The role of multiplexity and space in the evolution and sustainability of networks: An agent-based modeling approach.

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Abstract

In this work, we contribute to the literature on networks evolution by developing propositions on the emergence of macro-level dynamics from the micro-behaviors of individual actors, which will be explored using an agent-based computational model.

Previous research has found that the degree of embeddedness of each actor in its multiplex network (defined over communication, trust and knowledge transfer ties) is positively associated with its performance, and that geographical and socially constructed space negatively moderates this relationship (Fonti, 2003, 2006). Here, we explain how to use an agent-based model to test the robustness of these findings over the long term and to verify a possible explanation for them (i.e., the existence of a life cycle of a tie between two network members). Additionally, the model explores their longitudinal implications by looking at how the actor's micro-behaviors affect network evolution and, consequently, the performance of relevant network portions (in our case, of an industrial district) and of the network as a whole. Addressing these questions also allows us to shed light on a typical multi-level network issue, i.e. whether the influence of a given set of micro-behaviors on a network may be different depending on the level of analysis (individual, local, or global) one looks at.

We test the model focusing on the network dynamics of an entire industry featuring a strong industrial district and trade association. Results of the simulations allow us to both validate existing findings and to develop new hypotheses regarding the long-term viability and impact of the actors' micro-behaviors.

***Keywords*:** Networks, clusters, industrial districts, agent-based modeling, embeddedness, multiplexity, change.

Introduction

Networks are emerging as critical element to understand organizational phenomena. They have been moving from a simple methodology to analyze data (Wasserman & Faust, 1994), to a perspective to interpret a wide array of organizational phenomena (Wellman, 1988), all the way to a theoretical framework for explaining behavior in and of organizations. Concepts such a the strength of weak ties (Granovetter, 1973), embeddedness (Granovetter, 1985; Uzzi 1996, 1997), structural holes (Burt, 1992), closure and brokerage (Coleman, 1988; Burt, 2005) represent building blocks of an incipient network theory of organizations and are becoming widespread in studies trying to understand various organizational phenomena. Perhaps due to such a strong growth, network studies have not been able to keep up in depth what they have obtained in breadth. That is, while the use of networks has almost become commonplace in organizational research, certain limitations of these studies have only recently started to be addressed. Among them, two are particularly critical: the investigation of network relationships independently from each other and the lack of longitudinal studies. That is, most network research only focuses on networks defined on type of relationship at a time (i.e., the communication network, the trust network or the alliance network). In reality, though, organizations face a much more complex reality, where different types of relationships in which they are involved co-exist and influence their behavior. Additionally, most network research is conducted at the cross sectional level, with very little consideration for the fact that networks, similarly to all other organizational phenomena, have a strong processual element that is critical if one wants to capture their true effect on organizations. These limitations may be due to the limited availability of statistical methodologies to analyze longitudinal network data (which is just now starting to emerge; see Snijders, 2005) as well as to the enormous difficulty to obtain good longitudinal data on multiple relationships, given that for each one a researcher has to ask N-1 additional question to the interviewee. However, this is nonetheless problematic, both in terms of the validity of the findings in extant network research as well as for the questions that have not yet been explored due to these limitations.

This paper tries to address these two limitations. First, we build on research by Fonti (2003, 2006) which explicitly address the first one of these limitations by introducing the concept of multiplex embeddedness and linking it to organizational performance. However, given that these findings are still cross-sectional, we turn to simulation techniques (more specifically, agent-based models) to address the second issue. Here, we re-create the working of the network by providing agent with rules about their micro-behavior that will eventually allow the overall network structure to emerge. In doing so, we will be able to confirm the validity of the cross-sectional findings about multiplex embeddedness as well as test some of their longitudinal implications.

This paper is organized as follows. First, we introduce the concept of multiplex embeddedness and discuss its positive relationship with organizational performance. Second, we look at some research that has examined this relationship more in depth, by investigating the moderating role that space (both physically- and institutionally-determined) play in it. Both spaces are sub-sets of the interorganizational network we are examining; more specifically, our interorganizational network is a whole industry, while the physically determined space is an industrial district and the institutionally determined (or socially constructed) locale is an industry association. Third, we quickly talk about the importance of simulation techniques and introduce agent-based models. Fourth, we discuss trust and its implications on interorganizational cooperation, which happens to be critical for our network model. Finally, we introduce the propositions we plan to test using the agent-based model.

Theory

The influence of multiplex embeddedness on organizational performance

During the last 20 years, the organizational literature has seen a steady rise of networks studies aimed at explaining organizational phenomena. Many of them have focused on the role of network embeddedness (i.e., the level of direct and indirect involvement of an actor within a network; Granovetter, 1985, 1992) and found that it is significantly associated with various critical organizational outcomes, such as financial performance and survival (Uzzi, 1996, 1997; Dacin, Ventresca & Beal, 2001). While these studies represent a great step forward in understanding how organizations work, the majority of them still share a common shortcoming: they focus on the position of the organization (i.e., its level of embeddedness) in one network at a time. However, organizations within a given network are normally involved in more than one relationship at a time: they may or may not communicate with other organizations, which may or may not trust, to which may or may not transfer knowledge and with which they may or may not have a formal alliance. The combination of all these relationships is expressed by multiplexity, i.e. the degree to which two actors are connected through more than one relationship (Wasserman & Faust, 1994). Obviously, if a network is inherently multiplex and if embeddedness is so critical for explaining organizational phenomena, then we need to study these two phenomena together to get a realistic look at the influence of networks on organizations.

To address this gap, Fonti (2003) has recently introduced the concept of multiplex embeddedness, which is an organization's embeddedness in an interorganizational network simultaneously defined for all the critical relationships in which it is involved. This characterization of embeddedness emerges from the multiplex nature of any actor's ties, i.e. form the consideration that, in practice, any organization is simultaneously involved in different types of relationships that are critical for its functioning and all together affect its functioning (see Figure 1 for an example).

