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Proximity and the Evolution of Collaboration Networks:

Evidence from R&D projects within the GNSS industry

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Abstract: This paper analyses the influence of proximity on the evolution of collaboration networks. It determines empirically how organizations choose their partners according to their geographical, cognitive, organizational, institutional and social proximity. Relational databases are constructed from R&D collaborative projects, funded under the European Union 6th Framework Programme within the navigation by satellite industry (GNSS) from 2004 to 2007. The stochastic actor-based model SIENA is used to model the network dynamic as a realisation of a continuous-time Markov chain and to estimate parameters for underlying mechanisms of its evolution. Empirical results show that geographical, organizational and institutional proximity favour collaborations, while cognitive and social proximity do not play a significant role.

Keywords: Collaboration networks; proximity; economic geography; dynamic network models; GNSS

JEL classification: O32, R12

Résumé : Ce papier analyse l'influence de la proximité sur l'évolution des réseaux de collaboration. Il détermine empiriquement la façon dont les organisations choisissent leurs partenaires en fonction de leur proximité géographique, cognitive, organisationnelle, institutionnelle et sociale. Les bases de données relationnelles sont construites à partir des projets collaboratifs de R&D financés par le 6ème Programme Cadre de Recherche et de Développement de l'Union Européenne, dans la navigation par satellite (GNSS) de 2004 à 2007. Le modèle stochastique orienté par l'acteur SIENA est utilisé pour modéliser la dynamique du réseau par une chaîne de Markov en temps continu et pour estimer les paramètres liés aux mécanismes de son évolution. Les résultats empiriques montrent que les dimensions de proximité géographique, organisationnelle et institutionnelle favorisent les collaborations, tandis que les formes de proximité cognitive et sociale ne jouent pas un rôle significatif.

Mots-clés: Réseaux de collaboration ; proximité ; économie géographique ; modèles de réseaux dynamiques ; GNSS

1. Introduction

Increasing attention has been recently given to understand how networks affect organizational performance in innovation studies (AHUJA 2000, GAY and DOUSSET 2005, SCHILLING and PHELPS 2007, BOSCHMA and TER WAL 2007). This interest has contributed to a better understanding of innovative activity and clustering processes (SUIRE and VICENTE 2009). Surprisingly, the main drivers of the evolution of innovation networks have been neglected, and still remain unclear. By using network indicators, such as centrality, reachability, brokerage or structural characteristics as independent variables, attention has been focused on organizational performance. This has strongly contributed to consider the network as a black box, similarly to the localised knowledge spillovers in the geography of innovation (BRESCHI and LISSONI 2001). Indeed, the network is seen as an independent variable, with given structure and given positions of actors, but little attention is devoted to the underlying mechanisms of their morphogenesis (COHENDET, KIRMAN and ZIMMERMANN 2003).

Thus, even if different disciplines have recently contributed to identify patterns of relational change in organizational networks, these mechanisms remain still unclear. Influence of individual characteristics of organizations on collaboration choices have been analysed in economics (D'ASPREMONT and JACQUEMIN 1988, CASSIMAN and VEUGELERS 2002), and especially the importance of absorptive capacity (COHEN and LEVINTHAL 1990) has been highlighted in recent empirical approaches (GIULIANI and BELL 2005, BOSCHMA and TER WAL 2007). Following the seminal contributions about endogenous structural effects of network changes in sociology and physics, GLÜCKLER (2007), GIULIANI (2008) and TER WAL (2009) tried to analyse the path-dependent evolution of network structures. Beyond individual and structural characteristics, the ambiguous effects of proximity needs to be clarified and begins to be investigated theoretically (BOSCHMA

2005, KNOBEN and OERLEMANS 2006) and empirically (AUTANT-BERNARD *et al.* 2007, PONDS *et al.* 2007, TER WAL 2009, SCHERNGELL and BARBER 2010).

BOSCHMA and FRENKEN (2009) identify this research question as crucial for evolutionary economic geography and propose a theoretical framework, in order to link proximity concepts (BELLET *et al.* 1993, RALLET and TORRE 2001, BOSCHMA 2005, CARRINCAZEAUX *et al.* 2008) and the evolution of innovation networks (SNIJDERS 2001, GLÜCKLER 2007). Other contributions relating proximity concepts and inter-organizational collaborations appeared with papers analysing how geographical proximity facilitates face-to-face interactions (BOSCHMA 2005, WETERINGS 2006). Influence of proximity is in this sense close to the homophily effect (MCPHERSON *et al.* 2001, POWELL *et al.* 2005), where actors are supposed to interact more with other ones when they share similar attributes. Proximity researchers have produced many theoretical propositions in order to define various forms of proximity and their articulation. The paper uses the analytical distinction in five dimensions proposed by BOSCHMA (2005). Proximity between organizations can thus relate to their spatial area (geographical), their knowledge bases (cognitive), their corporate group (organizational), their institutional form (institutional) and finally to their social network (social). The paper contributes to this ongoing debate by determining empirically how organizations choose their partners according to their geographical, organizational, institutional, cognitive and social proximity.

Measuring proximity (NOOTEBOOM 2000, BOUBA-OLGA and ZIMMERMANN 2004, POWELL *et al.* 2005, CANTNER and GRAF 2006, CARRINCAZEAUX *et al.* 2008, MASSARD and MEHIER 2009) and obtaining appropriated data represents an empirical challenge for each form of proximity. In order to explain the respective influence of the proximity dimensions, a major issue of this paper is dedicated to measure proximity and analyze what happens when each form controls the effect of the four others. Doing this, the paper aims to clarify the influence of each form of proximity on the evolution of the Global Navigation Satellite Systems (GNSS) collaboration network. The relational database is constructed from publicly available information about R&D collaborative projects of the 6th European Union Framework Programme within the GNSS industry (FP6). Patterns of evolution are determined according to a longitudinal study of the relational changes occurred between four consecutive years, from 2004 to 2007. The paper models network changes as an evolutionary process, driven by the actors and the overall structure. It uses a statistical model specifically designed to deal with the complexity of network dynamics: the stochastic actor-based model SIENA (SNIJDERS 2001) that has already provided new insights in economic geography (GIULIANI and BELL 2008, TER WAL 2009). More precisely, the GNSS collaboration network dynamic is modeled as a realisation of a continuous-time Markov chain (NORRIS 1997) and parameters for underlying mechanisms of its evolution are estimated with the method of moments, implemented by computer simulation[1].

