

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