Papers in Evolutionary Economic Geography

09.14

Proximity and the evolution of collaboration networks: Evidences from R&D projects within the GNSS industry

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Abstract : Increasing attention had been given recently to understand how networks affect organizational performance in innovation studies. Surprisingly, underlying mechanisms of their evolution have been more neglected, and still remain unclear. This lack of interest is denounced today by recent papers which claim that it is a crucial issue for economic geography. Especially the influence of different forms of proximity on the network's changes needs to be clarified. This paper contributes to this ongoing debate by determining empirically how organizations choose their partners given to their geographical, organizational, institutional, cognitive and social proximity. The relational database is constructed from publicly available information on the R&D collaborative projects of the 6th European Union Framework Program within the navigation by satellite industry (GNSS). Patterns of evolution of the GNSS collaboration network are determined according to a longitudinal study of the relational changes occurred between four consecutive years, from 2004 to 2007. Empirical results show that geographical, organizational and institutional proximity favour collaboration. Inversely, organizations prefer to avoid partnerships when they share a cognitive proximity (same knowledge bases). The last result demonstrates that the kind of project studied does not create a sufficient level of social proximity to stimulate collaboration.

Keywords : Proximity; collaboration networks; innovation; network longitudinal analysis; R&D collaborative projects; SIENA

1 Introduction

Relations between organizations have often been a missing link between proximity and innovation, which has led especially to interrogations about the precise role of geographical proximity on innovation processes (Breschi & Lissoni 2001, Malmberg & Maskell 2002, Torre & Rallet 2005, Boschma 2005). Indeed, from the Marshallian "industrial atmosphere" of industrial districts to the more formalized empirical approach of localized knowledge spillovers (Jaffe 1989, Audretsch & Feldman 1996), it has been shown that proximity and innovation are narrowly and ambiguously linked. Nevertheless, the absence of networks in the localized knowledge spillovers literature had rapidly conduced to a claim for the opening of this "black box" (Breschi & Lissoni 2001) in order to understand how proximity, at least in the simple geographical form, influences innovation activity or conduces to clustering processes (Suire & Vicente 2009). Collaboration begins to be seen as a strong vector of the diffusion of knowledge, and consequently, their implication on organizational performance start to pay an increasing attention. Influence of network positions of organizations, like centrality, reachability, brokerage, or influence of the structure of the overall network on organizational performance is mostly studied (Ahuja 2000, Gay & Doucet 2005, Uzzi & Spiro 2005, Schilling & Phelps 2007, Boschma & ter Wal 2007, Gilsing et al. 2008) in the last decade. Nevertheless, focusing attention on organizational performance by using networks indicators as an independent variable has strongly contributed to create another black box, the network.

Indeed, networks are often seen as independent variable, with a given structure and a given position of actors, but little attention is paid about the underlying mechanisms which had led to this structure. More precisely, the main drivers of innovation network evolution still remain unclear, even if many different disciplines have in recent years contributed to study patterns of change in organizational networks (Borgatti & Foster 2003, Brass et al. 2004, Knoben & Oerlemans 2006, Gluckler 2007). Especially the ambiguous effects of proximity on the networks changes need to be clarified and begin to be investigated. Boschma and Frenken (2009) identify this research question as crucial for evolutionary economic geography and propose a theoretical framework to link proximity concepts and the evolution of innovation networks. Following Boschma (2005) in his five forms typology of proximity, this paper contributes to this ongoing debate by determining empirically how organizations choose their partners given to their geographical, organizational, institutional, cognitive and social proximity within an emerging technological field, the navigation by satellite industry (GNSS[1]).

Most of the longitudinal network analysis has studied structural, individual or proximity effects separately. Influence of individual characteristics of organizations on collaboration choices have been a great deal in Economics (d'Aspremont & Jacquemin 1988, Cassiman & Veugelers 2002), and had contributed to figure out the importance of absorptive capacity (Cohen & Levinthal 1990) in more recent empirical approaches (Giuliani & Bell 2005, Boschma & ter Wal 2007). Following the seminal contributions of endogenous structural effects of networks changes in sociology (Holland & Leinhardt 1971) and physics

[1] Global Navigation Satellite Systems

(Albert & Barabasi 1999), Glückler (2007), then Giuliani (2008) tried to figure out the influence of structural network effects on the evolution of innovation network. Recent papers begin to indicate ways to measure proximity (Nooteboom 2000, Bouba-Olga & Zimmermann 2004, Powell et al. 2005, Cantner & Graf 2006) which conduce others to show empirically how different forms of proximity affect the selection of partners (Autant-Bernard et al. 2007, Ponds et al. 2007). Nevertheless, it is hard to find empirical findings about the role played by more than two forms of proximity simultaneously, since ways to measure proximity and appropriated data represent an empirical challenge for each form of proximity. In order to explain respective influence of proximity forms, an important issue of this paper is dedicated to the integration of the five forms of proximity, to be able to analyze what happens when each form of proximity control the effect of the four others. Doing this, we will try to clarify the influence of each form of proximity on the evolution of the GNSS collaboration network.

The first part of the paper is dedicated to a theoretical presentation of the five forms of proximity. We present the definition of geographical, organizational, cognitive, social and institutional proximity, and their respective influence on the evolution of collaboration networks. The second part explains the origin and the nature of the relational data. We present specificities of the GNSS industry, but also how data are collected and the sample is constructed. The third part pays attention to the methodology we use to analyze the longitudinal data. We will especially insist on the operationalization of the forms of proximity, but also the statistical model used (SIENA) and its specification. We present a discussion of the main empirical results of the model in the fourth part of the paper. Open questions and future research agenda conclude the paper.

2 How Proximity influences the evolution of collaboration networks

This section elaborates a theoretical framework in order to explain the influence of proximity on the growth of the network. This theoretical part is thus based on the concept of proximity (Bellet et al. 1993, Rallet & Torre 1999, Boschma 2005, Carrincazeaux et al. 2008), which has recently been formally linked to the evolution of innovation networks in economic geography (Boschma & Frenken 2009). Seminal contributions relating proximity concepts and inter-organizational collaborations appeared with papers dealing with the fact that geographical proximity facilitates face-to-face interactions (Boschma 2005, Weterings 2006). This recent wave of formalization (Knoben & Oerlemans 2006, Ter Wal & Boschma 2008, Boschma & Frenken 2009) opened a new research area dedicated to the influence of proximity on the evolution of innovation network. Proximity researchers have produced many theoretical propositions in order to define various forms of proximity and their articulation. We use the analytical distinction in five forms proposed by Boschma (2005), where geographical, cognitive, organizational, institutional and social proximity are defined. The proximity effect supports globally the idea that actors are more likely to interact with the same kind of actors. This similarity can relate to the same spatial location (geographical), the same knowledge bases (cognitive), the same group of firms (organizational), the same kind of institutional form (institutional) or the same social network (social). The proximity effect is in this sense close to the homophily effect (McPherson et al. 2001, Powell et al. 2005), where actors interact more with other which have similar attributes.