The second section is dedicated to the definition of proximity retained in the paper. It presents theoretically geographical, organizational, institutional, cognitive and social proximity, and elaborates propositions about their respective influence on the evolution of collaboration networks. The third section describes the origin and the nature of the relational data. It details specificities of the GNSS industry, but also how data are collected and how the sample is constructed. The fourth section focuses on the methodology employed for the longitudinal data analysis, describing how the network dynamic is modelled by the stochastic actor-based model SIENA. The fifth section particularly insists on the operationalization of the forms of proximity and on the specification of the model. Main empirical results of the model are discussed in the sixth section. Open questions and future research agenda conclude the paper.

2. How proximity influences the evolution of collaboration networks

Various definitions and typologies of proximity have been discussed in order to provide a better understanding of coordination processes of economics activities. Institutions are highlighted in the first typology (BELLET, COLLETIS and LUNG 1993), where three types of proximity: geographical, organizational and institutional are defined. Interactions between actors matter more in a second approach (RALLET and TORRE 2001), which examines geographical and organized proximity, in order to insist on the link between a geographic notion and a relational one. The paper retains a third approach, based on the analytical distinction proposed by BOSCHMA (2005). It distinguishes five dimensions: geographical, cognitive, organizational, institutional and social proximity.

2.1 Geographical Proximity

Geographical proximity refers to the spatial separation between actors (GILLY and TORRE 2000), and it is supposed to enhance face-to-face interactions (BOSCHMA 2005). In its simplest form, geographical proximity is defined by the physical distance that separates two organizations, and can be measured by a metric system (miles or kilometres) or using travel times. Recently, authors have distinguished co-location and geographical proximity, in order to specify that organizations can share geographical proximity without being co-located (meeting, visit or conference) by using temporary geographical proximity (TORRE 2008). This paper adopts an approach where geographical proximity refers to the actors' perception of their spatial area (BOUBA-OLGA and GROSSETTI 2008), often expressed according to the boundaries of their country or their regions. Geographical proximity is in this sense closer to a perspective of co-location of the organizations. Beyond material reasons, like reducing transport cost or providing the utilisation of same technological platforms, strong relations exist between geographical proximity and the diffusion of knowledge (AUDRETSCH and FELDMAN 1996). The main underlying mechanism is that tacit knowledge, a key driver of innovation processes, is less likely to be transferred within distant collaborations (HOWELLS 2002). In addition, geographical proximity plays a more indirect role in knowledge transfer, by strengthening the other dimensions of proximity (BOSCHMA 2005). Following this, a first proposition will be tested:

Proposition 1. *Organizations are more likely to interact 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 it is necessary to communicate and transfer knowledge between partners (KNOBEN and OERLEMANS 2006). Nevertheless, organizations collaborate in order to access external knowledge, which requires a certain degree of cognitive distance between both partners. It 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 (NOOTEBOOM 2000) which will ensure novelty but also effective communication. Thus, cognitive proximity is certainly the most decisive dimension observed by organizations when they select their future partners (ANTONELLI 2000, BOSCHMA and FRENKEN 2009). The paper retains a definition of cognitive proximity based on the kind of knowledge developed, through a competencies matrix, in order to analyse if organizations have a preference for same or different knowledge bases. This methodology has already been used for the GNSS industry by VICENTE, BALLAND and BROSSARD (2010). Testing the preference for the same knowledge bases, a second proposition is elaborated:

Proposition 2. *Organizations are more 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 strategic interdependence between two organizations, and it reduces uncertainty about the behaviour of the future partner (BOSCHMA 2005). The literature provides two major definitions of this concept, which sometimes can lead to ambiguity. The first one refers to a relational space, in opposition to a geographical one, and it is defined by interactions of different nature (RALLET and TORRE 2001). This paper proposes a definition based on the second approach, where organizational proximity does not refer to collaboration networks (the dependent variable in the paper), or social networks (social proximity in the paper). It is understood as a specific form of proximity among firms of the same corporate group, i.e. within parent companies, the subsidiaries and their different establishments. So, two organizations can 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). When actors share a high degree of organizational proximity, it is easier to avoid unintended knowledge spillovers and to reduce uncertainty. Thus, it can reduce costs of collaboration by providing easier exchange of engineers, working groups or meetings. Finally, relevant information about knowledge bases of both partners is also more easily available, as described above with the definition of cognitive proximity, which is crucial for a good cognitive matching and an efficient collaboration. These considerations lead to the third proposition:

Proposition 3. *Organizations are more likely to interact with members of their corporate 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 shared by actors (NORTH 1990), where common representations, routines and incentives allow organizations to realize an efficient transfer of knowledge (KNOBEN and OERLEMANS 2006). The institutional proximity is thus composed by formal institutions, like laws and rules, and informal institutions, close to the sociological notion of habitus which is a way of conduct, constructed involuntarily through the socialization process. Following research on science-industry collaborations (LEVY, ROUX and WOLFF 2009), the paper considers institutional proximity as the belonging to the same institutional form. This measure has already been proposed by PONDS *et al.* (2007), applying the triple helix model (ETZKOWITZ and

LEYDESDORFF 2000), in order to distinguish among industry, academia and government. This paper considers also the “public” as a fourth helix (LEYDESDORFF and ETZKOWITZ 2003), in order to introduce the influence of non-profit organizations in knowledge creation. Organizations embedded in the same institutional form share to some extent common formal and informal institutions, making less easy collaborations among organizations belonging to different institutional forms. Indeed, both formal and informal institutions influence the coordination process of organizations (KIRAT and LUNG 1999), especially in R&D collaboration networks. Institutional proximity facilitates communication, especially for organizations that share and develop complex knowledge around collaborative projects. It leads to test a fourth proposition:

