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Structural and geographical patterns of knowledge networks in emerging technological standards: evidence from the European GNSS industry

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The concentration and dispersion of innovative activities in space have been largely explained and evidenced by the nature of knowledge and the geographical extent of knowledge spillovers. One of the empirical challenges is to go beyond this by understanding how the geography of innovation is shaped by particular structural properties of knowledge networks. This paper contributes to this challenge, focusing on the particular case of global navigation satellite systems at the European level. We exploit a database of R&D collaborative projects based on the fifth and sixth European Union Framework Programs, and apply social network analysis in economic geography. We study the properties both of the network of organizations and the network of collaborative projects. We show that the nature of the knowledge involved in relationships influences the geographical and structural organizations of the technological field. The observed coexistence of a relational core/periphery structure with a geographical cluster/pipeline one is discussed in the light of the industrial and geographical dynamics of technological standards.

Keywords: economic geography; knowledge networks; social network analysis; EU Framework Programs; technological standards; GNSS

JEL Classification: O32; R12

1. Introduction

Technological innovations emerge according to micro–macro dynamics in which networks and geography shape the process that turns new ideas into dominant designs. This paper aims to introduce a theoretical framework and an empirical assessment that grasps this process, focusing on the structural dimensions of knowledge networks. The literature focusing on the geographical concentration of innovation activities has provided important empirical

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evidence showing that firms learn more easily from each other when they are located within the same place (Feldman 1999). Geography needs to be considered because the main channels of knowledge transfer, such as informal contacts, spin off or labor mobility, are strongly localized (Breschi and Lissoni 2001; Boschma and Frenken 2006). The economics of innovation literature has also recognized early the central role of networks in the development of new products, new processes and new knowledge (Freeman 1991; Antonelli 1996; Hagedoorn 2002). And recent applications of concepts and tools originally developed in network science have pushed further our understanding of the role played by network structure on innovation processes (Ter Wal and Boschma 2009). It is now established that the particular way knowledge ties are organized not only influences the actor's innovation performance, but also more globally the creation, combination and diffusion of new knowledge within entire technological fields and industries (Cowan and Jonard 2003; Schilling and Phelps 2007; Ozman 2009).

To understand better the role of geography and networks in innovation activities and knowledge transfer, scholars have often investigated the type of knowledge which is actually exchanged between actors (Antonelli 2006). The conceptualization of the nature of knowledge has been a central debate in the field (Cowan, David, and Foray 2000), and especially the reference to tacit knowledge (as opposed to codified knowledge) has increasingly been used to explain the spatial patterns of innovative activities (Gertler 2003). Despite this strong interest, empirical studies that investigate how geographical and structural patterns of technological fields are affected by the nature of knowledge remain scarce. Indeed, knowledge spills over both network structures and geography (Breschi and Lissoni 2001; Cowan, Jonard, and Özman 2004), and little is said about the relationships between the nature of knowledge and the structural organizations of technological fields. Noticeable exceptions come from Broekel and Graf (2012), who investigate how the structure of R&D networks varies depending on the fundamental or applied nature of knowledge ties. In a more dynamic setting, Balland, de Vaan, and Boschma (2011) and Ter Wal (2011) show how spatial and structural determinants of network ties change with the evolution of the type of knowledge exchanged.

This paper aims at contributing to this emerging line of research by investigating empirically how geographical and structural patterns of technological fields change according to the different stages of technological development. To deal with this challenge, we focus on the particular case of global navigation satellite systems (GNSS). GNSS is a set of satellite systems that provide positioning and navigation solutions. The diffusion of these technologies, as for many information technologies and technological standards, depends on the level of interoperability at the infrastructure level, as well on the level of technological integration between infrastructures, materials (receivers, chipsets) and applications. This field is purposefully bounded in terms of knowledge and geography, in order to have a clear-cut frontier of the network. We chose to focus on GNSS rather than 'space industry', because network dynamics are more observable in technological fields than in industrial sectors (White et al. 2004). And we chose to focus on Europe (EU-25) since it corresponds to the area of the European Satellite Constellation developed in the *Galileo* project (Rycroft 2003).

The paper is organized as follows: Section 2 recalls the challenging introduction of structural properties of knowledge networks into the traditional parameters of the geography of innovation. Section 3 discusses a set of testable propositions that link cognitive and geographical dimensions of knowledge networks to their purely structural dimensions, stressing on the particular case of technological fields in which standardization influences the structuring of knowledge networks. Section 4 presents the data set of knowledge relations in the European technological field of GNSS. Section 5 discusses the methodology used for identifying the nature of knowledge involved in relationships and the structural properties of the knowledge network. Section 6 tests separately each proposition and discusses the formal results. Section 7 combines these results, emphasizing how and why the knowledge process at work in the European GNSS technological field matches geographical cluster/pipeline and network core/periphery structures in a way that permits an emerging innovation to be turned into a mass-market standard.