2.1 Geographical Proximity

Geographical proximity refers to the spatial separation between actors (Gilly & Torre 2000), and is supposed to provide easier and less expensive face-to-face interactions (Boschma 2005). It is the most used form of proximity in the literature. Nevertheless authors sometimes prefer the term of spatial or physical proximity. Even if geographical proximity is certainly the simplest and less ambiguous form of proximity, two mains streams are expressed in the proximity literature. The first one defines the geographical proximity by the physical distance that separate two organizations. It can be in this case measured on the basis of a metric system (miles or kilometres) or using travel times. The second kind of definition of geographical proximity refers more to the perception by actors of their spatial area (Bouba-Olga & Grossetti 2008). Spatial area is often express using traditional boundaries (nation), or political decentralized units (region). Recently quick development and massive utilization of transport and communications systems led authors to clarify the distinction between co-location and geographical proximity. Indeed, organizations can share geographical proximity without being co-located for the moment of a meeting, a visit or a conference using temporary geographical proximity (Torre 2008). Nevertheless, it is interesting to note that even if difference subsists on the definitions of geographical proximity, there is a common representation on the underlying mechanisms between geographical proximity and the evolution of collaboration network. First of all, distant collaborations implies a transport cost which can rapidly became prohibitive, especially in high-tech industries that sometimes requires the use of the same technological platform[2]. It is also claimed for far that tacit knowledge is an important driver of innovation processes (Nelson & Winter 1982, Howells 2002) and requires face-to-face interactions, easier with geographical proximity (Gilly & Torre 2000). Following this, we will test a first hypothesis:

> **Proposition 1**. *Organizations prefer to start collaborations when they belong to the same spatial area, i.e. when they share a geographical proximity.*

2.2 Cognitive Proximity

Cognitive proximity refers to the degree of similitude of the knowledge bases of organizations (Nooteboom 2000), and is necessary to communicate and transfer knowledge between partners (Knoben & Oerlemans 2006). The collaboration choice results of a situation where an organization needs external knowledge (held by the partner) in order to innovate. External knowledge of the partner is not interesting if it is exactly the same of the other organization. The existence of a certain amount of cognitive distance is indeed, in opposite to others forms of proximity, the only incontrovertible condition for a collaboration to exist,

[2] Clean rooms or testing equipments in the GNSS industry for example

especially for R&D collaborations. It is also certainly the more decisive form of proximity for an organization in the selection process of its future partners (Boschma & Frenken 2009). In other words, when two organizations share a high level of similarity of their knowledge bases, they will avoid collaborating. Nevertheless, a certain degree of cognitive proximity is also necessary to communicate and ensure an effective transfer of knowledge, which leads to a trade off between novelty (cognitive distance of knowledge bases) and communication (cognitive proximity of knowledge bases), illustrated by the existence of an optimal cognitive distance which will ensure novelty but also effective communication. Other forms of proximity play in a certain sense a more secondary role in the selection process of the partner with whom an organization will decide to engage collaboration. Told differently, if geographical proximity is neither a necessary nor a sufficient condition for interactive learning (Boschma 2005), contrariwise, the existence of a certain cognitive distance is per se necessary for a collaboration to take place. Cognitive proximity, define above as the proximity of the knowledge bases, can thus be understood according to technological distance of the final product, the similarity of the professional background of individuals or the kind of knowledge developed. In our empirical study, our measure of cognitive proximity will refer to the similarity of the knowledge bases according to the kind of knowledge developed: analytic (scientific), synthetic (engineering) or symbolic (artistic) (Asheim & Coenen 2005, Asheim, Boschma & Cooke 2007). We do not follow exactly Nooteboom (2000), because we do not test if organizations are collaborating with partners who are situated at an optimal cognitive distance. More precisely, we follow the idea previously formulated that actors are not attracted by organizations which develop the same kind of knowledge, and we elaborate the second hypothesis:

Proposition 2. *Organizations are less likely to interact when they have the same knowledge bases, i.e. when they share a cognitive proximity.*

2.3 Organizational Proximity

Organizational proximity is defined as the degree of hierarchical interconnections between two organizations (Boschma 2005) and reduces uncertainty about the behaviour of the future partner. The literature provides two major different definitions of this concept, which can sometimes leads to ambiguity. The first one refers to a "relational space", in opposition to a geographical one. In this literature, organizational proximity is defined by interactions of different nature (Rallet & Torre 2001). In the definition we propose, organizational proximity is a specific form of linkage between firms of the same group, which should not be confused with collaboration networks, or social networks[3]. It can nevertheless be considered as a network by itself, where the nodes are organizations, more often linked by financial ties. In the definition we adopt, two organizations can thus share an organizational proximity without any innovative, collaborative or social interactions. The degree of organizational proximity is defined by the degree of autonomy and control induced by their link (Boschma 2005). To give a concrete example extracted from the sample we will use in the empirical

[3]While the first definition of organizational proximity as a relational space can contrariwise relates to collaboration or social networks.

part, the French satellite constructor, Thales Alenia Space and the Italian one, Telespazio are characterized by an organizational proximity because they are both subsidiaries of Thales and Finmeccanica[4]. When actors share a high degree of organizational proximity, it is easier to avoid unintended knowledge spillovers and reduce the risk of opportunity. It can also increase the possibility to use temporary geographical proximity and help to reduce cost of collaboration by providing easier exchange of employees, working group or meeting organization. Finally, relevant information about knowledge base of both partners is also more available, which is crucial for a good cognitive matching and an efficient collaboration, as described above with the definition of cognitive proximity. These considerations lead to the third hypothesis:

> **Proposition 3.** *Organizations prefer to interact with members of their industrial group, i.e. when they share an organizational proximity.*