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

2.5 Social Proximity

Social proximity refers to the degree of common relationships, where friendship and trust are central, and it is supposed to diffuse informal knowledge and facilitates collaborations (BOSCHMA and FRENKEN 2009). It refers to the intersection between social networks of individuals of two organizations. Focusing on the personal level is very relevant for the understanding of mechanisms that provide the diffusion of tacit, sometimes more or less secret knowledge. Individuals embedded in a social network know each other personally (GRANOVETTER 1985), which determines their accessibility to information exchange or technical advice (BRESCHI and LISSONI 2003, GROSSETTI and BÈS 2001). The paper focuses on social proximity created through collaborations between organizations themselves (AUTANT-BERNARD *et al.* 2007). It is supposed that their degree of social proximity decreases with their geodesic distance, i.e. the shortest path between two organizations in the overall network. More precisely, social proximity is considered via the inverse of the geodesic distance separating two organizations (BOSCHMA and FRENKEN 2009). In this approach, social proximity is close to the structural mechanism of transitivity (DAVIS 1970, HOLLAND and LEINHARDT 1971) which leads to network closure according to Boschma and Frenken (2009, p.9): "the role of social proximity in the formation of network links relates to the concept of closure [...] closure simply means that if two actors have a social distance of two, they have a higher probability of getting connected". Social proximity refers mainly to reputation and trust effects, created by the experience of past collaborations and repeated contacts between partners. Thus, friendship, but mostly reputation and trust, contributes to provide the diffusion of informal knowledge that leads organizations with a common partner to be more likely to collaborate. Considering the social proximity induced by a weak geodesic distance, a last proposition is elaborated:

Proposition 5. *Partners of partners are more likely to interact than others, i.e. social proximity favour collaboration.*

Each of these five propositions will be tested empirically in order to clarify the respective influence of the different dimensions of proximity on the evolution of collaboration networks. The next section describes the longitudinal relational database.

3. Data

Adequate data are often difficult to obtain for social network analysis (TER WAL and BOSCHMA 2009), and it is obviously harder to gather longitudinal relational data (BAUM *et al.* 2003). Relevant information about knowledge collaboration, especially when collaborations start and finish, can be found in the database of the Framework Programmes (FPs) on research and technological development. Launched in 1984 by the European Union, the FPs aim to fund transnational and collaborative R&D projects, in order to support collaborative research and promote a European research area, reaffirmed trough the Lisbon European council in March 2000. The paper focuses on the FP6 within the GNSS industry.

3.1 The GNSS industry

GNSS is a standard term used to describe systems that provide positioning and navigation solutions. These technologies were mainly developed in the aerospace industry, for military reasons. Nowadays[2], in the technological and symbolic paradigm of mobility, GNSS are technologies which find complementarities and integration 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.* 2010).

Actors of the GNSS industry are thus organizations with heterogeneous institutional forms, big companies, SMEs, research centres, agencies[3] or non-profit organizations. Important organizations[4] are the competitors Thales Alenia Space and EADS Astrium, national space agencies CNES[5] (France) and DLR[6] (Germany), and the European Space Agency. Public actors are involved in the knowledge creation 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.

The geography of the GNSS industry crosses national boundaries, and more generally space industry has historically developed research collaboration among organizations from different European countries. Especially France and Germany for the beginning, and now Spain, England, Netherlands and Italy have also strong competencies and collaborate in the GNSS composite knowledge dynamic. BALLAND, SUIRE and VICENTE (2010) identified the seven main 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 Data collection

Aiming to study the evolution of collaboration networks in the GNSS industry, these databases are particularly relevant for at least two reasons related to the space industry history. Firstly, since the end of the 1950s space organizations are used to work by project. Each satellite is a project by itself and also a unique product that makes it difficult to produce it intensively in a standardized production chain. Secondly, space organizations are used to work under funded projects or programmes because the space exploration has always been a very strategic issue for countries. Data can be directly collected from the database of information services of the European Commission, publicly available on the Cordis[7] for all EU-supported R&D activities, and more precisely on the GNSS Supervisory Authority database[8] for FP dedicated to the GNSS industry. Some projects, often the big ones, are more detailed than others, so it led us sometimes to collect more precise information on the project websites, communication documents, work package reports, but also on the websites of the partners, if publicly available.

In spite of the completeness, the dating and the information about the projects and the organizations given in these databases, extracting collaborations from funded projects requires treating another kind of problem. Institutions which fund these projects, in this case the European Commission, select the partners according to scientific, technical, or economic reasons, but also for political reasons. Sometimes it leads to the inclusion of organizations that would not be selected as partners without the consideration of these guidelines. One solution is to think about the activity of the organizations as an indicator of their legitimacy to participate in these projects, focusing on relations between organizations which participate at least in two projects on the overall period, similarly to AUTANT-BERNARD *et al.* (2007). This approach is certainly not free from criticisms, but it helps to reduce the confusion between partners chosen for their competencies and partners chosen for political reasons.

3.3 The longitudinal network database

Thus, a secondary dataset is constructed, and four relational matrixes are distinguished from 2004 to 2007 (one for each year), corresponding to the observed moments in the model. Two organizations are linked when they participate in the same project. For the construction of the longitudinal relational database it is assumed that ties are active from the beginning to the end of each project. Relations are not directed, because by nature ties are reciprocal in collaboration networks, and dichotomized. Table 1 shows descriptive statistics about the cumulated number of projects and organizations on the overall period.

Table 1 here

The dynamic of the GNSS collaboration network is expressed by the number of relational changes, i.e when ties are created or dissolved. Numbers and shares of changes are detailed in table 2.

Table 2 here

Each year, more relations are created than dissolved, so it indicates that the network is growing during all considered periods. 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 2004 to 2007, where blue squares represent projects and red circles represent organizations.