2. Theoretical background

The geography of innovation exhibits structures that result from localization as well as knowledge externalities, and the geographical extent of knowledge spillovers is the critical parameter that shapes these structures. One of the main highly acknowledged results is that innovation activities tend to be concentrated since tacit knowledge limits the diffusion of knowledge and geographical dispersion occurs as far as knowledge grows in codification (Gallié and Guichard 2005). Concentration and dispersion phenomena coexist and structure the geography of innovation. If we do not consider innovation activities as a whole but as a specific industry, this coexistence can be analyzed in sequential stages since agglomeration and dispersion follow the life cycles of industries (Audretsch and Feldman 1996).

Many empirical studies have highlighted these typical patterns of the geography of innovation, and the necessity to enter the black box of knowledge spillovers has grown since the channels through which knowledge flows remained opaque or at least disputed. Indeed, for Carrincazeaux, Lung, and Rallet (2001), the evidence on the agglomeration effects of intensive R&D activities does not directly mean that local innovation rate depends on connectivity between them. For Breschi and Lissoni (2001), what is hidden behind knowledge externalities could be more the result of the intentional effort of organizations to share, exchange and combine knowledge than a simple corridor effect. In a similar way, for Boschma (2005), the critical factors that discriminate between intended and unintended knowledge spillovers should be highlighted in order to appraise the real effect of geographical proximity compared to social effects. The geographical extent of knowledge spillovers does not depend only on distance but also on the ability of knowledge to flow across relational structures, so that profiling the structural properties of knowledge networks constitutes a new empirical method in economic geography (Boschma and Frenken 2010).

Most innovations are the result of a composite knowledge process that combines geographically dispersed knowledge inputs (Crevoisier and Jeannerat 2009). The literature in knowledge economics has addressed the micro-motives for shaping knowledge relations, showing that these relations partly involve opportunities to access missing knowledge and partly involve risk of weakening knowledge appropriability (Antonelli 2006). One of the key parameters for the valuation of these risks and opportunities is the degree with which the knowledge bases of partners complement each other. Organizations decide to form a knowledge partnership only when each one assumes that the benefits of knowledge accessibility will exceed the costs and the risks of under knowledge appropriability. Structural properties will not be purely physical, but will be the result of the strategic behavior of organizations which deal with their own knowledge trade-off. Networks are thus characterized by an organizational demography (Owen-Smith and Powell 2004) along the phases of the knowledge value chain. Public research organizations, producing fundamental knowledge, are the main players of the very upstream phase of knowledge exploration, while small and big companies including their R&D department are mainly involved in engineering and market-related phases of knowledge integration and exploitation. Others organizations are also involved such as standardization and normalization agencies, and other organizations that participate in the knowledge process as future users or customers. Knowledge networks are constituted of organizations that display different structural roles and positions (Vicente, Balland, and Brossard 2011), with heterogeneous behavior facing the knowledge trade-off. Finally, geography needs to be considered for the micro-motives of organizations for shaping knowledge relations. Indeed, geographical proximity between organizations involved in a partnership has ambivalent effects on their respective innovation capabilities (Boschma 2005; Torre 2008). What these effects are will depend on at least two related criteria: the phases of the knowledge value chain and the gap between their absorptive capabilities (Nooteboom 2000). Geographical proximity will be more appropriate between partners when they have to favor mutual understanding, and when their core capabilities are sufficiently distant to avoid the risks of unintended knowledge spillovers. Conversely, when partners share close capabilities and compete in few differentiated markets but find opportunities for cooperation (in standards setting for instance), the risk of unintended spillovers is high and geographical distance or temporary proximity is more compatible than proximity.

For a particular knowledge process in a particular technological field, a knowledge network will be defined as the set of organizations that are involved in the field and the set of knowledge ties between them. From this relational matrix and considering the location of organizations, some structural properties of the network are good markers of the channels through which knowledge flows and geography structures itself. The level of connectivity, i.e. the possibility or not for organizations to reach another one through many or at least one pathways, is a suitable marker for understanding the reasons of the coexistence of arms-length and embedded relations in a technological field (Uzzi 1997); in particular, when the market diffusion of innovations in the field is concerned with the question of compatibility and standardization (Cowan, Jonard, and Özman 2004). Moreover, a knowledge network can be characterized by a heterogeneous level of relations for each organization, giving rise to particular structures, such as the regular core/periphery structure observed in many situations (Barabási and Albert 1999; Borgatti and Everett 1999). A network exhibits a core/periphery structure when a highly cohesive structure of knowledge interactions between organizations coexists with organizations that are poorly connected between themselves and with the core. Organizations that are embedded in the core of the structure are able to coordinate their action, exchange knowledge and favor its circulation, while the others constitute a pool of organizations being a potential furnisher of new and fresh ideas (Uzzi and Spiro 2005; Cattani and Ferriani 2008). Such a structure shows that knowledge relations are not randomly distributed within a network and can be interpreted as a particular stage of its dynamics. The geography of a knowledge network will reflect these properties. Since Porter's research (Porter 1998), clusters have been seen as efficient structures that favor innovation and growth. Nevertheless, thinking about innovation by focusing only on geographical clusters is a narrow view of innovations occurring in most technological fields. If clusters exist, they are generally embedded in larger geographical structures, and connected through global pipelines[1] (Bathelt, Malmberg, and Maskell 2004; Moodyson 2008; Trippl, Tödtling, and Lengauer 2009). Recent empirical studies go further, showing that these global pipelines can be the primary source of firm innovation (Dahl Fitjar and Rodríguez-Pose 2011).