2.4 Institutional Proximity

Institutional proximity is defined by the similarity of informal constraints and formal rules (North 1991) sharing by actors, where common representations and routines of working allow organizations to realize an efficient transfer of knowledge (Knoben & Oerlemans 2006). The institutional proximity is thus composed by formal institutions and informal institutions. Formal institutions are shared for example by individuals of a same country following national laws, but also by employees of a company when they accept privacy about professional secret or even by organizations which are constraints to follow technological standards (Suire & Vicente 2009) or safety rules. On the other hand, informal institutions are closer to the sociological notion of habitus which is a way of conduct, constructed involuntary through the socialization process. In this sense, the organization culture, or the national culture matters on the routines of working, and so influence the collaboration process. Both formal and informal institutions influence the coordination process of organizations (Kirat & Lung 1999), especially important in collaboration networks. Formal institutions can also refer to the institutional kind of organizations in the triple helix model (Etzkowitz & Leydesdorff 2000) where the industry, the research, the government, and now the public[5] as a fourth helix (Leydesdorff & Etzkowitz 2003) are distinguished. Empirical part will focus on the identification of institutional kind of institutions, similarly to Ponds et al. (2007). Indeed, organizations share and develop complex knowledge around collaborative projects, leading us to test a fourth hypothesis:

> **Proposition 4.** *Organizations are more likely to interact when they have the same institutional form, i.e. when they share an institutional proximity.*

[4]Thales holds 67% of TAS and 33% of Telespazio, while Finmeccanica holds the other 33% of TAS and 67% of Telespazio.

[5]The civil society

2.5 Social Proximity

Social proximity refers directly to a kind of proximity between individuals where friendship and trust are central, and is supposed to diffuse informal knowledge which facilitates collaborations (Boschma & Frenken 2009). It refers to the connexion between social networks of two organizations. In other words, social proximity between two organizations is determined by the degree of interpersonal interconnections between them. Social proximity conduces to the same mechanisms of trust and information diffusion discussed above the organizational proximity, but at another level. This individual level, the personal level can be very relevant for an efficient collaboration. Individuals embedded (Granovetter 1985) in a social network know each other personally, which is determinant in information exchange or technical advices (Breschi & Lissoni 2003, Grossetti & Bès 2001). Empirically, data about social proximity is very hard to gather when we study large organizations. Indeed, if we follow the theoretical understanding of social proximity, described above, we should access to information about the social networks of individuals of all organizations of the sample. This technical problem is often insurmountable, and leads authors to identify social proximity between organizations via the inverse of the geodesic distance[6] between organizations (Boschma & Frenken 2009) on the overall collaboration network or via informations about previous collaborations (Autant-Bernard et al. 2007). Closely to these studies, we will test the last hypothesis:

> **Proposition 5.** *Organizations situated at geodesic distance 2 are more likely to interact than others, i.e. social proximity favour collaboration.*

We will test each of these five propositions in order to show how the five forms of proximity described by Boschma (2005) matters on the way actors choose their partners in R&D collaborative projects, and so influence the evolution of collaboration networks. Doing this, we focus in this study on the underlying mechanisms which lead to a specific network structure, trying to isolate and clarify effects of proximity on the networks changes. Results can be found in section 4 of the paper.

3 Data

This part is dedicated to the description of the GNSS industry, then to the process of relational data collection and finally to detailed information about the longitudinal network databases.

3.1 The GNSS industry

GNSS (Global Navigation Satellite Systems) is a standard term for the systems that provide positioning and navigation solutions from signals transmitted from orbiting satellites. Before 1995, and the civil use of the American GPS, these technologies were mainly developed in the aerospace industry for the military industry. Nowadays, in the technological and symbolic paradigm of mobility, GNSS are technologies which find complementarities and integration

[6] Geodesic distance expresses the shortest path between two nodes in the network.

opportunities in many other technological and socio-economic contexts. Indeed, GNSS industry requires collaborations between public and private organizations, from different sectors, and so is characterized by a large variety of knowledge background(Vicente et al. 2008).

Actors of the GNSS industry are thus organizations coming from different institutional types. It can be big companies, SMEs, research centre, government agency[7] or community of users. The biggest spatial companies are the two competitors Thales Alenia Space and EADS Astrium, which both employs near to 2000 employees and are localized in Toulouse[8]. National space agencies, CNES[9] in France or DLR[10] in Germany are very integrated to collaboration network and the knowledge process around GNSS, because their applications are mostly dedicated to health, emergency or social services. Besides, the Egnos program and now Galileo are political key issues to insure a European independence of navigation satellite systems, especially considering the American GPS[11].

The geography of the GNSS industry is clearly a European one. Space industry has from far developed collaboration among organizations of European country. Especially France and Germany for the beginning, and now mainly Spain, England, Netherlands and Italy have also now strong competencies and collaborate in the GNSS composite knowledge dynamic. Indeed, Balland and Vicente (2009) identified the seven mains GNSS clusters in Europe in the regions of Midi-Pyrenees, Upper Bavaria, Ile de France, Inner London, Community of Madrid, Tuscany and Lazio.

3.2 The Data collection

Relational data is often difficult to obtain in social network analysis (ter Wal 2008), and obviously even more when we focus on longitudinal network data (Baum et al. 2003). Key issue of this empirical study is to find precise information about the beginning and the ending of each relation. Hopefully, relevant and exhaustive information about knowledge collaboration can be found in the database of the European Union. Indeed, the European Union launched in 1984 framework programmes on research and technological development in order to fund transnational and collaborative R&D projects. The seventh framework programme had just begun in 2007. The aim of these Framework Programmes is to support collaborative research in order to promote a European research area, reaffirmed trough the Lisbon European council in March 2000. Thereby, European Union funds all or part of some R&D collaborative projects, in different technological field.

These databases are particularly relevant for who aims to study the evolution of collaboration networks, especially in the GNSS industry for at least two reasons, strongly related to the space industry history. Firstly, since the end of the 1950'[12] space organizations are used to work by project. Each satellite is a project by itself and also a unique product that make it almost impossible

[7] Spatial agencies, but also agencies for the security of air flight or railroad.
[8] Midi-Pyrenees Region, France. More information can be found in Vicente et al. (2008)
[9] Centre National d'Etudes Spatiales
[10] Deutsche Zentrum für Luft- und Raumfahrt
[11] Global Positioning System
[12] In October 4, 1957, the Soviet Union successfully launched Sputnik I, the world's first artificial satellite who also was the starting point of the "space race", especially between USA and USSR.

to produce it intensively in a standardized production chain. Secondly, space organizations are used to work on funded projects or programmes because the space exploration had always been a very strategic issue for countries, which has conducted them to support and orient space industry through their space agency. Indeed, the way of collaboration in the Framework Program is close to the one we can find in the GNSS industry. Since 2002, the Framework Program in GNSS is undoubtedly a way for Europe to promote technology and applications for Galileo. This leads us to assume that there is a close link between the network of R&D collaboration from FPs and the R&D collaboration in Europe.