Figure 1 here

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. A density close to 0 indicates a poorly connected network, and when it is close to 1 the network is very connected. Mean degree expresses, on average, the number of organizations' partners.

Table 3 here

4. A stochastic actor-based model for network dynamics

This part presents how the network dynamic is modeled in the paper, using the stochastic actor-based model SIENA (Snijders et al. 2010). This statistical model simulates network evolution between observations and estimates parameters for underlying mechanisms of network dynamics by combining random utility models, Markov processes and simulation (VAN DE BUNT and GROENEWEGEN 2007).

4.1 Network changes as an evolutionary process

This model has been specifically designed to deal with the complexity of network panel data and thus to provide statistical analysis of the evolution of networks. Thereby, SIENA is complementary to mathematical models for network dynamics, but also to standard econometric tools, for at least two crucial reasons. First, the model estimates and tests parameters from empirical data, while mathematical models for network dynamics (BALA and GOYAL 2000, JIN et al. 2001, JACKSON and ROGERS 2007) are difficult to use for this purpose (SNIJDERS et al. 2010). Second, the model considers network changes as an evolutionary process (BOSCHMA and FRENKEN 2006), while traditional econometric analysis of collaboration networks are often static (AUTANT-BERNARD et al. 2007, PAIER and SCHERNGELL 2008, AHUJA et al. 2009). Moreover, the framework of econometric analysis of panel data (BATALGI et al. 2008) has not provided specific models for network dynamics, and is often constructed on the basis of discrete time models. Such discrete time models explain the totality of changes (i.e. the creation and dissolution of ties) in a single regression model, which seems to be a severe limitation to represent real change processes of networks structures. It seems to be more realistic to model network structures as evolving and changing gradually, according to an iterative process, between observed moments (SNIJDERS et al. 2010), as a realisation of a continuous-time Markov chain like proposed traditionally in models for social network dynamics since HOLLAND and LEINHARDT (1977). It appears that providing estimation from empirical data and considering network changes as an evolutionary process, stochastic actor-based models (Snijders 1996, 2001) are today a very promising tool to study the dynamic of networks in economic geography (TER WAL and BOSCHMA 2009). Beside, the model has already provided new insights not only in economic geography (GIULIANI and BELL 2008, TER WAL 2009), but also in management (CHECKLEY and STEGLICH 2007, VAN DE BUNT and GROENEWEGEN 2007), sociology (DE FEDERICO 2004, LAZEGA *et al.* 2008) and health studies (STEGLICH, SNIJDERS and WEST 2006).

4.2 The Markov process

Network structures, organized as time series $x(t), t \in \{t_1,...,t_m\}$ for a constant set of organizations $N = \{1,...,n\}$, are modeled as a continuous-time Markov chain $X(t)$. Each observation is represented by a $n \times n$ matrix $x = (x_{ij})$, where x_{ij} represents the link from the organization i to the organization $j\ (i, j = 1,...,n)$. Markov chains are statistical techniques widely used in econometrics (HANSEN and SCHEINKMAN 1995, CHIB and GREENBERG 1996) when time-dependent stochastic processes are analyzed. It expresses the idea that the current state of the network determines probabilistically its further evolution. Thus, t_1 to t_m are embedded in a continuous set of time points $T = [t_1; t_m] = \{t \in \Re \mid t_1 \le t \le t_m\}$. As specified in STEGLICH, SNIJDERS and WEST (2006, p.3) the basic idea "is to take the totality of all possible network configurations on a given set of actors as the state space of a stochastic process, and to model observed network dynamics by specifying parametric models for the transition probabilities between these states". In our case, the size of this state space is $\{0,1\}^{n(n-1)/2}$, and it corresponds to all possible binary and undirected networks on the given set of organizations.

SIENA deals with the complexity of network dynamics by modeling the change process through two crucial components: the change *opportunity* process (rate function), and the change *determination* process (objective function). Formally, opportunities for actor i to change one of the tie variables $X_{ij}\ (j = 1,...,n;\ j \neq i)$ occur at a rate λ_i, specified below in equation 3. Collaboration choices are determined by f_i, specified below in equation 4 as a linear combination of effects, depending on the current state (x^0), the potential new state (x), individual attributes (v) and proximity (w). The set of permitted new states, following on a current state x^0, is $C(x^0)$ and the product of the two model components λ_i and p_i determines the transition rate matrix (Q-matrix), of which the elements are given by (SNIJDERS 2008):

$$q_{x^0,x} = \lim_{dt \downarrow 0} \frac{P\left\{X(t+dt) = x \middle| X(t) = x^0\right\}}{dt} \tag{1}$$

where $q_{x^0,x} = 0$ whenever $x_{ij} \neq x_{ij}^0$ for more than one element (i, j)

and $q_{x^0,x} = \lambda_i(x^0, v, w)\, p_i(x^0, x, v, w)$ for digraphs x and x^0 which differ from each other only in the element with index (i, j).

If there is an opportunity for change for actor i, the choice for this actor is to change one of the tie variables x_{ij}, which will lead to a new state $x, x \in C(x^0)$. For this choice a traditional multinomial logistic regression model is used (SNIJDERS et al. 2010) and the choice probabilities are given by:

$P\{X(t)$ changes to $x \mid i$ has a change opportunity at time $t, X(t) = x^0\}$

$$= p_i(x^0, x, v, w) = \frac{\exp\left(f_i(x^0, x, v, w)\right)}{\sum_{x' \in C(x^0)} \exp\left(f_i(x^0, x', v, w)\right)} \tag{2}$$

