The impact of interpersonal networks on the innovativeness of inventors: From theory to empirical evidence

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Abstract. This paper aims to investigate the impact of interpersonal networks on the innovativeness of inventors. A large literature has been devoted to the analysis of network effects in economic and managerial sciences. The main research works in this field have emphasized the strong relation between interpersonal networks and cooperation. Cooperation is the best way to success in complex project as is an innovative one. We make here the hypothesis that repeated collaborations in a network of inventors have an influence on their innovativeness – i.e. on their dynamic innovative capacity. On the one hand, we propose some theoretical clarifications on interpersonal networks and innovativeness and we sum the main conclusions of the more important empirical researches connected with this subject. On the other hand, we run an empirical study involving 1157 French prolific inventors who obtained 30477 patents for the period 1975-2002. Logistic regression results underline the significant impact of extended collaborations on the innovativeness of inventors.

Keywords: innovativeness, interpersonal network, prolific inventor, cooperation, patent documents data

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1 Introduction

Since the seminal works of sociologists as Granovetter (1973), Coleman (1988) and Burt (1992), an abundant literature has been developed in different social sciences around the concept of network. This literature concludes that economic actors are embedded in social relationships. Hence, the question of embeddedness has become a singular research object both in managerial and economic sciences. Even though the existing contributions are varied, they share the idea that network can be approached as the web of an actor's relationships allowing him to access to complementary resources and to achieve a specific purpose. Thus, network sheds light on cooperation that is the social organization of collective entities. According to Gulati and Gargiulo (1999: 1446), the relational embeddedness of the whole network "highlights the effects of cohesive ties between social actors on subsequent cooperation between those actors". The emergence of cooperation rests on cohesive elements – as trust, commitment, reputation or relational interdependence.

A large literature has analyzed inter-organizational networks and intra-organizational networks. But too little attention was given to interpersonal networks, which focus on individuals' exchange networks. Individuals are the key elements of networks and so of organizations. In each economic organization, actors seek to manage their own network in line with their purpose – with the resources they need. As a result, there is a positive relation between interpersonal network and personal power. The scarcity of resources and the position in a social exchange network determine the relative power of an individual (Chassagnon 2009). In this sense, personal power is strongly linked to a common organizational purpose as is an innovative collaboration project.

Concerning the innovation activities, insofar as knowledge is tacit and anchored to individuals, the interpersonal network of an inventor is crucial and merits to be investigated. Indeed, it is via his personal network that the inventor can access to certain critical resources and knowledge necessary to his invention activity (Paruchuri 2009). Hence, his recurrent interactions with others in the interpersonal network of inventors are crucial. Because inventors work together, they acquire an experience, a confidence and a reputation that can generate new and successful collaborations; which strengthens the innovativeness of an inventor – i.e. his durable innovative capacity.

The main objective of this paper is thus to show the relation between interpersonal network effects and the ability of inventors to dynamically invent. In a first time, we apprehend this relation in a theoretical perspective and, in a second time, we analyze the relation interpersonal network/innovativeness in an empirical perspective. This empirical work is based on a French inventors database which pools the French inventors and their co-inventors during the period 1975-2002. We test the relation between the dynamics of interpersonal network effects and the inventors' innovative capacity.

The paper is organized in three sections. Section 2 proposes both an original synthesis of contributions to network concept and a theoretical framework for interpersonal networks. The relation between interpersonal networks and cooperation is hence clarified. Section 3 investigates the impact of interpersonal network effects on innovativeness. After defining the notion of prolific inventor and proposing some insights on the innovativeness of inventors, we put forward the theoretical hypothesis that there is a strong relation between the innovativeness of an inventor and his past repeated collaborations. Section 4 sums the main conclusions of some important empirical works on this question. Then, a presentation and a discussion of our empirical investigation are proposed. Section 5 briefly concludes.

2 A Theoretical Characterization of Interpersonal Networks

Many scholars have made contributions to the network concept notably in sociology. The main conclusions of the seminal works are briefly summarized. Departing from this synthesis that clarifies the notion of network, this section proposes to theoretically analyze the impact of social capital – notably trust and reputation – on cooperation. This gives crucial insights for the concept of interpersonal network.

2.1 A Brief Synthesis on Networks

Since the beginning of 1970s, the literature on networks has been grown. This literature has focused on different research questions and has shown the impact of network effects on individual performance, project team performance, organizational competences or innovative capabilities (Adler and Kwon 2002). Specific attention has been given both to the analysis of inter-organizational networks (e.g., Benson 1975; Powell *et al*. 1996; Uzzi 1997; Gulati *et al.* 2000) and the analysis of intra-organizational networks (e.g., Hansen 1999; Tsai 2001; Reagans and Zuckerman 2001; Holly and Krackhardt 2001).