——— Insert Figure 1 about here ———

The level of involvement in these different critical relationships taken simultaneously ends up constraining or enabling its economic action, hence affecting its financial performance and long-term viability and survival. After identifying the critical relationships for the network he investigated (task-based communication, interorganizational trust and knowledge transfer), he defined two different types of multiplex embeddedness: strong and weak. The 'strong multiplex embeddedness' condition (ME strong) is a situation where two organizations share a multiplex tie only if this tie is 'fully multiplex', i.e. if the pair shares all three critical relationships (communication, trust and knowledge transfer). To identify the level of ME strong he built a new network out of the three critical relationships using an intersection rule (i.e., a network where the cell aij gets a 1 only if organization i and organization j share all three relationships, and a 0 in any other case; see Figure 2), then operationalized it using degree centrality.

——— Insert Figure 2 about here ———

However, these three critical relationships are not always all present between two organizations. To capture also these 'partial' instances, he identified a relaxed form of multiplex embeddedness, called 'weak multiplex embeddedness' condition (ME weak). Here, the level of embeddedness of an organization in the network is represented by the sum of all its ties with another actor (whether or not they share all three relationships). To identify the level of ME weak, he built an additional network by compounding the three critical relationships using a union rule (i.e., a network where the cell aij gets a value that varies from 0 to 1, depending on how many relationships organization i and j share with each other; see Figure 1b), and operationalized it using degree centrality.

In his analyses, he found that a high degree of ME strong is positively affecting organizational performance, while the opposite happens for ME weak: a high degree of it is negatively associated with the financial performance of an organization. These findings can be at least partially explained by the existence of a life cycle of a tie (LCT), which is illustrated in Figure 3 and 4.

——— Insert Figure 3 and 4 about here ———

The idea behind the LCT is that any two organizations first start their relationship by interacting (i.e. communicating) with each other for task related issues. Then, if this interaction is ongoing for a while, trust eventually ensues among these parties and, after they learn to trust each other, they eventually start transferring knowledge to each other. Such transfer of knowledge can also happen in a less than purposeful way through communication: interacting continuously with another firm may lead to knowledge to brush off from one party to the other just due to the continuous exposure to each other practices and routines. If the knowledge exchange results in positive outcomes for these organizations, this eventually reinforces trust and task-based interaction between these firms, which will seek more of each other for business. However, developing even more trust and getting to know well each other will allow the partners to develop a common language and therefore need less communication to get their business done (Uzzi, 1997). This means that while they get the benefit coming from trust and knowledge transfer, once the LCT becomes full fledged each organization does not need to spend much time to sustain the cycle (and the benefits associated with it). Hence, the LCT is a virtuous cycle that in the end becomes almost self-sustaining, requiring little relational resources to be maintained and yet allowing the parties involved to reap maximum benefits. Organizations with a high degree of ME strong have many LCTs, which positively influence organizational performance. In fact, the co-existence of all the critical relationships positively affects firm performance due to the increased quality of the flows deriving from it to the pair of actors simultaneously engaging in all the critical relationships, and to their ability to maintain them by using minimal relational capital (due to the instantiation of a virtual cycle among the different critical flows). On the other hand, given that for the virtuous cycle to get started (and for the firm to benefit from it) all the critical relationships need to be present, having a high level of ME weak is actually counterproductive for an organization. To maintain relationships throughout the network with many different organizations, without aiming at progressing through the LCT with each of them (thus reaching the virtuous cycle associated with ME strong) leads to waste of its limited relational resources (i.e. the resources that each actor can devote to the creating and maintaining a set of ties; Hansen, Podolny & Pfeffer, 2001). Many multiplex ties are good only when developed with the same other actors. However, if in addition to these a firm adds ties randomly throughout its network, without regard on whether it builds all the critical ties with other actors, then this behavior will hurt performance. In layman's terms, in the case of a high ME weak an organization is simply 'spreading out too thin'.

The role of physical and socially constructed space

The working of multiplex embeddedness has been further detailed in a successive study, where the role of space as a moderator of the relationship between multiplex embeddedness and organizational performance has been examined (Fonti, 2006). Here, he considered space, i.e. the location of the organizations in the network, and checked whether it plays a moderator role in the relationship between multiplex embeddedness and organizational performance. In order to do so, he first distinguished between two different types of space: physical space and institutionally created (or socially constructed) space. The former captures the organizations' location in the network (i.e., geographic proximity), while the latter is the space that comes to exist because it is socially constructed by institutions. In particular, the context of this study was an entire industry, with an important industrial district and a strong industry association (see Figure 5 for the spatial distribution of the industry's firms).

——— Insert Figure 5 about here ———

In the study, firms that belonged to the industrial district were assumed to be geographically proximate. Then, he focused on the industry association and considered its members as parts of the same socially constructed space. In this case, the industry association is an institution that brings together organizations which may or may not be physically proximate, but that are made close to each other by their sharing of the common rules and agenda of the association, as well as by the attendance of periodic meetings and seminars that the association organizes. In both cases, he found that space moderates negatively the relationship between both types of multiples embeddedness and organizational performance. That is, organizations that are part of industrial districts (or industry association) still have a positive relationship between ME strong and their financial performance; however, this relationship is not as strong as the one for non-district (or non-industry association) firms. Similarly, while the relationship between ME weak and financial performance is still negative for the firms that are part of the cluster (or the industry association), it is much more negative than the one for non-cluster (or non-industry association) firms. This is likely do to inefficiency associated to munificent environments such as districts and industry associations. While firms that can not tap into this resources make the most of their set of relationships, for example extracting every single ounce of the benefits that derive form a high level of ME strong, the organizations that are in the cluster (or in the industry association) seem to waste some of these benefits. This may be because they live in an environment that is extremely munificent and, therefore, they feel that they can pass up an opportunity because another one will represent soon. In a sense, the idea here is akin to what happens in many biological systems: while populations that live in inhospitable environments (such as the artic tundra or the subtropical desert) have learned to make the most of every single resource they have available, people living in much more rich context (such as a large metropolitan area) waste much more of the resources available to them. The powerful conclusion, though, is that it is better for a given firm to be outside the cluster and/or the industry association because the same level of ME strong will provide it with better financial performance (or, alternatively, its level of ME weak will have les of a negative impact on its finances). While this goes against the common literature on industrial clusters, it is aligned with the findings of some recent works detailing the costs associated with being located in an industrial district.