Data are directly collected from database of information services of the European Commission. These databases are publicly available on the Cordis[13] and the GNSS supervisory authority[14] website for the 6th Framework Programmes. Some projects, often the big ones, are more detailed than others, which lead us to collect more precise information on the project's websites, communication documents, work package reports and organization's websites, also publicly available.

Considering the completeness, the dating and the informations about the projects and the organizations given in these databases, one can think that it is the panacea for longitudinal network analysis, but extracting collaboration from funded projects raises another kind of problem. Indeed, institutions which fund these projects, in this case the European Commission, select the partners of a project according obviously to scientific or technical reasons, but also ask in their call for projects for the respect of guidelines dictated by more political reason. It leads sometimes to include organizations which were not selected by the other partners without the consideration of these guidelines. Most of social network analysis which uses framework programmes has to deal with this problem. One solution is to focus on relations between organizations which participate to at least two projects on the overall period, like did Autant-Bernard et al. (2007) in order to exclude what they call "alibi partners". Even if this approach is not perfect, it certainly helps to avoid mistakes about the process of partner selection, by focusing on a reduced sample of active organizations which have all the chance to be real partners.

3.3 The longitudinal network database

Thus, we have constructed a secondary dataset on collaborations between organizations which participate at least at one project from 2004 to 2007. Four distinct relational matrixes are constructed, one for each year. Two organizations are linked when they participate to the same project. It is assumed for the construction of the longitudinal relational database that ties are active since the beginning to the end of each project. Relations are not directed according to the fact that we study a collaboration network, which means that ties are always reciprocate. All relations are also dichotomized[15], the measure of relations is binary: 0 if organizations do not participate to the same project during the year, and 1 if they participate at least at a same project during the year. Table 1[16] shows some descriptive statistics about the longitudinal database. By con-

[13] http://cordis.europa.eu/

[14] http://www.gsa.europa.eu/

[15] The statistical model used, SIENA can only run dichotomized networks.

[16] Cumulated number of projects and organizations on the overall period

struction of the network, there is no missing data because we have access to all GNSS projects funded by the UE under the 6th from 2004 to 2007. Basically in longitudinal network studies, missing data occurs with data gathered by survey.

Projects		**Organizations**	
Number of projects	66	Number of organizations	104
Number of organizations by project	5.47	Number of project by organizations	3.47
Standard error	4.66	Standard error	2.43
Minimum	1	Minimum	2
Maximum	23	Maximum	17

Table 1: Descriptive statistics of the longitudinal data

The dynamic of the GNSS collaboration network is expressed by the number of relational changes. Relational changes occur when a tie is created, dissolved or maintained. Numbers of changes are detailed in table 2. We can observe for each year that more relations are created than dissolved. Indeed, the network is growing during all considered periods as shown by the growth rate indicator. Nevertheless, after a very quick expansion between 2004 and 2005, the network grew slowly in 2005-2006 and the last period, 2006-2007 is a period of stabilization with more or less the same number of ties created and dissolved. Figure 1 gives a bi-partite visualization of the GNSS collaboration network for each year, from 2003 to 2007, where blue squares represent projects and red circles are organizations.

Observed period	**$0 \rightarrow 0$**	**$0 \rightarrow 1$**	**$1 \rightarrow 0$**	**$1 \rightarrow 1$**	**Missing**
2004-2005	4758	413	61	124	0
2005-2006	4455	364	139	398	0
2006-2007	4367	227	215	547	0

Table 2: Network changes

Structural characteristics of the network are described in table 3 for each year. Density expresses the number of effective linkages divided by the maximum number of possible linkages, where a density close to 0 indicate a poor connected network and close to 1 a very connected one. Mean degree express, on average, the number of partners of organizations.

Year	Nodes	Links	Density
2004	39	185	0.25
2005	77	537	0.18
2006	100	762	0.15
2007	95	774	0.17

Table 3: Structural network characteristics

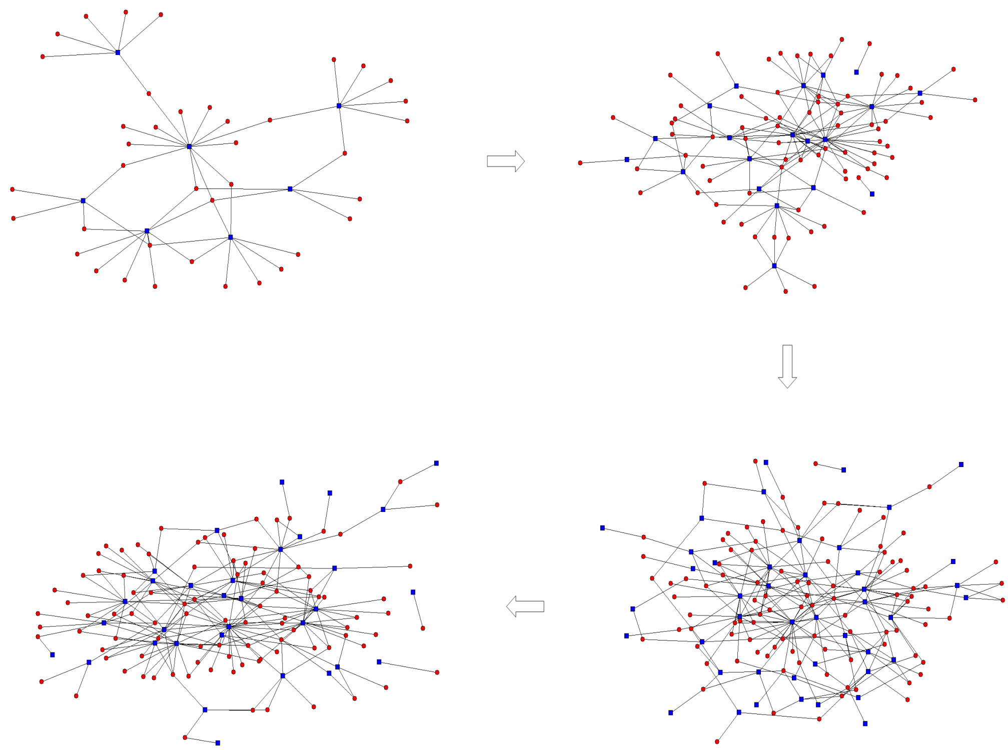

Figure 1: Evolution of the GNSS collaboration network

4 Methodology

In this part, we will describe the methodology we used to analyze the patterns of changes in the network. We begin by focusing on the basic principles of the statistical model utilized in the longitudinal analysis of the GNSS collaboration network: SIENA (Snijders 2001). Then, we describe how the different forms of proximity have been measured to be included in the model. Finally, we insist on the specification of the model.