In fact, the introduction of social network in economics and in management dates from 1980s and the crucial change in the industrial landscape which has led to the development of intra-organizational and inter-organizational cooperation. Before, economic relationships were supposed to be coordinated by the price mechanism, complete contracts and property rights allocation. The marketing logic supplanted the relational logic in the coordination of economic activities. The dominant theories did not give a place to affects and emotions in exchange relationships (see Lawler 2001). But it became clear that individuals and organizations do not evolve in a closed environment. Economic actors are indeed embedded in social relationships and networks. For Granovetter (1985: 487), economic actions are embedded “in concrete, ongoing systems of social relations”. He sheds light on the role of the structure and nature of social relations in the performance of the whole system of economic actors. Finally, the concept of “embeddedness” gives a better understanding of economic phenomena and proposes a new representation of exchange relationships.

The literature on networks is interested by the relationships economic actors establish. Including in economic actors are individuals, groups, organizations or institutions. Arguably, there are different levels of analysis. Marsden (1990) makes a distinction between the "whole network" and the "egocentric or personal" network. The former – which is also the larger – refers to the study of the whole social structures. The main purpose is to compare the different forms of network. The aggregative level is here analyzed. The latter refers to the study of individual actors. The main aim is to analyze inter-individual relationships and the social ties that bind them. This approach aims to explain the differences between individuals in terms of social position, outcome or performance. The individual level is here considered. Independently of this distinction between the individual level and the aggregative level, the main difficulty for social research is to define the boundaries of the analyzed network. Who is in the network? Who is outside the network?

What is clear is that a network is characterized by both its structure and its embedded relations. The network structure mainly refers to the famous sociological works that emerged during last decades; most notably Granovetter (1973) on the distinction between the weak ties and the strong ties, Coleman (1988) on the concept of closed network, and Burt (1992, 2004) on structural holes and brokerage opportunities. The analysis of the network structure – namely its size, density, opening and closure degree or weak and strong ties – allows to identify the network configuration that better matches the access conditions to required complementary resources. Gulati (1999) proposes to define these resources as "network resources".

The literature is largely dominated by research works on the network structure. If the structural heritage is very important in the field of networks (Borgatti and Foster 2003), the relational dimension is also crucial. Structural and relational elements seem to function as complements (Gulati 1988; Rowley *et al.* 2000). The relational dimension refers to the nature of the network ties, i.e. the nature of the personal relationships economic actors have thanks to their repeated interactions (Nahapiet and Ghoshal 1998). This relational embeddedness is characterized by the cooperation of a network's members. In this paper, we particularly consider the so-called interpersonal network; which is in part the result of this relational approach to networks.

2.2 Cooperation, Social Capital and Interpersonal Networks

The concept of interpersonal network rests on two crucial social dimensions, namely a great cooperation and a strong social capital. Cooperation is linked to the ties economic actors create to achieve a common purpose. More precisely, "cooperation refers both to the ability to act for a common purpose and to the cohesion necessary to achieve this collective purpose" (Chassagnon 2009: 3). A large part of the literature on network focuses on social capital and finds regularities in the emergence of cooperative behaviors. It results that interpersonal relationships are imbued with trust, reputation and mutual identification. These social and cohesive elements are at heart of cooperation (Cohen and Prusak 2001).

Numerous research works have shown that the greater the trust, the stronger will be the social ties and the cooperation (Nahapiet and Ghoshal 1998). Trust can be here defined as the belief in good intentions and reciprocity in a given social exchange. Put it differently, trust is a rational and credible expectation of cooperative behaviors (Mayer *et al*. 1995). Bouty (2000) argues that the type of exchanged resources is related to the degree of trust. When economic actors exchange with each other but do not really know each other, they have limited trust towards each other – which implies a poor sharing of information and potential opportunistic behaviors – and the shared knowledge is poorly socially constructed. In general terms, the information individuals exchange is quasi-common and not valuable. However, when individuals know each other and have trust towards each other, the exchanged resources are varied, socially constructed and so valuable. Hence, the shared knowledge is less generic and more strategic and tacit. Arguably, trust is a necessary condition for the exchange of critical resources.

Trust is based on experience and past interactions between actors (Ring and Van de Ven 1992). More exactly, there is a biunivocal relation between trust and cooperation. Indeed, if trust is a requirement for cooperation, cooperation strengthens trust (Leana and Van Buren 1999). Thus, trust is not a given and fixed component but evolves in time, according to the network members' behavior. When interactions between individuals are repeated, their mutual trust is strengthened. This is the point of view of Blau (1964: 94) who considers that "processes of social exchange (…) generate trust through their recurrent and gradually expanding character". Recurrent interactions allow economic actors to have a better acquaintance of each other, share crucial information and identify their common purpose (Tsai and Ghoshal 1998).