These findings are quite powerful; however, the one problem that they share is that they come from the analysis of cross-sectional data. The lack of longitudinal data entails at least two types of limitations. First, the LCT as a potential explanation for the positive link between ME strong and organizational performance is only posited by Fonti and has not been tested using actual data. Second, we do not know whether the negative moderating influence of both types of space on the ME-performance link is a characteristic of a particular phase of the life cycle of the industry or if, instead, it is a long-term characteristic of the system. In addition to these two things, having over time data will also allow us to test the long-term implications of these findings. More specifically, if it is true that space has this role on the ME-performance link, to what extent is a cluster (or an industry association) viable over the long-term? In addition, what is the impact on the survival of the industry (i.e. of the larger network)?

In order to answer these questions, we can enlist the help of computational simulation, in particular of Agent-based Modeling (AbM).

The use of simulation in social sciences

Simulation studies have a long tradition in organizational research. Dating back to the seminal works in the area of the behavioral theory of the firm and organizational decision theory (Cyert, Feigenbaum & March, 1950), some of the most important theoretical pieces in the theory of the firm and organizational theory are based on simulations studies. This is true, for example, for the 'garbage can' model (Cohen, March & Olsen, 1972) and for the work leading to the development of the behavioral theory of the firm (Cyert and March, 1963). More recently, simulations have characterized studies in organizational evolution and dynamics, and, in particular, inter-organizational evolution (Lomborg, 1996; Lomi & Pattison, 2004), intra-organizational evolution (Burgelman & Mittman, 1994; Larsen & Lomi, 2002) and organizational change (Mezias & Glynn, 1993; Lant & Mezias, 1992; Sastry, 1997; Lomi & Larsen, 2001).

Modeling and simulation constitute a fundamental element of many research designs and are getting increasing attention in the economic literature. Simulation helps rigorously to deduce consequences from modeled assumptions, when complexity makes it difficult to obtain closed-form solutions. In addition, simulation allows looking at unfolding organizational and social processes, capturing the behavioral characteristics in transitory states.

Multi-agent based simulation

The use of computer simulation models (Axelrod 1997) is an emerging paradigm within the social sciences. Within the context of simulation, social scientists are increasingly using the techniques of multi-agent based simulation (MABS) to explore complex dynamics in artificial social systems (Hales et al, 2003) and, in particular, economic systems (Mollona & Hales, 2006) and organizations.

Here, we use an agent-based model to simulate firm interaction in an entire industry (which represents the interorganizational network we are studying). Firms have the possibility to interact with each other and with the environment through their 'micro-behavior', i.e. the set of rules that define their decision-making processes. Firms' mental models are not fully rational: they base their decision on a local subset of information and therefore they maximize their local utility. This often leads to an unexpected aggregate behavior of the system. The use of an agent-based model not only allow us to replicate some of these rationally-bounded decisions, but also to introduce a longitudinal aspect, allowing us to shed light on certain aspects of the extant research on cluster networks that so far have been carried on at the cross-sectional level (Fonti, 2003, 2006).

We think that an ABM would be extremely useful for tackling these longitudinal issues. In particular, we focus on two issues. First, ABM allows to model micro-behaviors and to explore, by the means of computer simulation, the macrostructures emerging from the interaction of local agents. Differently from other modeling and simulation techniques, ABMs have a very low specified macrostructure. Generally, they define four key elements. First, a number of different classes of agents are defined, such as, for example, an Environment, Firms and/or Employees. The second element in an ABM is the definition of the individual micro-behaviors of agents within a specific class. That is, incentives, objectives and attitudes that describe the behavior of each agent within each given class. The third element is given by rules of interaction among agents, which define how agents within a class or belonging to different classes interact. Finally, an ABM has a container hierarchy, which specifies the relationships among the different classes of agents; for example, the hierarchy specifies that both Firms and Employees are in the Environment and that Employees may or may not be into Firms. The idea is to let the elements within a model to give raise to a specific emerging macro-structure as a consequence of local interaction, without imposing exogenously such structure.

The second element that motivates us to use an ABM approach is that ABMs allow to investigate how the topology of local agents, having different characteristics, lead to specific emerging aggregate behavior. Agents may decide to connect or to disconnect dynamically to other agents grounding this decision upon, for example, the result of previous interaction. In this respect, ABM give rise to conceptual objects that are very similar, and can be compared, with empirical data collected via social network analysis. In other words, we can define the sufficient and necessary micro-conditions to generate, over time, empirically observed macro-structures with specific topologies.

As for the limitations of this approach, first we should notice that the micro-behavior of our agents should not be considered as a precise replica of real firms. Real dynamics are way too complex to be represented precisely by a computational model; our work should rather be viewed as an 'artificial society'-type model (i.e. similar to the SugarScape model illustrated in Epstein & Axtell, 1996). The agent-based model allows to express formally (i.e., computationally) a number of hypotheses about potential processes that may occur in real districts of firms in a stylized and executable manner, such that experiments can be performed to deduce the consequences of those hypotheses when they are combined in complex, adaptive systems (CAS). Hence, here we purposefully present a simplified model where we hope to capture the kinds of complex dynamics in which we are interested. Additionally, in this work we are not attempting to test hypotheses; rather, we are trying to confirm theoretical propositions that are either underpinning extant research or that can emerge naturally from it. Our findings, in addition to strengthen and further validate previous research, will then represent extremely good hypotheses to be tested in future studies.