4.3 Specification of rate function and objective function

Indeed, the dynamic of the network is modeled according to the idea that when there is an opportunity for change (determined stochastically by the rate function), the probability of the change is assumed to be proportional to the exponential transformation of the objective function obtained if this change is made (Snijders et al. 2010). The *rate function* models the speed by which the dependent variable changes. This expected number of relational changes per organization determines the opportunity for organizations to make a relational change. For each actor i, opportunities to collaborate occur according to a Poisson process with rate λ_i. In the simplest specification of the model, all the organizations have the same opportunity of change, that is equal to a constant parameter $\lambda_i = p_m$. In more complicated models, heterogeneity is introduced in the rate of the actors, in order to consider that individual characteristics , that can be actor attributes or their network position, may considerably influence their opportunity to change their relations, i.e. to start more quickly than others new projects. Thus, when individual attribute (v_i) and degree $(\sum_j x_{ij})$ are considered, rate function is given by the following logarithmic link function:

$$\lambda_i(x^0, v) = p_m \exp(\alpha_1 v_i + \alpha_2 \sum_j x_{ij}) \qquad (3)$$

As detailed above, when there is an opportunity for tie change, the second model component specifies the collaboration choice, as depending on preferences and constraints of the organization, represented by the *objective function.* As it is an actor-oriented statistical network model, it can be interpreted as the idea that organizations make rational choices to change their relations, myopically maximizing their objective function (Steglich, Snijders and Pearson 2010):

$$f_i(x^0, x, v, w) = \sum_k \beta_k s_{ki}(x^0, x, v, w) \qquad (4)$$

In the objective function, $f_i(x^0, x, v, w)$ represents the value of the objective function of the organization $i \in \{1,...,n\}$, at the state $x \in X$ of the network, weights β_k are statistical parameters that indicate the strength of the different variables s_{ki} that can relate to the current state (x^0), the potential new state (x), individual attributes (v) and proximity (w). Discrete choice models are applied in order to define a probability set of choice where organizations can create, maintain or dissolve collaborations with all others. It is interesting to note that creation and dissolution of ties are not generally strictly inverse mechanisms, and it is often interesting to evaluate them separately. However, analyzing why ties are dissolved (endowment function modelisation in SIENA) in the case of projects whose length is fixed from the beginning seems less relevant.

The parameters are not estimated using the classical maximum likelihood according to the complexity of the stochastic models (SNIJDERS 2001), but with the method of moments (BOWMAN and SHENTON 1985) implemented by computer simulation. The solution of the moment equation is obtained by a variation of the ROBBINS-MONRO (1951) algorithm (see SNIJDERS 2001 for the detailed procedure).

5. Model specification and operationalization of the objective function variables

For the analysis of non directed networks, SIENA proposes different kinds of specifications detailed in SNIJDERS *et al.* (2007). The specification matters in the simulation phase, according to the rate function. The closest model to the reality for collaboration networks (VAN DE BUNT and GROENEWEGEN 2007), called *unilateral initiative and reciprocal confirmation model*, is the one used in the paper. It expresses the idea that an organization (randomly chosen) proposes to engage collaboration with another one, on the basis of its expected amount of utility (defined by the variables of the objective function). Then the chosen partner has to confirm if he agrees, also on the basis of its expected amount of utility. Variables of the utility function are geographical, organizational, institutional, cognitive and social proximity, together with two others to control for structural effects and individual characteristics. Variables of the model are summarized in table 4.

Structural effects are included with the density effect (and with the transitivity effect through social proximity). Also called out-degree effect in the literature of longitudinal network analysis (SNIJDERS *et al.*

2010) it refers to the cost induced by the establishment of a relation, and explains why all nodes are not able to be fully connected to all others (McPherson *et al.* 2001). This effect is a control variable, which should always been included in the specifications of the models using SIENA in order to control for the observed density of the network and to explain the general likelihood for organizations to collaborate. Theoretically, it refers back firstly to the fact that organizations have a limited capacity to start collaborations, which are time-consuming, then to the higher probability of ties redundancy (Burt 2004) and finally because it increases the risk of unintended knowledge spillovers (Brossard and Vicente 2007). This risk is effective each time organizations decide to share knowledge, and even more when they operate on the same market or when their cognitive distance is weak.

The level of absorptive capacity of organizations is also included in order to introduce individual characteristics. It refers globally to the heterogeneity of the ability to exploit external knowledge. Organizations establish relationships in order to access to external knowledge according to their absorptive capacity. Absorptive capacity, defined as the ability of organizations to evaluate, assimilates and exploits external knowledge (Cohen and Levinthal 1990), will thereby determine the benefit expected from collaboration. Empirical studies have already shown that organizations with a high absorptive capacity are more likely to establish collaborations (Giuliani and Bell 2005, Boschma and Ter Wal 2007, Morrison 2008). It leads us to include it as a control variable in the model.

The way proximity concepts have been turned into variables and how they have been measured will be described below. Note that proximity variables depend on pair of organizations, and appear as five different and not directed *n x n* matrices, where a binary measure of proximity is applied (1 if organizations share a proximity and 0 if they do not), except for geographical proximity, where three degrees are distinguished.

Geographical proximity

Geographical proximity is determined according to the co-location within the same spatial area. When missing in the GNSS Supervisory Authority database, small size of the sample permitted to find postal addresses of the organizations mainly on their own web sites, and sometimes directly on web sites of the projects, to find for example the establishment of the engineers involved in the work package reports. If doubts remain, it is coded as a missing data (96 addresses were finally found). Following the NUTS[9] classification, three spatial areas are distinguished to determine the degree of geographical proximity, i.e. same country (1), same NUTS 1 (2) or same NUTS 2 (3).

Cognitive proximity

Cognitive proximity occurs when organizations develop the same kind of knowledge according the classification proposed by Vicente *et al.* (2010). This typology distinguishes four core competencies (knowledge segments) within the GNSS industry: (i) the infrastructure segment with all the spatial and ground infrastructures; (ii) the hardware segment, including all the materials and chipsets which receive, transmit or improve the satellite signal; (iii) the software segment, including all the software applications that use navigation and positioning data; (iv) the whole of applications and services segment, which concerns many heterogeneous agents and socioeconomic activities where navigation and positioning technologies are introduced. Indeed, it is assumed that two organizations share a cognitive proximity (scored 1) if they share the same knowledge base (scored 0 if they do not).