4.1 Some words about SIENA

As discussed above, precise and reliable longitudinal relational data is often hard to access, but also to analyze according to the complexity of the network structures (Hagedoorn 2006), which requires the development of specific methods of data analysis. The major problem faced by models used for network analysis is that they have to explain and represent the statistical dependence between observations, i.e. the relations between organizations(De Federico De la Rua 2004). This problem prevents the use of conventional econometric techniques, such as regression models, which are precisely based on the assumption of statistical dependence between observations. Thus, the SIENA model have been proposed by Snijders (2001) in order to provide a statistical model able to analyse empirically the evolution of such complex network structures. By combining random utility models, Markov processes and simulation (Van de Bunt & Groenewegen 2007), the SIENA model has permitted to study the dynamic of networks and thus to provide recently new results in many fields of social science, from sociology (De Federico De la Rua 2004, Lazega et al. 2008), to management (Checkley & Steglich 2007), and now in economic geography (Giuliani & Bell 2008).

A large variety of mathematical models have been proposed to study networks changes over the time (Snijders et al. 2009). First statistical models for network analysis evaluated the correlation between variables and a network structure at a certain moment but they are not able to explain relational changes between two moments. These kinds of models were called the "p" models: the p1 model (Holland & Leinhardt 1971, Wasserman 1987, Wasserman & Faust 1994), the p2 model (Van Duijn 1995) and the p* model (Wasserman & Pattison 1996). On the contrary the SIENA model we use is able to explain how networks structures change over time. SIENA is a part of STOCNET, a platform of open software system for the statistical analysis of social networks using advanced statistical models.

Thus, the dependent variable is the network structure itself, represented by a $n*n$ matrix $x = (x_{ij})$, where x_{ij} represents the link from the organization i to the organization j $(i, j = 1, ..., n)$. Siena explains the evolution of such network structures, organized as time series from t to t+1, then t+1 to t+2... for a constant set $\{1, ...n\}$ of actors ($n = 104$ in our empirical study), and as the result of endogenous effects (structural effects), exogenous affects (individual characteristics and proximity) and stochastic effects. Stochastic effects are an outcome of a Markov process, used to calculate the *rate function,* that is to say the expected number of relational changes per organization, which determines the opportunity for organizations to make a relational change. Markov processes are statistical techniques, used when time-dependent stochastic processes are analyzed. One can define continuous time Markov chains as the statistical translation of the evolutionary concept of path dependence. Indeed, we talk about Markov processes if the current state of the network determines probabilistically its further evolution. SIENA made the assumption that all relevant information is included in the past.

SIENA is an actor-oriented statistical network model. It means that organizations are actors, which made rational choices to change their relations, according to the structure of the network and the distribution of individual characteristics and their proximity. Siena defines a utility function for each actor, called objective function, which is the "driving force" (Snijders, Koskinen & Schweinberger 2007) of the model:

$$f_i(\beta, x) = \sum_k \beta_k S_{ki}(x)$$

In the objective function, $f_i(\beta, x)$ represents the value of the objective function of the organization i, at the state x of the network, β_k represent the weight of the parameter, and $S_{ki}(x)$ represents the structural, individual and proximity variables. This function is supposed to be maximized by organizations and thus determine the future structure of the network. Discrete choice models are applied in order to define a probability set of choice where organizations can create, maintain or dissolve a collaboration with all potential other organizations, but notice that in the model we will use, only the creation of ties is explained. It is not statistically relevant to explain why ties are maintained or dissolved in the case of projects, because the length of the collaboration is fixed contractually, at the beginning of each project. The choice supposed to be taken is the one where the change in utility is maximized, associated with a random effect. It leads to traditional multinomial logistic regression (Snijders et al. 2009):

$$P_{it}(x) = \frac{\exp(f_i(\beta,x))}{\sum_{x' \in C} \exp(f_i(\beta,x'))}$$

It refers to the idea that the probability that an actor makes change its relations is proportional to the exponential transformation of the objective function obtained if this change is made. The parameters are not estimated using the classical maximum likelihood according to the complexity of the stochastic models (Snijders 1996, Snijders 2001), but with the method of moments implemented by computer simulation (Schweinberger & Snijders 2007).

4.2 Operationalization of Proximity concepts

A difficult task for who aims to study empirically the different forms of proximity is to measure it. Sometimes referring to well known ways to measure proximity, sometimes proposing new approaches, this part explain how geographical, organizational, institutional, cognitive and social proximity concepts have been turned into measurable observations, in order to be included in the statistical model.

Geographical proximity is measured by the co-location on the same spatial area. The first data required for the measure of geographical proximity is the addresses of the organizations involved in the collaboration network. The database of the European Union rarely gives this information, so we had to find it on projects web sites or directly on organizations web sites. Nowadays, high-tech organizations, like one involved in the navigation by satellite industry want to communicate about their activity, their internal organization and their location. The easier task was to find addresses of university and one establishment firms. We also found documents, like work package reports with addresses of organizations directly. When a doubt still remains for multi-establishment firms, different possibilities occur. If one of the establishments concentrates the R&D, or is known as the research leader establishment, we consider that he was the one involved in the project. If a doubt still remains, it is considered as a missing data. 96 addresses were found. In our perspective, the geographical proximity is determined by the co-location of both organizations in the same spatial area. We distinguish three spatial areas between the national area, NUTS[17] 1 and NUTS 2. National area is defined by the boundaries of the country, NUTS 1 is a country part and NUTS 2 is the most often an administrative region. A level of proximity is applied. If organizations belong to different country, they are geographically distant (0). If they belong to the same country, they share a low geographical proximity (1). If they belong to the same NUTS 1, they share a

[17] The Nomenclature of Territorial Units for Statistics (NUTS) was established by the European Union (Eurostat) in order to provide a standard classification of European spatial units.

medium one (2). Finally if they are co-located on the same NUTS 2, they share a high one (3).