One of the central concepts of our model is trust: we are interested in exploring its role in the network, especially in terms of how it can stimulate cooperation among a cluster of firms. Doing so will allow us to come up with rules for our actors that will approximate the actual behavior of the firms involved in the network.

Therefore, before getting at the propositions we would like to test, we quickly highlight the critical role of trust and of inter-organizational cooperation.

Trust and cooperation

The concept of trust is central in social sciences. According to Noteboom, Berger and Noorderhaven, trust concerns the partner's ability to perform according to the intentions and expectation of a relationship or her intention not to defect (1997). In this paper, we focus on two elements of trust: the presence of trust between two or more agents defined as the belief that other agents will follow shared rules of behavior and trust defined as the situation in which agents expect that other agents, in favor of whom they show a particular positive behavior, will reciprocate such behavior. In both cases, the concept of trust is connected to the agents' perception that they belong to the same community, in which, implicitly or explicitly, some rules are shared (see Coleman, 1988). This was also emphasized early on by Adam Smith (Granovetter, 1985); in his description of markets as mechanisms of interaction based on price, he complained that transactions often do not take place in a space completely void of social interaction. Indeed, agents share the idea of belonging to a community in which a social structure exists. This social structure includes more tangible elements such as money as a (more or less) widely accepted mean of payment and the assumption that who sells a good holds a property right on what she sells, but also less physical ones, such as boundedly rational decision-making based on a set of expectations where trust plays a critical role. Hence, trust is a social construct that is necessarily interlinked with economic activity. Such a tight linkage stimulates a number of questions.

The first question is why trust is important and where its positive influence on economic activity comes from. As Milgrom and Roberts state (1992), in a world of incomplete contracting, trust is crucial to realizing many transactions. More specifically, Noteboom et al (1997) and Hill (1990) note that trust reduce transaction costs by reducing the specification and monitoring of contracts as well as uncertainty. In particular, trust, induced by institutionalization and habitualization, has a negative effect on risk in the form of the perceived probability of loss (Noteboom, Berger and Noorderhaven, 1997).

The second question has to do with how trust emerges in a group of agents. A number of authors support the idea that trust is strictly connected to the continuity and duration of a relationship (Tsai and Ghoshal, 1998; Nahapiet & Ghoshal, 1998; Granovetter, 1985; Gulati, 1995). Other scholars explain that the permanence of relationships contributes to the institutionalization of behavior (Berger & Luckmann, 1966) and emergence of shared values, which then lead to trust (Larson, 1992; Barney & Hansen, 1994; Ouchi, 1980).

A third question deals with the connection between trust and cooperation. For example, let us take the Prisoner Dilemma game (PD). Here agents may cooperate rather than defect for a number of reasons. First, they can cooperate for pure altruism, without any expectation of economic or social remuneration. Second, in a rational-choice approach, self-interested agents may cooperate in a multiple-stage PD motivated by the reaction of the other agent in the next round. For example, a player may play a tit-for-tat strategy to teach to the other partner to cooperate. In this light, cooperation is a long-term, rather than short-term, rational strategy. Of course, at least according to game theorists, in non-repeated PD, agents should not cooperate. In this setting, cooperation follows from the fear of a punishment. In a multiple-stage PD, though, the other player may punish a defector in next stages. This latter one is a situation much more akin to what organizations face daily. A similar mechanism takes place when cooperation is enforced by law or other social rules punishing defection. In these cases, given the cost associated to defection, a community uses laws to make it rational not to defect. The cost of defection not necessarily needs to be a material one. For example, as Boyd and Richerson suggest (1989), cooperation has been perpetuated in human communities with moralistic aggression. Enquist and Leimar (1993) refer to gossip and suspiciousness as mechanisms to enforce cooperation.

Now that we have determined that cooperation is a viable long-term strategy, a more specific question concerns how cooperation may emerge as the effect of spontaneous coordination of interacting agents. Here, we are interested in interaction that is more complex than simple tit-for-tat strategies. Imagine a one-time PD in which an agent has an incentive not to cooperate. This agent may think that if the other agent is rational, the payoff received will be the lowest one, i.e. the one associated to both agents defecting (the rational behavior, without knowing what the other party will do). Yet, the agent has two solutions to increase her payoff. First, she can play defector with a player who has a tendency to cooperate. While the PD may be a non-repeated game in the sense that two players do not play again with each other, though, each of the two players may go to play with another player. Having defected the first time implies that, to play again, the defector agent needs to move in another community, where their reputation for defectors in not known yet. This strategy may be costly because it implies continuous movements. The second strategy to increase the payoff is to play cooperative; however, in this case the agent must be sure that the other agent will play cooperatively as well. Thus, we expect cooperation to emerge in communities of agents sharing behavioral norms that make it an efficient organizational form by penalizing defection. For this community to be resilient, agents need to trust other agents and be sure that they will not defect. In this vein, social structure, such as norms of behavior, entails cooperation; however, for this type of social structure to be effective agents need to trust each other. As a consequence, cooperation is more likely in groups that have produced social markers, such as languages (Nettle and Dunbar, 1997). In this respect, cooperation emerges in communities that share values, norms of behavior, and where trust is widespread. This could very well be the case for an industrial district, with its extremely tightly knit set of relationships, often criss-crossed by kinship ties.