Organizational proximity

Two organizations share an organizational proximity if they belong to the same corporate group. A corporate group is composed by parent companies, their subsidiaries and their different establishments. This information is available on the websites of the different companies, most of the time directly signalled, like Telespazio as “a Thales/Finmeccanica company”, or sometimes in a specific part dedicated to their corporate governance or to the internal organization of the group they belong to.

Institutional proximity

Institutional proximity appears when organizations have the same institutional form according to the triple helix model (ETZKOWITZ and LEYDESDORFF 2000), already used as a measure of proximity by PONDS *et al.* (2007). The paper distinguishes among university (universities and public research centre), industry (the firms), government (political organizations and spatial agencies) and a fourth helix (LEYDESDORFF and ETZKOWITZ 2003) with the public (civil society, represented by non-profit organizations).

Social proximity

The paper measures social proximity through the geodesic distance 2 between two organizations (i.e. if they have a partner in common), closely to the structural mechanism of transitivity, which leads to network closure (BOSCHMA and FRENKEN 2009). Indeed, social proximity permits to control for transitivity, a major structural mechanism (SNIJDERS et al. 2010) without using the transitive triplets effect, inadequate to the structure of collaborative projects data[10]. Social proximity evolves each year, so three matrices of geodesic distance 2 are distinguished in order to test if partners of partners in the year *t*, i.e. who share a social proximity in *t*, are more likely to collaborate in *t+1*.

Density effect

The density effect considers the number of relations of each organization, measured by:

$$S_i(x) = \sum_j x_{ij} \tag{5}$$

where $x_{ij} = 1$ indicates presence of a relation from i to j and $x_{ij} = 0$ indicates that i and j are not linked.

Absorptive capacity

Absorptive capacity is measured according to the sum of scores of R&D sectoral intensity [according to the OECD[11] classification: high-technology (4), medium-high-technology (3), medium-low-technology (2) and low-technology industries (1)] and the size [according to the number of employees: 1 to 10 (1), 11 to 50 (2), 51 to 250 (3), 251 to 500 (4) and more than 501 (5)], rescaled from 1 to 6.

Table 4 here

6. Empirical results

All parameter estimations of the model are based on 2000 simulations runs, conditional method of moments estimation is used, and convergence[12] is excellent for all models (t-values < 0.1). Table 5 summarizes the results of intermediate and final models[13]. Discussion of the results is presented below in order to consider specificities of the GNSS industry.

Table 5 here

The rate function presented in the first part of table 5 models the temporal progression of the GNSS collaboration network. This rate is defined in the simulation model as "the expected frequencies, between successive waves, with which actors get the opportunity to change a network tie" (SNIJDERS et al. 2010, p.51). The first result about the network dynamic shows that the general parameter ($\lambda_{t,\ t+1}$) is decreasing over the years. Its significance only means that changes occur in the network during the period. The decreasing expected number of changes induces the lower growth of the collaboration network, and means that there are fewer opportunities to change relationships in the last period than in the two previous ones. In order to consider that organizations may change their relations at a different frequency according to their positioning in the network, the last model tests the influence of the degree on this rate function. A positive and significant effect is found, and it indicates that organizations with a high degree have more opportunity to find new partners.

The second part of the table 5 is dedicated to explain the observed network changes, through the specification of the objective function. The density effect is negative and significant, which is generally the case for social networks, except for networks with an extremely high density. This structural control variable expresses the idea that there is an opportunity cost in the establishment of each relation. Thus, to decide to start collaboration, organizations have to be driven by other structural, individual or proximity forces that compensate this cost.

In order to control for heterogeneity among individual characteristics of the organizations, the influence of the absorptive capacity is estimated. Results show that it is a strong parameter for collaboration. This effect means that organizations prefer to start partnerships when their absorptive capacity is high, converging with the findings of other empirical studies (GIULIANI and BELL 2005, BOSCHMA and TER WAL 2007, MORRISON 2008). This result confirms the idea that organizations that absorb easily knowledge from their environment are more interested to collaborate.

The first result about the influence of proximity shows that organizations prefer to start collaborations when they share a geographical proximity. It clearly shows that geographical proximity matters in the establishment of collaboration, because organizations are more likely to choose partners of the same spatial area. The paper confirms here the findings of other empirical network studies (AUTANT-BERNARD *et al.* 2007, PONDS *et al.* 2007), and more generally the idea that innovation and knowledge creation processes require geographical proximity and face-to-face interactions. This result is all the more interesting as one of the aims of the European Union in the FPs is precisely to try to avoid massive collaborations between geographically close organizations in order to promote a European Research area. This result demonstrates that geographical proximity still remains a strong vector of collaboration for organizations of the GNSS industry that are localised in few clusters in Europe, and even when this effect is controlled by the four other forms of proximity (see model 4 in table 5).

A second result confirms the proposition 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 corporate group than with others. Besides the theoretical argument which explains that organizational proximity develops trust and provides relevant information from the future partner, and so avoids the risk of unintended knowledge spillovers, specificities of the GNSS industry and collaborations within funded project are likely to increase the effect of organizational proximity. The

GNSS industry is strongly dominated by the two major competitors Thales Alenia Space and EADS Astrium, which have themselves subsidiaries and many establishments in different European countries. This kind of duopoly leads often, by nature, to find companies, subsidiaries or their establishment as partners of the same projects. To collaborate preferentially with organizations of the same group can also reveal a strategy to control knowledge creation and diffusion within the projects, but also to get a maximum external R&D funding for the corporate group.

A third result demonstrates that social proximity measured through transitivity has a positive effect, but the difference with organizations that do not share social proximity is not significant. It means that organizations are not more likely to start collaboration with partners of partners, so it does not confirm the proposition about the positive influence of social proximity. Indeed, even if we expect that collaborations (geodesic distance = 1) develop social proximity between partners, it is not enough to encourage partners of partners (geodesic distance = 2) to collaborate. Nevertheless, the paper does not conclude that social proximity does not influence the relational changes in other collaboration networks. In fact, this result shows that friendship, trust, or informal knowledge, i.e. the basis of social proximity, are less likely to happen in multiple partners collaborations than in bi-lateral collaborations.