Trust and reputation are two linked elements. Besides, a good reputation is a necessary condition to make individuals cooperate. Reputation is the guarantee for an economic actor's future partners to be informed of his present behavior. In this sense, Raub and Weesie (1990: 626) argue that "reputations depend on the embeddedness of interactions in structures or networks of social relations" and add that reputations "illustrate the effects of such embeddedness on the outcomes of interactions". It is clear that reputation – as a complement of trust – results from strong and repeated interactions between actors. But contrary to identification, reputation is never an individual trait. The reputation of an actor is a characteristic perceived by partners and is determined by the regular attitudes and behaviors of an actor. This implies that when an actor anticipates that his present behavior has both present and future consequences, he is supposed to make a trade-off between the short-term effects of his decisions and the long-term effects on his reputation (*ibid.*). Information relative to the behavior of an actor for a given social exchange can be used in the future by his partner or other network's partners, according to the embeddedness of interactions in social networks (Granovetter 1985).

As soon as actors are in a situation of mutual interdependence, reputation effects are crucial so that opportunistic behaviors are reduced. This argument is often used by transaction cost economics to reduce hold-up risks (see e.g., Williamson 1985). The example of diamond merchants proposed by Coleman (1988, 1994) illustrates well the articulation between trust and reputation. The market of diamonds is held by a community in which social and familial ties are very important. There is a strong degree of trust between actors; which facilitates transactions. Indeed, it reduces costs due to security, insurance and the writing of contracts. In this view, opportunistic behaviors are discouraged because reputation makes that each actor is informed on the present behavior of his partners. The fear of being sanctioned for dishonest practices has both short-term and long-term effects that could lead to the exclusion from the community. Actors adhere to a norm of honesty. This example shows that networks promote trust and social norms, but also sanctions; which facilitates transactions. Besides, the more cohesive the networks, the greater will be the probability that an actor acquires a bad reputation by cutting past ties (Ma *et al.* 2008).

The identification to a group allows an individual to access to social exchange opportunities and to increase the frequency of cooperation (Lewicki and Bunker 1996). Interestingly, the actors, who are strongly linked to each other, become identified as the members of the same entity. Hence, the interpersonal network can be appreciated as a single collective entity (see Chassagnon 2008). As a unified group, actors cooperate – notably by diffusing and sharing privileged information – to achieve a collective purpose (Bolino *et al.* 2002). It is hence possible to define the interpersonal network from these theoretical considerations. The interpersonal network is a social network that unites actors who have had repeated interactions through a specific structure of communication allowing them to achieve a common purpose. Actors are embedded in the structure of the interpersonal network. This one is capable of shaping how actors diffuse information and create knowledge (Fang *et al.* 2006). In other words, the specific structure of communication of the interpersonal network can be used to promote creativity and generate productive value in a knowledge economy (see e.g., Uzzi and Spiro 2005). This explains why innovation scholars have introduced the role of network effects in their analytical and theoretical frameworks.

3 Interpersonal Networks and Innovativeness

After having clarified the notion of interpersonal network and its role in the cooperation process, we propose to apply these theoretical insights to the case of the innovation process. Indeed, an innovation is not only the result of organizational structures and financial resources but also and mainly the result of some key individuals or inventors who contribute to the whole knowledge-creating process. Arguably, the past and repeated collaborations between these key inventors strengthen and increase their innovativeness.

3.1 Knowledge-Creating Process and Prolific Inventors

The conception of innovation has evolved significantly for fifty years. During the 1950s, innovation was considered as the result of knowledge developed by isolated inventors and isolated researchers (Landry *et al.* 2002). This is no longer the case nowadays. Innovation is the result of a collective process resting on interactions, exchange of knowledge and cooperation between actors involved in complementary research activities. To create new products or improve existing products, firms need to combine different new resources or to use differently existing resources (Hagardon and Sutton 1997). The innovation process needs to integrate the complementary competences of different actors. These complementary competences and knowledge are exchanged and combined in interpersonal networks of inventors that constitute the main mechanism to facilitate exchanges of new scientific knowledge (Nerkar and Paruchuri 2005). The knowledge-creating process requires strong interactions between actors manifested by the exchange of tacit and explicit knowledge (Nonaka and Konno 1998). Modern knowledge economy is confronted to incomplete and scattered information; which gives importance to networks (Ejermo and Karlsson 2006) and explains that the interest of networks in innovation has been grown over the two last decades.