Organizational proximity is measured by the membership of the same financial group. A binary measure of organizational proximity is applied. We consider that two organizations share an organizational proximity if they are both subsidiaries of the same company, if one is a subsidiary of the other or if they have a common joint venture.

The social proximity is measured according to a matrix of geodesic proximity, at level two. In other words, it is a matrix of partners of partners. Interpersonal relations between individuals of organizations are more or less impossible to collect at a European level for the network we study. We consider here that social networks between organizations of the sample are more likely to emerge with partners of partners. This measure is close to the transitivity effect (Boschma & Frenken 2009). A positive effect would mean that organizations prefer start collaboration with partners of partners.

Institutional proximity is measured by the belonging of the same institutional form. We follow a large literature of research about collaboration between research and industry, formalized as the "triple helix model" (Etzkowitz & Leydesdorff 2000) and already used as a measure of proximity by Ponds et al. (2007). The triple helix model focuses on the role of university-industry-government relations for innovation dynamics. Indeed, in our model, institutional proximity will occur when actors belong to the same kind of organizations. We distinguish four kinds of organizations instead of the three classics ones, according to the recent increasing implication of the community of users, called "the public" (Leydesdorff & Etzkowitz 2003) in order to refer to the civil society. Thereby, an organization can be a firm, an academic research centre, a governmental agency or a non-profit organization. We use a binary measure, where two actors share an institutional proximity when they have the same institutional form.

Cognitive proximity is measured by the Synthetic-Analytic-Symbolic model. Complexity of cognitive proximity can leads to a large variety of measure. Nooteboom (2000) measures cognitive proximity according to the technological distance between patents. An interesting approach is the reference to the SAS model. The SAS model (Asheim & Coenen 2005) is a typology which will helps us to distinguish different knowledge bases of organizations involved in the GNSS collaboration network. Analytic knowledge base refers to the theoretical knowledge (scientific). In a large extent, we found in this category universities and public research centre. The synthetic knowledge base is a more applied and contextualized kind of knowledge (engineering). We found in this part the engineering companies of the GNSS industry, mainly satellite constructor, hardware and software companies. Finally, the symbolic knowledge is introduced. This third category is a very recent one (Asheim, Boschma & Cooke 2007, Asheim, Coenen, Moodysson & Vang 2007), and represents a kind of knowledge which has been for a long ignored by theoretical and empirical study of innovation. It will refer to all knowledge used in innovation network which is nor scientific nor technological. For high technological networks, one can tell that we call symbolic knowledge the kind of knowledge who links the technology and the user. We can found in this class the final users firms (aviation, automotive or railway companies), users non-profit organizations (blind people), business consultants which study the needs of customers or again designers involved in the definition of interface between human and technology. We again use a binary measure, where organizations have to develop the same kind of knowledge in order to be supposed to share a cognitive proximity. Notice that our measure of cognitive and institutional proximity leads obviously to some extent to colinearity. It is induced by organizations who share the same institutional form and also the same knowledge base, which happens in 50% of the cases.

4.3 The model specification

For the analysis of non directed networks, SIENA proposes six different types of models (Snijders, Steglich, Schweinberger & Huisman 2007), grouped in two categories according to the mathematical interpretation of the rate function. The rate function expresses the opportunity for actors to change their relations (create or dissolve a tie). In Models B, the rate function expresses the maximum expected number of changes per dyad, which induces that opportunities for change of the single tie variable x_{ij} occur at the rate $\lambda_i * \lambda_j$. Models A express the idea that there is always a first mover in the creation of a relation. Organizations rarely decide together, at the same time to engage collaboration. There is often one of them who propose more or less directly a possible collaboration. In this other category of models, the rate function express the maximum expected number of changes per dyad, which induces that opportunities for change of the single tie variable x_{ij} occur at the rate λ_i. Choice between these different kinds of models is leaded by theoretical considerations.

B models are composed by four models where a random pairs of actors are chosen first. Then, four solutions can occur. Ties can be created on the basis of the average of objective function: tie-based model. The relation can also be created if and only if both agree: pairwise conjunctive model. A third solution is then if at least one of the actors chooses for the tie: pairwise disjunctive (forcing) model. Finally, the relation can be created on the basis of the sum of the utilities of the two actors: pairwise compensatory (additive) model.

A models are composed by only two types of models. The forcing model is employed when one actor decides to create or dissolve a tie, unilaterally. In this case, the only condition for a relation to exist is to maximize the utility of one of the two partners. This model can be used to characterize very hierarchical networks, but seems to be less interesting in our case for collaboration networks. The other model, called unilateral initiative and reciprocal confirmation model is the one we will use. In this case, one actor proposes to engage a relation, and the other has to confirm if he agrees. In our point of view, this model is the closest to the reality of collaboration networks.

SIENA will explain the choice to engage (0 to 1) or not (0 to 0) a collaboration according to three kinds of independent variables, individual (characteristics of the organization), structural (dependent of the structure of the network itself) and dyadic (proximity between actors). Even if our ambition is to study effect of proximity on the evolution of the network, we include two control variables, the first one for structural effect (cost effect)[18], and the second one for

[18] Traditionally, transitivity is also a control variable. Nevertheless, we are not able to include transitivity because transitivity is artificially high in networks affiliated from bi-partite network (Robins and Alexander 2004). Obviously, because each project is a clique by itself, where every partner is link to every other partner it leads to a very strong transitivity effect.

individual characteristics (absorptive capacity). All independent variables of the model can be found in table 4.

Firstly we control for the cost effect. The cost effect does not explain why ties are formed, but why they are not. Called out-degree or density effect in the literature of longitudinal network analysis (Snijders et al. 2009) it refers to the cost induced by the establishment of a relation. The cost effect explains why all nodes are not able to be fully connected to all others (McPherson et al. 2001). It has to be taken into account and well understood in order to explain the present structure of the innovation network and its evolution. Organizations often engage partnerships around an innovation project, which leads to make available financial resources before returning benefits. Beyond the financial aspect, another cost is induced by the risk of unintended knowledge spillovers diffused between the cooperation. This risk is effective each time organizations decides to share knowledge, and even more when they operate on the same market and when there cognitive distance is weak (Brossard & Vicente 2007). The cost effect refers indeed to the out degree of the organizations measured by:

$$S_i(x) = \sum_j x_{ij}$$

We also include absorptive capacity levels of organizations in order to introduce individual characteristics. It refers globally to the heterogeneity of the ability to exploit external knowledge, and expresses the idea that networks still result to decisions of organizations with heterogeneous knowledge bases (Dosi 1997). Organizations establish relationships in order to access to external knowledge according to their absorptive capacity. Absorptive capacity, understood as the ability of organizations to evaluate, assimilate and exploit external knowledge (Cohen & Levinthal 1990) will thereby determine the benefit expected from collaboration. Collaborations became more attractive for organizations with a high absorptive capacity. Empirical study has already shown that organizations with a high absorptive capacity are more likely to establish collaborations (Giuliani & Bell 2005, Boschma & ter Wal 2007, Morrison 2008). It leads us to include it as a control variable in the model. The measure of absorptive capacity used here crosses the R&D expenditure and the size of the organization.