A fourth result demonstrates that the effect of cognitive proximity is not significant. Organizations do not necessarily prefer to collaborate when they share the same knowledge base, in order to be able to access also to external different knowledge. It is particularly true for this knowledge dynamic, characterized by the fact that GNSS are technologies that find complementarities in many other technological and socio-economic contexts, often interconnected around an emerging technological window or standard (VICENTE and SUIRE 2007). Thus, organizations of the navigation by satellite industry definitively require access to various knowledge bases, from infrastructure, hardware, software to more general application and services knowledge. This accessibility of external different knowledge bases is decisive for organizations, in order to be able to propose GNSS innovative solutions for a large variety of sectors and applications. However, it has to be noticed that this result is strongly dependent on the way cognitive proximity is measured, and other type of measure could lead to different results (NOOTEBOOM *et al.* 2007; PAIER and SCHERNGELL 2008).

The last result concerns institutional proximity, and it is the third form of proximity that has a significant and positive impact on the probability to collaborate. It means that organizations prefer to collaborate with partners which belong to the same institutional form, as already shown by PONDS *et al.* (2007). Institutional proximity favours collaboration because it is easier to collaborate when actors share the same mode of working. Institutional proximity will not only help to communicate and to transfer knowledge between partners, but also it will improve their coordination (KIRAT and LUNG 1999) and successful collaborations because "when institutional proximity is high […] collaboration takes place within a common framework of incentives and constraints" (PONDS *et al.* 2007, p.427).

7. Conclusion

This paper analyzes the effects of proximity on the evolution of the GNSS collaboration network. This contribution follows a recently opened research area (BOSCHMA and FRENKEN 2009), dedicated to the articulation between research on proximity (BELLET *et al.* 1993, RALLET and TORRE 2001, BOSCHMA 2005) and research on patterns of network evolution (SNIJDERS 2001, GLÜCKLER 2007). Indeed, the central interest of this study was to identify how organizations choose their partners, with a special interest on their proximity or distance. The empirical investigation took place in an emerging collaboration network, based on projects funded by the European Union (FP6) within the navigation by satellite industry.

The contributions of this paper can be summarized in three points. Firstly, even if this paper is mainly oriented toward empirical analysis, a major issue was to discuss theoretically about the definition and the influence of proximity on the evolution of collaboration networks. Then, a second important effort was dedicated to the measurement of geographical, organizational, institutional, social and cognitive proximity. In fact, even if several typologies dedicated to the definitions of 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 the cognitive proximity. Finally, the way the statistical model is constructed, with five forms of proximity included, but also where each form controls for the effect of each other furnishes original empirical results.

The empirical results on the evolution of the GNSS collaboration network can be summarized as follows: organizations prefer to start partnership when they share one or more forms of proximity, except for the cognitive and social proximity, which have not a significant effect. Indeed, geographical, organizational and institutional proximity favour collaborations. Cognitive proximity has not a significant effect on collaboration, because organizations need not only partners with the same knowledge base but also to access to different knowledge in the GNSS industry. Otherwise social proximity is less likely to happen in projects with multiple partners than in bi-lateral collaborations.

This paper studies how organizations choose their partners according to their proximity. However, two crucial questions for the research agenda about proximity dynamics are not developed in the paper. First, the paper does not investigate how the different forms of proximity interact among each other. In fact, even if the paper proposes to control the effect of each form of proximity on each other, it does not show in what extent some forms can be substitutes (one form replaces another one), or complementary (one form needs another one). Second, these different forms are considered as given data, like explanatory variables of the evolution of the collaboration network. Put differently, the paper does not explain where this degree of proximity comes from, and how it evolves[14]. A future interesting research area may be found in the co-evolution of proximity and networks (MENZEL 2008, TER WAL and BOSCHMA 2009, TER WAL 2009). Thus, the central question will be 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 an important theoretical contribution that will help to unravel the complex linkages of co-evolution. Then, it is also an empirical challenge, in order to provide and compare results from other industries with different measures of proximity dimensions.

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Notes

1. In the stochastic model proposed, calculations for statistical inference are too complex to be carried out analytically (SNIJDERS et al. 2010).

2. Massive civil use of the American GPS really begun in May 1, 2000.

3. Spatial agencies, but also agencies for the security of air flight or railroad.

4. Detailed information can be found in VICENTE *et al.* (2010).

5. Centre National d'Etudes Spatiales.

6. Deutsche Zentrum für Luft- und Raumfahrt.

7. Community Research and Development Information Service (CORDIS): http://cordis.europa.eu/

8. GNSS Supervisory Authority (GSA): http://www.gsa.europa.eu/

9. 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.

10. Accounting transitive triplets to measure transitivity is inadequate to affiliations networks constructed from bi-partite data (Robins and Alexander 2004) and leads to artificially high transitivity parameter (by construction of the data, each project is a clique, where organizations are fully connected).

11. OECD, ANBERD and STAN databases, May 2003.

12. The convergence indicates the deviations between simulated values and observed values.

13. For standards errors: *p<0.10; **p<0.05; ***p<0.01.

14. Except for institutional proximity, static by nature as measured in the paper, all dimensions of proximity are dynamics. Organizations are moving (geographical), financial (organizational) as well as social ties (social) are changing and knowledge (cognitive) is a dynamic process.