The analysis of networks of innovation cannot be reduced to interactions between organizations or institutions but must be extended to interactions between individuals (Gay *et al.* 2008). Interpersonal networks – both between and within firms – are used for idea exchanges and knowledge acquisition. Cooperation inside an interpersonal network is a way to exchange and diffuse information and knowledge (Sorenson 2003; Cantner and Graf 2006). Many studies shed light on the key role of certain individuals in the innovative activities of a firm. Different terms and expressions are used to designate these key individuals, as are star scientists (Zucker and Darby 1996), great inventors (Kahn and Sokoloff 2004), star inventors (Harhoff *et al.* 1999), key inventors (Pilkington *et al.* 2009), central inventors (Paruchuri 2009) or prolific inventors (Narin and Breitzman 1995). We use here the term of prolific inventors.

In this paper, a prolific inventor is an inventor whose name is present in at least 15 obtained patents (Le Bas, 2009)[3]. Prolific inventors are a very recent research field. This term has been used firstly by Narin and Breitzman in 1995. However, the interest for highly productive scientists is not new. In 1926, Lotka

[3] Le Bas (2009) explains the threshold of 15 patents for an inventor to be considered as a prolific one. This threshold is the result of the recent empirical studies on the relation between patents and inventions. These empirical investigations show that firms patent more than one patent for protecting an invention. Reitzig (2004) finds, from a sample of patents deposited in different technological fields, that an invention is protected – on average – by at least 5 patents, even though there are some variations between industrial sectors. In manufacturing machinery, the averaging number of patents per invention is 3, whereas in chemicals the averaging number is near to 8. By fixing the threshold to 15 patents and considering an average of 5 patents per invention, Le Bas (2009) considers that the less productive prolific inventors have at least contributed to 3 inventions.

was already interested by this question. He observed that the number of highly productive scientists – measured by their papers publication – was a small part of the whole scientific community. These results lead to the inverse productivity relationship. This means that the number of scientists who produce *n* articles is proportionally $1/n^2$. For 100 scientists who will write a paper, there will be 25 ($100/2^2$) scientists who will write two papers, 11 who will write 3 papers ($100/3^2$) and so on. There will be only 1 scientist who will write 10 papers. In their 1995 article, Narin and Breitzman test the law of Lotka. The performance measuring is not the articles publication but the number of patents deposited by inventors. They study the deposited patents of 4 firms (2 Japanese firms and 2 American firms) in the semiconductor sector for a period of 8 years. In the case they study, the distribution of inventors is conformed to the law of Lotka. Indeed, they find that there is both a small number of inventors who have contributed to the production of a large number of patents and a large number of inventors whose name is cited in just one patent document. For them, certain individuals play a key role in the innovative activities of their firm. Narin and Breitzman (1995: 519) argue that “the key role of a few researchers seems to be a law of nature, and, therefore, a laboratory manager should expect to find such a distribution in his laboratory”. Hence, they conclude that “it also seems clear that, in order for a company to stay active and technologically competitive, it must identify, nurture, and work to retain its leading producers” (*ibid.*).

3.2 Collaboration as the Basis of the Innovativeness of Inventors

We have seen that network effects are crucial in the innovative process to acquire, share, create and develop resources and knowledge. Katz and Martin (1997) underline that collaboration in a research and project perspective is very important and should be encouraged. Many studies rest on the literature on networks to analyze the innovation of firms (Powell *et al.* 1996; Tsai and Ghoshal 1998; Ahuja 2000). All these studies share the view that the position of a firm in a network has a strong influence on its innovativeness (Paruchuri 2009). The concept of innovativeness has been the object of a growing number of researches, particularly interested in the comparison of the innovation capacities of the different countries (Mairesse and Mohnen 2002), the relation between innovativeness and business performance (Hult *et al.* 2004) or the interdependence between network competences and innovativeness (Rodrigues *et al.* 2006). Nevertheless, the notion of innovativeness should be clarified. What elements are included in this concept? In what innovativeness differs from innovation?

Innovativeness is sometimes applied at the macroeconomic (nations) level, even though authors generally use the concept of innovativeness at the microeconomic (firms and individuals) level. For example, Rogers (1983: 252) defines innovativeness as “the degree to which an individual or other unit of adoption adopts new ideas relatively earlier than other members of a system”. Thus, innovativeness refers to the ability to have an idea before others. But innovativeness can also be assimilated to “the degree to which an individual is relatively earlier in adopting an innovation than other members of his social system” (Rogers and Shoemaker 1971: 27). Mairesse and Mohnen (2002) define innovativeness as the innovative ability or capacity of nations. In this view, if the study of innovation is based on outputs, innovativeness refers to the ability to transform innovation inputs to innovation outputs. In the literature, the notions of innovativeness and innovative capacity are combined and often used as synonyms. For Tuominen *et al.* (2004: 497), “innovativeness refers to an organization’s capacity to innovate – to create and adopt innovations and implement them successfully”. But Hurley and Hult (1998) adopt a different vision of innovativeness which is complementary to innovative capacity but not synonym. In this view, innovativeness rests on the ability of an individual entity to be open to new ideas, whereas innovative capacity refers to the ability of a firm to successfully implement new ideas and products. Anyway, this distinction has been the object of a debate between Woodside (2005) and Hurley *et al.* (2005). Other authors, coming from the resource-based view school, consider that innovativeness is composed of two components: a technological component and a behavioral component. This view of innovativeness focuses both on the capacity and the commitment of a firm to innovate (Avlonitis *et al.*1994; Rodrigues *et al.* 2006).