Variable	**Operationalization**	**Valuation**
Cost effect	Out degree	0 to $n-1$
Absorptive capacity	Size + R&D	1 to 6
Geographical proximity	NUTS spatial area	0 to 3
Organizational proximity	Financial link	0/1
Institutional proximity	Triple helix	0/1
Social proximity	Geodesic distance 2	0/1
Cognitive proximity	SAS Knowledge bases	0/1

Table 4: Operationalization and measurement of variables

5 Main empirical results

Parameters have been estimated in different consecutive steps. All parameter estimations of the model are based on 2000 simulations runs, and convergence[19] is excellent for all models (t-values < 0.1). Table 5 summarizes the results of the final model[20]. This final model exclude the effect of social proximity, non significant in the intermediate models [21]. Explanations of the results are given below.

Variables	Estimate parameters	Standard deviation
Rate $\lambda_{2004-2005}$	13.9949***	0.7577
Rate $\lambda_{2005-2006}$	12.4560***	0.5874
Rate $\lambda_{2006-2007}$	9.4593***	0.4498
Cost effect	−0.3561***	0.0249
Absorptive capacity	0.1555***	0.0190
Geographical proximity	0.0879***	0.0268
Organizational proximity	0.3446**	0.1678
Institutional proximity	0.2285***	0.0664
Cognitive proximity	−0.1595**	0.0629

Table 5: Estimation results of the final model

The general parameter (λ_{t-t+1}) became smaller each year. Its significance only expresses the idea that changes occurs in the network during the period. This expected number of changes per organization is 14 between 2004 and 2005, then 12.46 between 2005 and 2006 and finally 9.46 between 2006 and 2007. It induces the lower growth of the collaboration network presented in the descriptive statistics of the part 3. It means that there is less opportunity to change relationships in the last period than in the two previous one. The cost effect (density) is negative and significant, which only explain that the establishment of a relation is not costless. To decide to start collaboration, organizations have to be driven by other forces: structural, linked to its characteristic or according to the degree of proximity of others.

In order to control for heterogeneity between individual characteristics of the organizations of the sample, we estimate the influence of the absorptive capacity. Results show that it is a strong parameter for collaboration. This effect means that organization prefers to start partnerships when their absorptive capacity is high, following the findings of other empirical studies (Giuliani & Bell 2005, Boschma & ter Wal 2007, Morrison 2008) . In other words, a high absorptive capacity increases rewards of collaboration, and so the growth of the network.

> **Result 1.** *Organizations prefer to start collaborations when they share a geographical proximity.*

The first result shows clearly that geographical proximity matters in the establishment of collaboration in this network, because organizations are more

[19] The convergence indicates the deviations between simulated values and observed values.

[20] Estimations are based on 2000 simulation runs and conditional method of moments estimation is used.
For standards errors: *p<0.10; **p<0.05; ***p<0.01.

[21] See table 9 in appendix for estimation results of a model which include social proximity

likely to choose partners of the same spatial area. We follow here the findings of other empirical network studies (Autant-Bernard et al. 2007, Ponds et al. 2007), and the idea that innovation processes requires geographical proximity and face-to-face interactions. Nevertheless, it is interesting to note that even if one of the aims of the European Union in these Framework Programmes is to promote a European Research area, trying to avoid massive collaborations between geographically closes organizations, the influence of geographical proximity still remains a strong vector of collaboration.

Result 2. *Organizations are less likely to interact when they share a cognitive proximity.*

In fact, the parameter of cognitive proximity is significant but it has a negative effect on collaboration. It is the only form of proximity where actors prefer to interact with distant organizations. Organizations with the same knowledge base (analytic, synthetic or symbolic) prefer to avoid collaborations in order to access to external heterogeneous knowledge bases. It is particularly true for this knowledge dynamic, characterized, as we said above, by the fact that GNSS are technologies which find complementarities in many other technological and socio-economic contexts, often interconnected around an emerging technological window or standard (Vicente & Suire 2007). Thus, organizations of the navigation by satellite industry definitively requires to access to various knowledge bases, from scientific (analytic) and technical (synthetic) knowledge to a more artistic one (symbolic). This accessibility to external heterogeneous knowledge bases is decisive for organizations, in order to be able to propose GNSS innovative solutions for a large variety of sectors and applications.

Result 3. *Organizations prefer to interact when they share an organizational proximity.*

We also confirm our hypothesis about the role played by organizational proximity, which is also positively correlated with the establishment of new linkages. Organizations prefer to collaborate with other organizations of their group than organization financial independent. The GNSS network is in fact dominated by two competitor companies, Thales Alenia Space and EADS Astrium, which respectively belong to the Thales and the EADS group. Other groups, like GMV, Logica or Deimos have also the same kind of behaviour, which consists to collaborate preferentially with organizations of the same group. Besides the theoretical argument which explains that organizational proximity develops trust and relevant information of the partner, another effect is likely to increase this effect. One can imagine that big groups give incentives to their subsidiaries to collaborate together in Framework Programs in order to get the maximum money and access to strategic network position.

Result 4. *Organizations are more likely to interact when they share an institutional proximity.*

Institutional proximity is the third form of proximity which also matters positively on the probability to collaborate, confirming our hypothesis. It means that organizations prefer to collaborate with partners which belong to the same kind of institution. Institutional proximity favours collaboration because it is easier to collaborate when actors share the same mode of working. Indeed, even if proximity of knowledge bases and institutional proximity are correlated[22], we observe empirically that they have opposite effects on collaboration. It raises an interesting trade-off phenomenon between institutional proximity and heterogeneity of knowledge bases, for organizations who share simultaneously the same institutional form and the same knowledge base. This result describes somehow the mechanisms at work with the optimal cognitive distance concept (Nooteboom 2000). In fact institutional proximity will help to communicate and transfer knowledge between partners, whereas access to external heterogeneous knowledge bases is a strong vector of innovative performance in the GNSS industry.