We may also investigate the opposite causal relationship, according to which shared norms and trust are part of an emerging structure following from cooperation. In other words, cooperation may also emerge in communities simply because agents in these communities share the same history in which cooperative behavior proved to be an efficient mechanism to cope with selective pressures. In this line of reasoning, cooperation may be a consequence of interaction and learning (Macy, 1991) and the fear of extinction, rather than of widespread trust and behavioral norms supporting such behavior. For example, Macy and Skvoretz (1998) suggest that trust and cooperation among strangers can emerge as local norms, which are built up and then spread to strangers through weak ties. The concept of trust, its strong linkages with cooperation and the causal relationships between the two concepts is crucial to interpret the evolution of industrial districts. In particular, does trust follow from pre-existing social relationship and stimulate cooperation or does it emerge as a consequence of interaction and learning and how complex is the dynamics of such an interaction? These are two questions we will try to address in our agent-based model, whose rules (and actors' micro-behavior) will be informed by these insights.

In addition to use trust and cooperation as a centerpiece of the rules that we will develop for our model, we will also look at the literature on communication and knowledge network for additional guidance on developing such rules. Lastly, we will also model the interaction between communication, interorganizational trust and knowledge transfer, trying to infuse the actors with literature-derived and fieldwork-emerging rules for how each relationship interact with the others.

Propositions for the agent-based model

Here, we will articulate the set of propositions that we want to test using an agent-based model, to address the two limitations in the network literature mentioned in the introductory section. As already mentioned, our work is fully grounded on Fonti's work on multiplex embeddedness (Fonti, 2003, 2006). While this work addresses the first of the limitation of network studies we identified (i.e., lack of multiplex network studies), though, it is cross sectional. To help with the second limitation of network literature (i.e., lack of longitudinal studies) we enlist the help of agent-based modeling. Using this model, we will test assumptions that will both validate the findings on multiplex embeddedness and test some of their longitudinal implications.

First of all, Fonti (2003) credits the positive influence of multiplex embeddedness on firm's performance to the existence of the LCT. However, the LCT is intrinsically dynamic; hence, we use the agent-based model to test if the micro-behaviors of the various agents in the system actually lead to the emergence of a self-sustaining LCT. By In particular, focusing on the formation of multiplex ties between network agents, we will provide additional credence to the rationale used in justifying the positive (negative) influence of high levels of ME strong (ME weak).

- *Proposition 1: The life cycle of a tie between two firms is typically organized in the following way: first, after a certain amount of communications, we see the emergence of trust. Then, after trust emerges, they start to transfer knowledge to each other. At the same time, communication also leads to some degree of knowledge transfer. If the knowledge transfer is beneficial for both firms, this leads to more trust. More trust and more interaction lead to the development of a common language, which leads to less communication (it takes much less time to get the same amount of business done). This cycle therefore becomes almost self-sustaining, with much less relational resources needed to keep it going.*

The findings of a strong positive influence of multiplex embeddedness on organizational performance and of a negative moderation role of space are quite powerful. In the context of the studies we examined, though, they are still limited by the cross-natural nature of the data. Here, we use the agent-based model to verify whether the influence of the network on the performance of individual actors extend to the long term, or is instead just limited to a specific phase of the life of the network.

- *Proposition 2: Over time, high levels of ME strong (ME weak) are positively (negatively) related to financial performance, with location in the industrial district and membership in the industry association negatively moderating this relationship.*

The ABM also allows us to test some longitudinal implications of findings related to multiplex embeddedness, and especially to the moderating role of the locales. In fact, if locales cause an inefficient management of one's relationships due to their innate munificence, isn't it better for organizations to migrate out of them? More importantly, will their inefficiency lead to their demise, over the long term. Or, maybe, will it make them less munificent and, in doing so, keep them viable?

- *Proposition 3a: Over time, the industrial district (the industry association) dies out due to the strong inefficiencies in managing existing relational resources that are ensuing from its munificence.*

- *Proposition 3b: After a period in which firms that belong to the industrial district (the industry association) are at a disadvantage compared to their non-cluster (non-industry association) counterparts, the industrial district (industry association) loses many of the resources that it made available to its members. However, this makes this environment less munificent, therefore forcing the remaining cluster (industry association) firms to adapt and make the most of the resources still available, including the relational ones. Hence, the deterioration of the locales plateaus at a given level, where the negative moderating influence of space disappears.*

Finally, we need to look at the sustainability of the entire network (i.e., of the industry). More specifically, what is the influence on the network as a whole of the impact that multiplex embeddedness and space have on individual actors and on critical sub-systems of the industry such as the industrial district (or the industry association)? Are dynamics that are beneficial for individual actors while at the same time negatively affecting the industrial district going to bring about the demise of the industry over time? That is, could we be in a situation where the micro-behaviors which benefit certain individual actors in the end kill the system?

- *Proposition 4a: Over time, the industry will see a major retrenchment and then disappearance, due to the strong inefficiencies in managing existing relational resources that are typical of munificent locales such as the industrial district and the industry association.*

- *Proposition 4b: Over time, the industry will see a major retrenchment, followed by a tapering off and possibly some sign of recovery, due to the interplay of individual organization and locales' dynamics. After a period in which firms that belong to the industrial district (the industry association) are at a disadvantage compared to their non-cluster (non-industry association) counterparts, the industrial district (industry association) loses many of the resources it made available to its members. However, this makes this environment less munificent, therefore forcing the remaining cluster (industry association) firms to adapt and make the most of the resources still available, including the relational ones. Hence, the deterioration of the locales plateaus at a given level, where the negative moderating influence of space disappears, with the repercussions listed above on the industry as a whole.*

Testing these propositions represents a starting point for a comprehensive dynamic theory of interorganizational networks, allowing us also to see more clearly what happens within relevant locales such as industrial districts or industry associations. If verified, they will not only provide validity to the findings on multiplex embeddedness and the role of locales, but also represent very interesting hypotheses to test in future research using longitudinal network data.