The more important resource for a potential partner is his ability to increase the probability of success of a given research project (Cantner and Graf, 2006). The innovativeness of a firm depends directly on the ability of its members to innovate. Certain individuals play a more important role than others. Consequently, by working together and cooperating, inventors acquire experience, trust and reputation. These organizational and relational elements facilitate future collaborations which strengthen the ability of inventors to innovate which improve the innovativeness of firms and so on. We define here the innovativeness as the dynamic capacity of an inventor to invent.

Concerning the case of co-invention, the collaboration between inventors requires an extended communication structure, which is both verbal and non-verbal, and a mutual sharing of the core competences of each one (Tushman 1979; Singh 2005). Indeed, during the co-invention process, inventors share their own understandings of the problems they must resolve as well as the methods and resources necessary to resolve them. It is impossible for a scientist to conceal all the knowledge and competences necessary to complete a complex research project successfully. Collaboration can be appreciated as a strong mechanism of interactions allowing to share competences and resources. In a knowledge economy, collaboration between scientists is a modern requirement (Melin and Persson 1996). Collaboration generates a cross-fertilization of ideas (Katz and Martin 1997), which can lead to new insights and perspectives and promote lead time. Hence, collaboration strengthens creativity and gives access to new ideas and projects that could not exist without it.

If it is interesting to analyze cooperation at the inter-organizational level, it seems particularly accurate here to analyze the collaboration between individuals. Indeed, even though organizational arrangements are crucial in the cooperation process, physical interactions take place only through individuals (Cantner and Graf 2006). The basic unit of analysis of collaboration is the cooperation between two or more individuals; it makes no odds that it takes place at the intra-organizational level or at the inter-organizational level. This remark can be easily transposed to networks. If there are many papers both on inter-organizational networks and intra-organizational networks, there is also a growing interest for adding interpersonal networks to them (e.g., Ma *et al.* 2008; Paruchuri 2009).

To measure the innovativeness of inventors through interpersonal networks, we have to take scientists as the unit of analysis. Each scientist uses his network to mobilize resources necessary to achieve professional – both individual and collective – purposes. The literature often uses the term of “the innovation of firms”, but the innovation process is in fact the result of the work of one or more key individuals. That’s why, in this paper, we prefer using the term of “interpersonal network of inventors” rather than the one of “network of inventors”. Indeed, the latter must be understood as the given set of actors of an innovative system; which includes organizations, State and public institutions. We define here the interpersonal network of an inventor as the set of co-authors with whom he has repeatedly patented an innovation.

As regards with this clarification on interpersonal networks of inventors, we make the theoretical assumption according to which the effects of interpersonal networks resulting from repeated collaborations between the network’s members have a positive influence on the innovativeness of inventors – i.e. on the individual capacity of inventors to dynamically invent. Thus, the next and last step of this research work consists in testing, empirically, this relation.

4 Some Empirical Evidences on The Interpersonal Networks of Inventors

The question of the role of network effects in scientific production and innovativeness is not really new. Some empirical works have ever tried to test this relation. However, the measure of the impact of interpersonal networks on the innovativeness of inventors is more recent and less investigated. That’s why we propose here to bring some new insights on this question by testing the relation between the interpersonal networks of inventors and their probability to be highly prolific, from patent documents data.

4.1 What the Empirical Literature Says

The literature on networks has been interested in the effects of the collaboration between scientists for a long time. Many researches have been based on co-authors of scientific papers and, more recently, on co-authors of patents.