> **Result 5.** *Collaborations do not create enough social proximity to favour future partnerships.*

Social proximity is not significant in intermediate models, so this effect does not appear in the final model. It means that organizations are not more likely to start collaboration with partners of partners, which does not confirm our hypothesis about the positive influence of social proximity. Nevertheless, we do not conclude that social proximity does not influence the relational changes in others collaboration network. In fact, a way to explain this result is that trust, the basis of social proximity is certainly more difficult to happen in project collaboration, with multiple partners, than in bi-lateral collaborations.

6 Conclusion

This paper analyzes the effects of proximity on the evolution of the GNSS collaboration network. This contribution follows thus a recently opened research area (Knoben & Oerlemans 2006, Boschma & Frenken 2009), dedicated to the linkage between two wide literature, the researches on proximity (Bellet et al. 1993, Rallet & Torre 1999, Boschma 2005) and the researches on patterns of network evolution (Snijders 2001, Powell et al. 2005). Indeed, the central interest of this study was to identify how organizations choose their partners, with a special interest dedicated to their proximity or distance. The empirical investigation took places in an emerging collaboration network, based on project funded by the European Union in the 6th Framework Programme, in the navigation by satellite industry (GNSS).

Crucial issues of this paper can be summarized in three points. Firstly, even if this paper is mainly oriented toward empirical elements, a major issue was to discuss theoretically about the influence of proximity effects on the evolution of collaboration networks, especially according to new lightening of diversified streams of literature. Then, a second important effort was dedicated to the measurement of geographical, organizational, institutional, social and cognitive proximity. In fact, even if several contributions dedicated to definitions or typology of the different forms of proximity exist, relatively few papers focus on the way to measure it. Thereby, this paper contributes to give a quick overview of existing measures and also tries to propose new ones, for the organizational and

[22] Colinearity decrease the significance of the variables by increasing standards errors, but here, both cognitive and institutional proximity are anyway highly significant.

the cognitive proximity. Finally, the way the statistical model is constructed, where five forms of proximity are included, but also where each form control for the effect of each other furnish original empirical results.

These empirical results can be summarized like this: organizations prefer to start partnership with organizations with which they share one or more forms of proximity, except for the cognitive and social proximity. Indeed, geographical, organizational and institutional proximity favour collaborations. Cognitive proximity of the knowledge bases has got a negative effect on collaboration, because organizations prefer to choose a partner with a different knowledge base, in order to access to heterogeneous knowledge. Otherwise, the fact that social proximity is not significant in the model seems to show that cooperation under the GNSS FP of the European Union does not create enough social proximity between partners to diffuse trust between partners and so influence new collaborations.

This paper studies how organizations choose their partners according to their degree of proximity. However, the different forms of proximity are considered as given data, like explanatory variables of the evolution of the collaboration network. Told differently, we do not explain where this degree of proximity comes from and how it is likely to evolve itself. A future interesting research area may be found in the co-evolution of proximity and networks (Menzel 2008, Ter Wal & Boschma 2008, Ter Wal 2009). The central question will be thus to understand how proximity contributes to create or dissolve collaborations, and at the same time how these relations contribute to increase or decrease the degree of proximity between organizations. This issue requires first an important theoretical contribution which will help to lighten these complex linkages of co-evolution. Then, it is also an empirical challenge, with precise methodology and data.

Acknowledgements

We are grateful to Jérôme Vicente and Olivier Brossard for their continual help. We also thank Ainhoa De Federico for her comments, and Tom Snijders for the fruitful discussions we had with him during the Oxford Spring School. This research has received financial support from the EURODITE Project (Regional Trajectories to the Knowledge Economy: A Dynamic Model, Sixth Framework Program, contract no 006187).

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Appendices

A. Measure of absorptive capacity

R&D of the organization is measured according to the R&D intensity of its sector. Firstly, four R&D classes are distinguished following the OECD[23] : high-technology (4), medium-high-technology (3), medium-low-technology (2) and low-technology industries (1). We then measure five classes of size, according to the number of employees 1 to 10 (1), 11 to 50 (2), 51 to 250 (3), 251 to 500

[23] OECD, ANBERD and STAN databases, May 2003

(4) and more than 501 (5). Finally, we add both results to order absorptive capacity level of each organization, from 1 to 6[24] .

B. Covariance matrix

	Cost ef.	**Cog.**	**Geo.**	**Inst.**	**Org.**	**Abs. Cap.**
Cost effect						
Cognitive proximity	0.043					
Geographical proximity	−0.054	0.003				
Institutional proximity	−0.056	−0.798	0.016			
Organizational proximity	−0.103	−0.026	−0.044	−0.011		
Absorptive capacity	−0.060	−0.031	−0.053	−0.047	−0.081	

Table 6: Covariance matrix of estimates (correlations below diagonal) of the final model

C. Intermediate models

Variables	**Estimate parameters**	**Standard deviation**
Rate $\lambda_{2004-2005}$	12.4260***	0.6319
Rate $\lambda_{2005-2006}$	11.5783***	0.5422
Rate $\lambda_{2006-2007}$	9.1005***	0.4220
Cost effect	−0.3271***	0.0243

Table 7: Model 2

Variables	**Estimate parameters**	**Standard deviation**
Rate $\lambda_{2004-2005}$	13.9082***	0.7208
Rate $\lambda_{2005-2006}$	12.3907***	0.5980
Rate $\lambda_{2006-2007}$	9.4343***	0.4649
Cost effect	−0.3491***	0.0240
Absorptive capacity	0.1671***	0.0189
Geographical proximity	0.0884***	0.0264

Table 8: Model 3

[24] After addition, the lower level is 4, so 4 become 1, 5 become 2, 6 become 3 etc. . .

Variables	Estimate parameters	Standard deviation
Rate $\lambda_{2004-2005}$	14.0236***	0.7803
Rate $\lambda_{2005-2006}$	12.3930***	0.6006
Rate $\lambda_{2006-2007}$	9.4109***	0.4516
Cost effect	0.3573***	0.0294
Absorptive capacity	0.1606***	0.0195
Geographical proximity	0.0864***	0.0260
Social proximity	0.0236	0.0488
Organizational proximity	0.3642**	0.1535

Table 9: Model 2