Last but not least, using the ABM to test these propositions will allow us to delve into a third limitation of network studies: that is, whether certain network properties have a local or global nature. The influence of multiplex embeddedness, for example, is positive on individual actors: however, it remains to be tested what is its impact on relevant network sub-systems (such as the industrial districts or the industry association) or even on the network as a whole. If the positive impact is maintained at all three levels (individual actor, relevant network sub-system and entire network), then we can say that the influence of multiplex embeddedness on networks is a global property. If not, then it will be only local, i.e. apply only to a part of the network, making it a weaker property. So far, network studies have usually examined the influence of networks on one level (usually, the individual actor), not multiple ones. However, we need to gain more insight on whether or not certain network properties that can be found in the extant theory have the same type of effect on he network as a whole (or on relevant sub-systems of the network) that thy have on individual actors. Otherwise, we may risk passing on to managers wisdom that can be beneficial to individual players but, ultimately, kill the network.

Bibliography

Axelrod, R. 1997. Advancing the art of simulation in the social sciences. R. Conte, R. Hegselmann, P. Terna, eds. *Simulating social phenomena*. Springer, Berlin (Germany).

Barney, J.B., M.H. Hansen. 1994. Trustworthiness as a source of competitive advantage. *Strategic Management Journal* **15** 175-190.

Berger, P. L., T. Luckmann. 1966. *The socia1 construction of reality*. Doubleday, Garden City, NY.

Boyd, R., J. Richerson. (1989) The evolution of indirect reciprocity. *Social Networks* **11** 213-236.

Burgelman, R.A., B.S. Mittman. 1994. An intra-organizational ecological perspective on managerial risk behavior, performance, and survival: Individual, organizational, and environmental effects. J.A.C. Baum, J.V. Singh, eds. *Evolutionary dynamics of organizations*. Oxford University Press, New York.

Burt, R.S. 1992. *Structural holes: The social structure of competition*. Harvard University Press, Cambridge, MA.

Burt, R.S. 2005. *Brokerage and closure: An introduction to social capital*. Oxford University Press, New York.

Cohen, M.D., J.G. March, H.P. Olsen. 1972. A garbage can model of organizational choice. *Administrative Science Quarterly* **17** 1-25.

Coleman, J. 1988. Social capital in the creation of human capital. *American Journal of Sociology* **94** 95-120.

Cyert, R.M., E.A. Feigenbaum, J.G. March. 1959. Models in a behavioral theory of the firm. *Behavioral Science* **4**(2) 81-95.

Cyert, R.M., J.M. March. 1963. *A behavioral theory of the firm*. Prentice-Hall, Englewood cliffs, NJ.

Dacin, M., M. Ventresca, B. Beal. 1999. The embeddedness of organizations: Dialogue and directions. *Journal of Management* **25**(3) 317-356.

Enquist, M., O. Leimar. 1993. The evolution of cooperation in mobile organisms, *Animal Behaviour* **45** 747-757.

Epstein, J.M., R. Axtell. 1996. *Growing artificial societies: Social science from the bottom up.* MIT Press/Brookings Institution, Cambridge, MA.

Fonti, F. 2003. One relationship is not enough: Toward a theory of multiplex embeddedness. Academy of Management Annual Meeting. Seattle, WA, August 1-6.

Fonti, F. 2006. Networks and space: Reconsidering the effects of locales on firm's performance. Academy of Management Annual Meeting. Atlanta, GA, August 11-16.

Granovetter, M. 1973. The strength of weak ties. *American Journal of Sociology* **78** 1361-1380.

Granovetter, M. 1985. Economic action and social structure: The problem of embeddedness. *American Journal of Sociology* **91** 481-510.

Granovetter, M. 1992. Problems of explanations in economic sociology. N. Nohria, R.G. Eccles, eds. *Networks as organizations: Structure, form and action.* Harvard Business School Press, Boston, MA, 25-56.

Gulati, R. 1995. Does familiarity breed trust? The implications of repeated ties for contractual choice in alliances. *Academy of Management Journal* **38**(1) 85-112.

Hales, D., B. Edmonds, E. Norling, J. Rouchier, eds. 2003. *Multi-agent-based Simulation III.* Proceedings of the 4th International Workshop, MABS 2003, Melbourne, Australia, July 2003. Springer, Berlin (Germany).

Hansen, M.T., J.M. Podolny, J. Pfeffer. 2001. So many ties, so little time: A task contingency perspective on corporate social capital. *Research in the Sociology of Organizations* **18** 21-57.

Hill, C. L. 1990. Cooperation, opportunism, and the invisible hand: Implications for transaction cost theory. *Academy of Management Review* **15** 500-514.

Lant, T.K., S.J. Mezias. 1992. An organizational learning model of convergence and reorientation. *Organization Science* **3**(1) 47-71.

Larsen, E.R., A. Lomi. 2002. Representing change: A system model of organizational inertia and capabilities as dynamic accumulation processes. *Simulation modeling practice and theory* **10** 271-296.

Larson, A. 1992. Network dyads in entrepreneurial settings: A study of the governance of exchange relationships. *Administrative Science Quarterly* **37** 76-104.

Lomborg, B. 1996. Nucleus and shield: The evolution of social structure in the iterated prisoner's dilemma. *American Sociological Review* **61** 278-307.

Lomi, A., E.R. Larsen. 2001. *Dynamics of organizations: computational modeling and organizational theories.* Menlo Park, CA, AAAI Press.

Lomi, A., P. Pattison. 2004. Introduction to the CMOT Special Issue on mathematical representations and models for the analysis of social networks within and between organizations. *Computational & Mathematical Organization Theory* **10** 5-15.

Macy, M.W. 1991. Learning to cooperate: Stochastic and tacit collusion in social exchange. *American Journal of Sociology* **97**(3) 808-843.

Macy, M.W., J. Skvoretz. 1998. The evolution of trust and cooperation between strangers: A computational model. *American Sociological Review* **63**(5) 638-660.

Mezias, S. J., M.A. Glynn. 1993. The three faces of corporate renewal: Institution, revolution, and evolution. *Strategic Management Journal* **14** 77-10.