Concerning the studies on the role of collaboration in the production of scientific papers, they use bibliometric data in order to measure the number of co-authored papers and appreciate collaboration networks. For example, Melin (2000) analyzes the collaboration between researchers and considers that two scientists collaborate as soon as they co-write a paper together. He identifies the reasons that lead researchers to collaborate, the different forms the collaboration can take and the resulting effects. Finally, it appears that it is access to critical resources[4] and potential profits that constitute the main motivation for researchers to cooperate. The co-authors who were questioned made reference to an improvement of their knowledge and the emergence of new ideas. Many other researches have been realized on this view. Newman (2001a, 2001b) proposes to analyze both the collaborations between scientists in physics, biomedical science and computer science and the structure and properties of their networks. He finds that typical distance between pairs of authors through the networks is small so that the networks form a "small world". Melin and Persson (1996) study the different forms of collaboration between Swedish researchers. They show that "interactions between academia and industry are not only a matter of national concern" and that "the national industrial base is not broad enough to satisfy the collaborative needs of the university" (*ibid*.: 369). In the spirit of Lotka (1926), diverse studies have been carried out to test the hypothesis according to which a high degree of cooperation is correlated with a high degree of productivity. Thus, Pravdic and Oluic-Vukovic (1986) analyze the collaboration in the chemical sector and measure the scientific output by the number of publications. They find a positive relation between the frequency of the collaboration between authors and their number of publications. Besides, the collaboration with highly productive authors increases the individual productivity of an author, whereas the collaboration with low productive authors decreases his individual productivity.

Concerning the studies on the role of collaboration in innovation, some recent works have used patent documents data in order to analyze the networks of inventors and the intra-network diffusion of knowledge. The used data rest on co-inventors or patent citations. A part of these studies takes an interest in the diffusion of knowledge and the configuration of networks in which knowledge is diffused. For example, Balconi *et al.* (2004) analyze the transfer of knowledge between university and industry in Italy. They show that the role of geographical and cognitive proximity in the transfer of technologies depends on the nature of knowledge and the social structure of Italian inventors. They emphasize the specific role of academic inventors in different technological areas. Singh (2005) analyzes both the collaborations between inventors and the patent citations. He focuses on intra and inter-firm knowledge flows and intra and inter-region knowledge flows and finds that the interpersonal network has an influence on the patterns that diffuse knowledge. Ejermo and Karlsson (2006) also base their investigation on the coauthorship of patents to study the knowledge exchanges and flows between inventors and the structure of the inter-regional network of inventors in Sweden. They conclude that "spatial affinity extends beyond the region if it has less own R&D-related resources (business R&D, university R&D and patenting); if it is close to the other region and if it is relatively small" (*ibid.*: 412).

[4] In critical resources are included knowledge, competences and even materials.

Other studies aim to investigate the collaboration between inventors. Mariani (2000) examines the impact of the interpersonal network of inventors on the implementation of innovation from European chemical patents. The main purpose of this research work is to identify if the regional features and the features of firms have an influence on the probability of collaborating on innovation. His results suggest that multinational firms and technological clusters increase the probability of collaborating between inventors. Cantner and Graf (2006) propose to analyze the evolution of the aggregative network of inventors and the scientific mobility in Jena in Germany. They distinguish two periods and show that present cooperation does not reproduce past cooperation (with the same partners). In this sense, cooperation is not persistent in Jena. The evolution of the network of inventors depends more on scientific mobility and technological overlap between actors rather than on past cooperation. Fleming *et al.* (2007) complete patent documents data by interviews with inventors and investigate the regional networks of small-world[5]. They reveal "the existence of regional small-world structures and the emergence and disappearance of giant components in patent collaboration networks" (*ibid.:* 938). Their main conclusion is that both short path lengths and larger connected components are correlated with an increase in subsequent patenting. Wilhelmsson (2007) also uses patent documents data in Sweden for the period 1994-2001 and gives a particular attention to the obtaining of patents. He shows that the researchers who collaborate improve their effectiveness in the innovation process thanks to more patent applications approved. His main result is that the probability of obtaining a patent is increased from 1.1 to 1.5 if there are collaborations. Furthermore, he also analyzes the collaboration in line with the technological fields and finds that the collaboration is more important in the IT sector than in mechanical engineering sector.

Paruchuri (2009) looks into both the intra-firm and inter-firm collaboration. More exactly, his article shows that the position of a firm in an inter-firm network has an influence on the internal dynamic of innovation of its intra-firm network. His study rests on 8 pharmaceutical firms and looks at their patent documents (more particularly the data of co-invention and patent citations) for the period 1982-1999 in order to assess the internal innovative dynamic of firms. One of his main results is that the participation of central inventors[6] to the innovative activity of the firm adopts an inverted U curve. The impact on the creation of new knowledge for inventors is reduced from a certain level of centrality within the intra-firm network.

These different contributions symbolize very well the interest of using co-authors data and patent documents data in network analysis as a large part of the empirical applications do (Cantner and Graf 2006). The inventors who appear in a same patent document work together on a long-term basis. Hence, information on co-authors provided by a patent document includes the majority of the interper-

[5] For them, small-world networks are clusters of locally dense interaction that are connected via a few bridging ties.