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Projects		Organizations	
Number of projects	66	Number of organizations	104
Number of organizations per project	5.47	Number of project per 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

Observed period	0→0	0→1	1→0	1→1	Missing
2004-2005	4758	413	61	124	0
	89%	8%	1%	2%	0%
2005-2006	4455	364	139	398	0
	83%	7%	3%	7%	0%
2006-2007	4367	227	215	547	0
	82%	4%	4%	10%	0%

Table 2. Network changes

Observation time	Nodes	Links	Average degree	Density
t_1 = 2004	104	185	3.592	0.035
t_2 = 2005	104	537	10.427	0.100
t_3 = 2006	104	762	14.796	0.142
t_4 = 2007	104	774	15.029	0.145

Table 3. Structural network characteristics

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

Table 4. Operationalization and measurement of variables

	Model 1 (N=104)		Model 2 (N=96)		Model 3 (N=96)		Model 4 (N=96)		Final Model (N=96)	
Rate function										
Rate $\lambda_{2004\text{-}2005}$	12.426***	(0.632)	13.908***	(0.720)	14.024***	(0.780)	14.030 ***	(0.759)	9.987 ***	(0.488)
Rate $\lambda_{2005\text{-}2006}$	11.578***	(0.542)	12.390***	(0.598)	12.393***	(0.601)	12.454 ***	(0.581)	7.536 ***	(0.355)
Rate $\lambda_{2006\text{-}2007}$	9.100***	(0.422)	9.434***	(0.465)	9.411***	(0.452)	9.400 ***	(0.465)	5.250 ***	(0.245)
Degree effect on rate									0.031 ***	(0.007)
Objective function										
Density	-0.327***	(0.024)	-0.349***	(0.024)	-0.357***	(0.029)	-0.360 ***	(0.030)	-0.275 ***	(0.028)
Absorptive capacity			0.167***	(0.019)	0.161***	(0.019)	0.152 ***	(0.020)	0.145 ***	(0.019)
Geographical proximity			0.088***	(0.026)	0.086***	(0.026)	0.088 ***	(0.026)	0.086 ***	(0.026)
Organizational proximity					0.364**	(0.153)	0.324 **	(0.162)	0.293 *	(0.156)
Social proximity (transitivity)					0.024	(0.049)	0.022	(0.048)		
Cognitive proximity							0.001	(0.039)		
Institutional proximity							0.108 ***	(0.041)	0.100 **	(0.041)

Table 5. Estimation Results: parameter estimates and standard errors

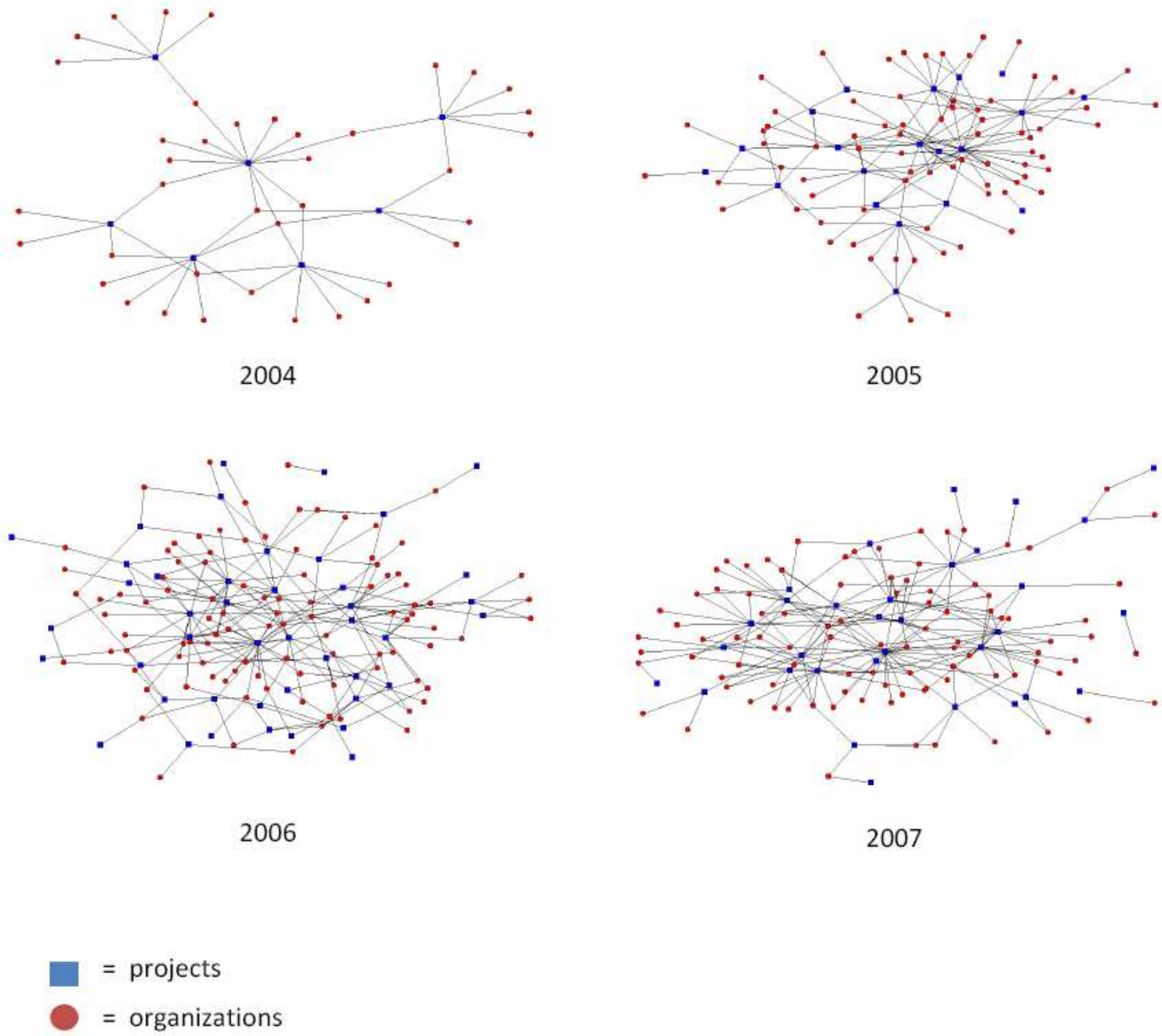

Figure 1. Evolution of the GNSS collaboration network