Mollona, E., D. Hales. 2006. Knowledge-based jobs and the boundaries of firms: Agent-based simulation of firms learning and workforce skill set dynamics. *Computational Economics* **27**(1) 35-62.

Nahapiet, J., S. Ghoshal. 1998. Social capital, intellectual capital and the organizational advantage. *Academy of Management Review* **23** 242-266.

Nettle, D., D.I.M. Dunbar. 1997. Social markers and the evolution of reciprocal exchange. *Current Anthropology* **38**(1) 93-99. Noteboom, B., H. Berger, N.G. Noorderhaven. 1997. Effects of trust and governance on relational risk. *Academy of Management Journal* **40**(2) 308-338.

Ouchi, W.C. 1980. Markets, bureaucracies, and clans. *Administrative Science Quarterly* **25**(1) 129-141.

Sastry, M.A. 1997. Problems and paradoxes in a model of punctuated organizational change. *Administrative Science Quarterly* **42**(2) 237-275.

Snijders, T.A.B. 2005. Models for longitudinal network data. P. J. Carrington, J. Scott, S. Wasserman, eds. *Models and methods in social network analysis.* Cambridge University Press, Cambridge (UK), 215-247.

Tsai, W., S. Ghoshal. 1998. Social capital and value creation: The role of intrafirm networks. *Academy of Management Journal* **41**(4) 464-476.

Uzzi, B. 1996. The sources and consequences of embeddedness for the economic performance of organizations: The network effect. *American Sociological Review* **61** 674-698.

Uzzi, B. 1997. Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly* **42** 35-67.

Wasserman, S., K. Faust. 1994. *Social network analysis: Methods and applications.* Cambridge University Press, New York.

Wellman, B. 1988. Structural analysis: From method and metaphor to theory and substance. B. Wellman, S.D. Berkowitz, eds. *Social structures: A network approach.* Cambridge University Press, Cambridge (UK), 19-61.

FIGURES

Figure 1 - A graphic example of multiplex embeddedness

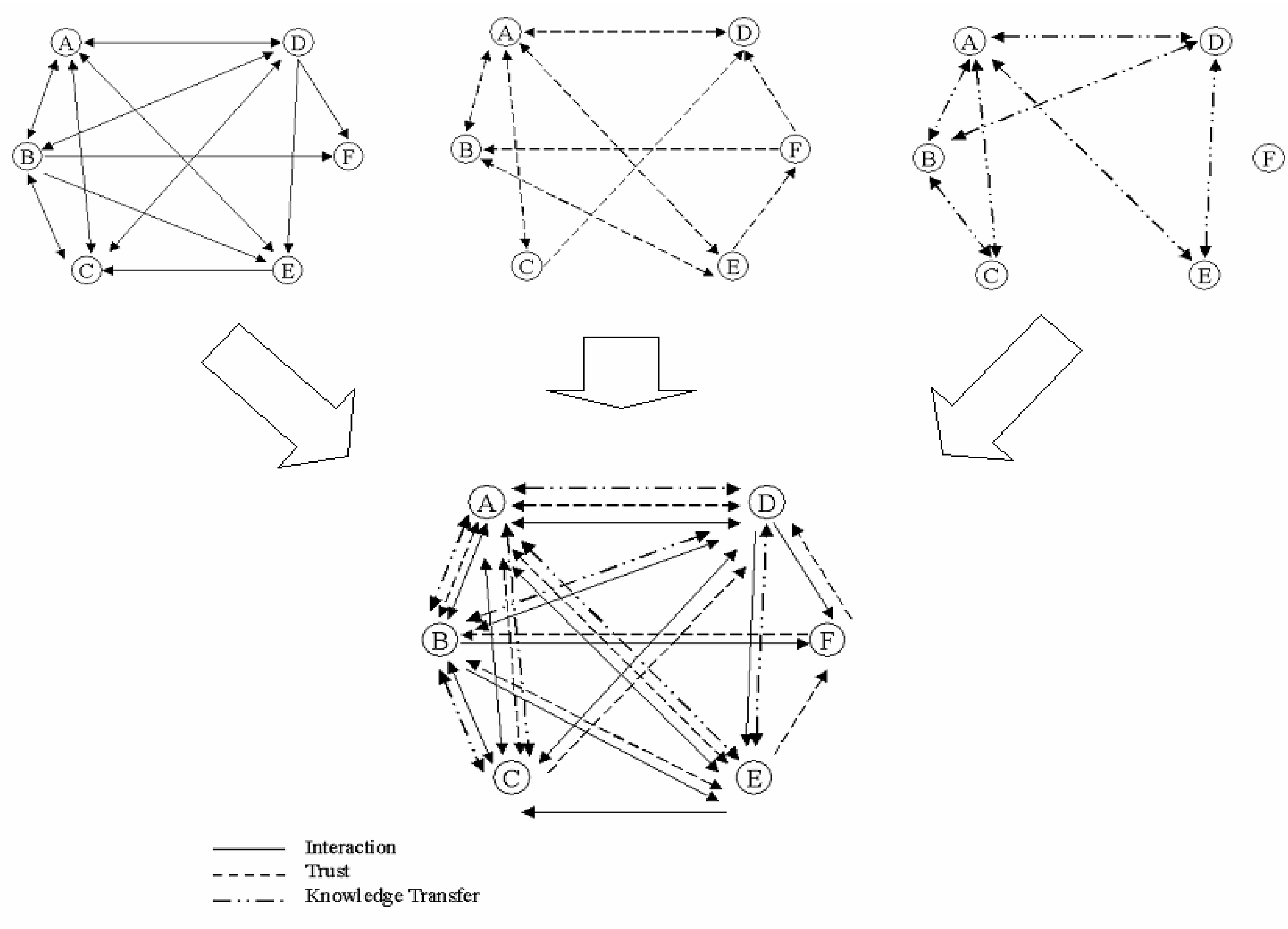
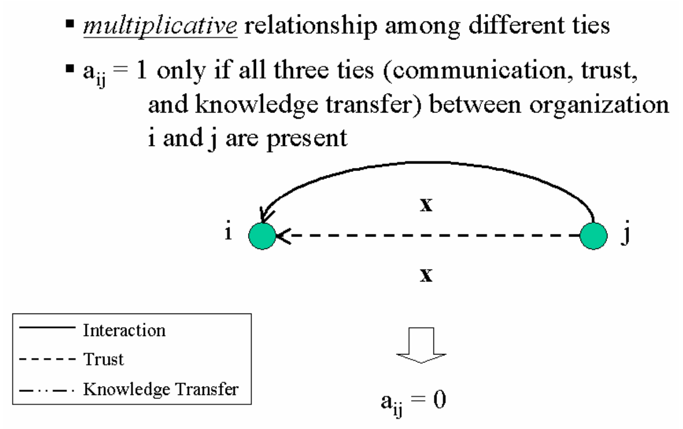
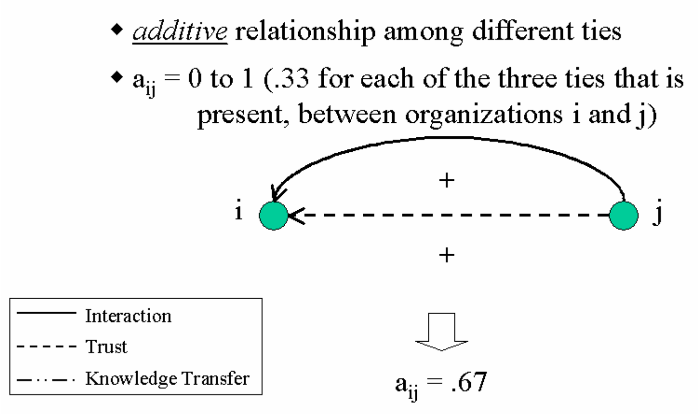