[6] A central inventor has an influence on the innovative activity of a firm insofar as future innovations are constituted from his knowledge.

sonal ties which exist between the inventors having contributed to the project (Singh 2005).

4.2 The Case of Prolific Inventors in France

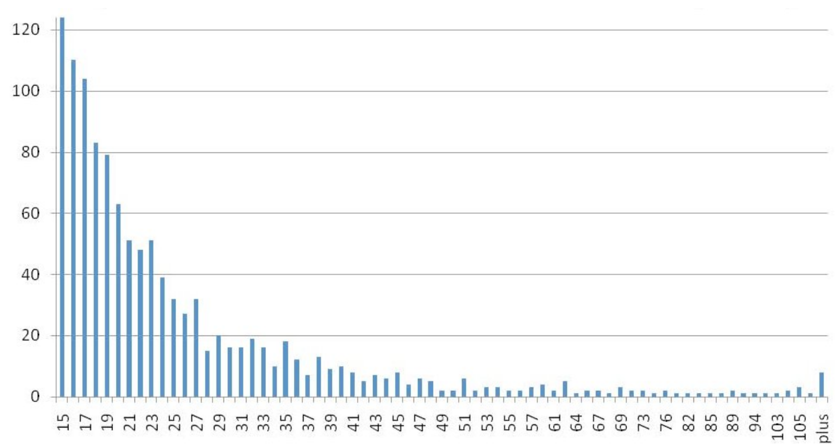
In this paper, we have chosen to test the theoretical hypothesis according to which interpersonal network effects have an influence on the probability for inventors to be highly prolific. Our empirical investigation concerns the French highly prolific inventors. In this view, a highly prolific inventor is an inventor who has participated to at least 30 obtained patents.

4.2.1 Sample and data collection

Our study rests on an individual data base. This base has been constituted from data provided by USPTO (United States Patent and Trademark Office), completed by NBER (National Bureau of Economic Research) data, for the period 1975-2002. The base pools 1157 French prolific inventors who obtained 30477 patents on this period. We find the name of the less prolific inventors on 15 patent documents. The more prolific of them appears in 243 patents. Figure 1 gives the distribution of prolific inventors (on the ordinate) as regards with the number of patents to which they have contributed (on the abscissa). This is a decreasing and right skewed distribution. We can observe that the population of French prolific inventors takes on the dissymmetry emphasized by the law of Lotka. This means that many prolific inventors have contributed to few patents. On the contrary, few prolific inventors have contributed to many patents. We can identify and strongly distinguish prolific inventors from highly prolific inventors. Thus, we make the assumption that an inventor is highly prolific as soon as he is associated to at least 30 obtained patents.

We dispose of some crucial information on co-authors for each patent. As in Balconi *et al.* (2004), Ejermo and Karlsson (2006), Cantner and Graf (2006) and Wilhelmsson (2007), we consider that each inventor who appears in the same patent document shares his technical and scientific knowledge. Besides, we do not take into account the fact of being in the same firm. Interestingly, Singh (2005: 756) reveals that “being in the same region or firm is found to have little additional effect on the probability of knowledge flow among inventors who already have close network ties”.

Figure 1: The distribution of French inventors' patents



4.2.2 Variables and measures

The main purpose of our empirical investigation is to test the hypothesis according to which the inventors who have the more dynamically collaborated are the ones who have the best innovativeness. Many studies on R&D collaboration have been focused on scientific or technological outputs (Mariani 2000). In this article, we are not interested in network effects on innovation as an output but in the favourable conditions for successfully implementing innovation.

The dependent variable called "innovativeness" is the capacity of inventors to innovate measured by the number of obtained patents. We use patent data to make the distinction between highly prolific inventors (equal to or more than 30 patents) and prolific inventors (between 15 and 29 patents). Hence, we create a binary variable:

Var_innovativeness = 1 if the inventor has contributed to at least 30 patents
Var_innovativeness = 0 it the inventor has contributed to less than 30 patents

The independent variable called "collaboration" has been created to estimate interpersonal network effects. To create it, we have observed the repeated collaborations between an inventor and his co-inventors. Thanks to patent documents data, we have identified the past successful collaborations between inventors working on the same project and made the distinction between the first collaborations and the extended collaborations. In other words, to measure repeated collaborations between prolific inventors, we have identified, for each patent, the different co-inventors. Thus, the variable 'collaboration' has been constructed regarding the names of prolific inventors who have been repetitively associated with the same co-inventors in patent documents. In the literature, it is accepted to consider that the first collaboration marks the beginning of an interpersonal tie between actors (Singh 2005). Thus, as we have observed in dynamic the interpersonal network of inventors by considering the date of the obtaining of the patent, it is necessary to code data in order to operate this distinction between the patents obtained without past collaborations and the patents obtained with past collaborations. Morone and Taylor (2004) have shown that the structure of network is modified consecutively to interactions; which allows to model the dynamic of knowledge diffusion and collaborations. As a result, when for a given patent, the observed inventor co-patents with inventors who already belong to his network (owing to past collaboration) and with one or several new inventors, we consider that there is "past collaboration" since some inventors of the patent have ever invented together and so on. Hence, we create again a binary variable:

Var_Collaboration = 1 if the inventor of a patented invention has ever collaborated with at least one of the co-inventors
Var_Collaboration = 0 if the inventor of a patented invention has never collaborated with at least one of the co-inventors

To test the relation between the innovativeness of inventors and past collaborations, we use a binary logistic regression.

$P(Y=1/X) = \Phi\ (\beta 0 + \beta 1X)$; where Y is the probability that the inventor is highly prolific and X the fact that the inventor has ever collaborated with at least one of the co-inventors.

4.2.3 Results, short discussion and future research orientations

Table 1 presents the different results of the binary logistic regression. There are three main results:

(1) The percentage of concordance shows that our model predicts the innovativeness of an inventor with a success probability of 59.8%.
(2) The results of the logistic binary regression show a significant relation between the dynamics of interpersonal network effects – measured by past and extended collaborations – and the innovativeness of inventors – measured dynamically by at least 30 obtained patents. More explicitly, the binary logistic regression indicates that the probability that an inventor will be persistently and highly prolific varies significatively ($p<.001$) with interpersonal network effects.
(3) The odds ratio is 2.22. This means that the probability for an inventor to be highly prolific is multiplied by 2.22 if he has repeatedly collaborated. This result is in line with the empirical work of Wilhelmsson (2007).

Table 1: Results from binary logistic regression

Dependent (Response) Variable: Y					
Data Set: Binary Logit					
Number of Response Levels: 2					
Optimization Technique: Fisher's Scoring					
Parameter	Estimation	Std Deviation	Khi-2	Pr > Khi-2	Exp(Est)
Intercept	-0.6796	0.0169	1608.8366	<.001	0.507
X	0.7985	0.0236	1144.6299	<.001	2.222
Sample Size: 30477					
Number of Observations Used: 30475					
Concordance Percentage: 59,8%					
Likelihood Ratio (R): 1167.9403					
AIC: 40495.743					
-2 Log L: 40491.743					

As regards with this model, it seems that – as the theoretical hypothesis predicts – persistent cooperation has an influence on the persistent innovativeness of inventors. This result is not surprising because innovation is a social process implying different and complementary resources. Collaboration is finally the meeting point of key human resources. From this study at the individual level, it is possible to find some implications for the management of firms. Hence, firms should encourage interpersonal cooperation in order to dynamically innovate and increase their durability. The nature of the firm in a knowledge economy with innovation and incomplete knowledge diffusion is indeed "to capture value (profit) from its advantages and actions; and that the way in which the firm tries to achieve this (by establishing quasi-sustainable competitive advantage) is its essence" (Pitelis and Teece 2009: 5). But it involves to have new ideas and to regularly invent new processes and products. Innovation is a strong source of competitive advantage. Arguably, the overall evidence is also in line with the work of Singh (2005: 756) according to whom "interpersonal networks are important in determining observed patterns of knowledge diffusion". Innovation is not an isolated and individualistic process. In this view relational elements are very important; which gives a crucial role to social capital in the competitive advantage of firms.

The model proposed in this paper is very simple and aims only to test the relation between cooperation and innovativeness at the individual level. Three limitations and so future research directions must be mentioned. Firstly, this model does not include technological fields. These ones could be introduced as control variables. Secondly, the innovativeness of inventors is explained by other important variables than extended collaborations. It would be interesting to propose a more complete model. Thirdly, interpersonal network effects are here limited to prolific inventors; which excludes a large part of collaborations. Thus, the future model should analyze the innovativeness of prolific inventors from the whole network of collaborating inventors and not only from the network of prolific inventors.

5 Conclusion

This article investigates the threefold relation between networks, cooperation and the innovative capacity of inventors. The paper here suggests that the innovativeness of inventors is a function of the propensity of inventors to continue collaborations. More precisely, we have tested the relation according to which the persistent collaborations of an inventor lead him to be highly prolific. Even though there is a large theoretical and empirical literature on the link between network effects and innovation, we think that this paper is among the first to focus on the dynamic effects of interpersonal network on innovativeness. Using a survey dataset of 30477 patent documents for the period 1975-2002, we find the significant probability that the innovativeness of inventors varies with the fact they have ever collaborated together. This conclusion has strong implications both for managers and economists who have the mission of developing the devices necessary to encourage and promote cooperation within the firm and between firms.

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