Figure 2 - Operationalization of multiplex embeddedness



a. 'Strong ME' condition (multiplicative)



b. 'Weak ME' condition (additive)

Figure 3 - Interconnectedness among critical relationships I

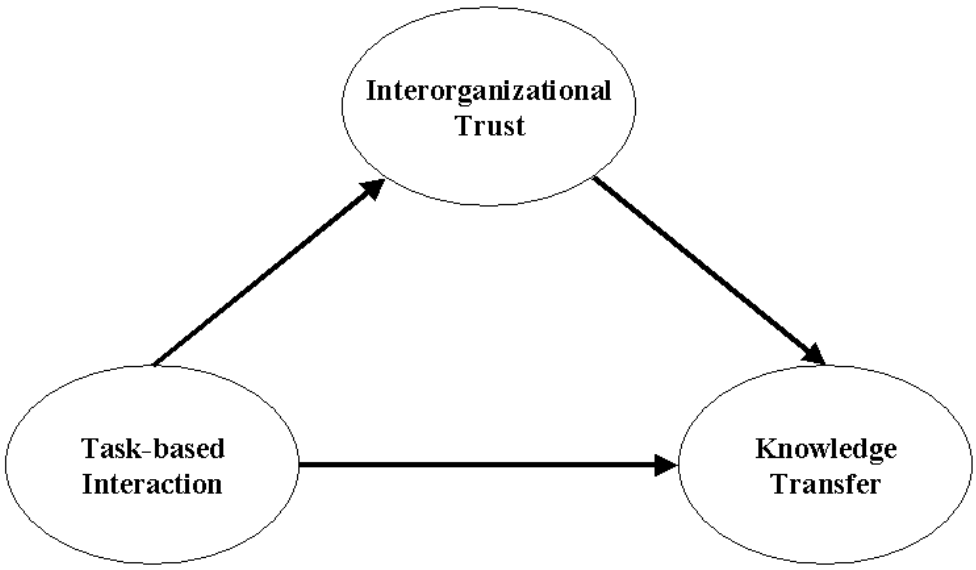


Figure 4 - Interconnectedness among critical relationships II

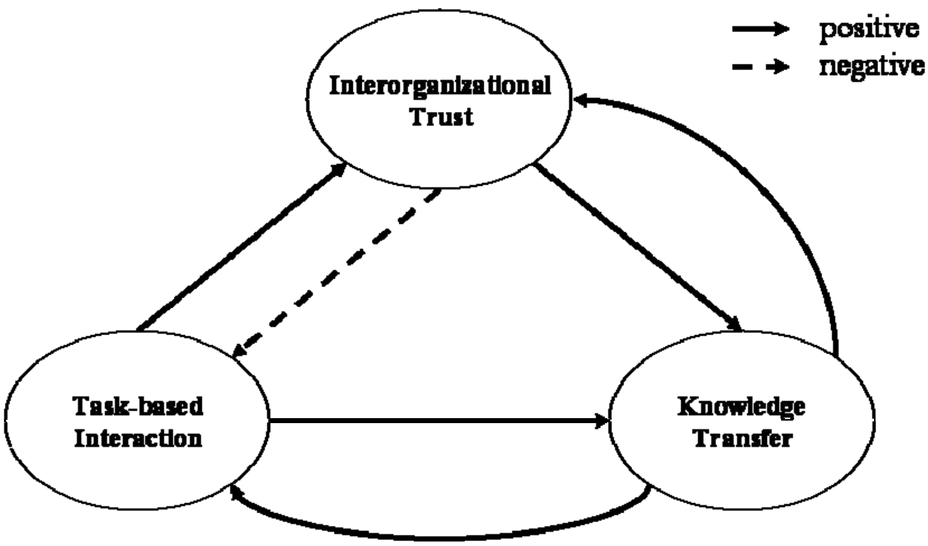


Figure 5 - Firms' spatial distribution in the industry