The structural properties of knowledge networks have been increasingly investigated in the last couple of years, theoretically (Ter Wal and Boschma 2009; Boschma and Frenken 2010) as well as empirically (Owen-Smith and Powell 2004; Autant-Bernard et al. 2007; Boschma and Ter Wal 2007; Balland 2012; Vicente, Balland, and Brossard 2011; Broekel and Graf 2012). These studies concern different industrial sectors and technological fields, consider different geographical areas and use different sources of relational data. Even if some standard results appear, the structural and geographical properties will differ according to the knowledge dynamics under study, and thus require traditional tools of economics for a good interpretation of the results. For instance, technological fields or industrial sectors in which a high degree of competition remains will probably exhibit a lower level of connectivity than a technological field in which standardization and compatibility are the rule of mass-market success (Suire and Vicente 2009; Eisingerich, Bell, and Tracey 2010). Moreover, technological fields will differ structurally according to their research or market-oriented nature, as well as the level of public funding in the field (Broekel and Graf 2012). The identification of the structures of knowledge flows in space therefore gives an interesting representation of how technological fields structure themselves from the early market to the mass market, and according to complementary logics of cooperation in networks and competition in markets.

3. The structural and geographical properties of the European GNSS knowledge network: two propositions

The framework defined, Section 3 discusses testable propositions that link cognitive and geographical dimensions of knowledge networks to their purely structural dimensions, focusing on the particular case of a technological field in which standardization and the emergence of a dominant design influence the structuring of knowledge networks.

3.1. An overview of GNSS in Europe

GNSS is a standard term used to describe systems that provide positioning and navigation solutions, and is perceived as ‘a fifth utility, on a par with water, gas, electricity and communication’ (Braunschvig, Garwin, and Marwell 2003, 158). These technologies were mainly developed in the aerospace and defense industries and, currently, in the consumer-driven technological paradigm of mobility, find complementarities and integration opportunities in many other socio-economic contexts and have a large number of civilian applications. The diffusion of GNSS-related innovations depends on a high level of interoperability and compatibility, as well as a growing number of applications for consumers. That is why innovations in the field are driven by public incentives as a strategic challenge for policy-makers to set a European standard of navigation and positioning. The field requires collaborations between public and private organizations from different sectors and so is characterized by a large variety of knowledge backgrounds, from transport, security, tourism or telecommunication. The organizations belonging to the GNSS technological field display heterogeneous knowledge profiles and institutional forms. We can find the biggest companies of the space industry, small and medium enterprises, research centers, spatial agencies, non-profit organizations and a large array of other organizations. In addition, the Egnos and Galileo programs are key political issues for the European independence on navigation satellite systems. Indeed, the main objective is ‘to make GALILEO not just a functioning system but also the world’s leading satellite navigation system for civilian applications’.[2]

3.2. Knowledge networks, structural properties and the diffusion of a technological standard

The structural organization of the GNSS technological field will depend on the interplay between the phases of the knowledge value chain (Cooke 2006), the degree of maturity of the field regarding the market conditions (Audretsch and Feldman 1996), as well as its degree of relatedness regarding the interoperability and compatibility constraints of technological standards diffusion (Vicente, Balland, and Brossard 2011; Broekel and Graf 2012). Indeed, GNSS are considered general-purpose technologies for which the willingness of consumers to pay and adopt depends on the weight of direct and indirect network externalities on the demand side, and thus requires a high level of interoperability between competing suppliers and a large extent of uses and applications (Katz and Shapiro 1994). First, technological fields in which standardization matters for reaching the mass market exhibit relational structures typified by a cohesive matrix of relations. A knowledge network can thus exhibit a core of dense relations when competition depends on standards harmonization, as observed in the 1980s for the development of the mobile phone industry and the collaborative research on the GSM standard definition (Rice and Martin 2008). Considering that GNSS should be becoming a public utility in the growing paradigm of mobility, the diffusion of GNSS will depend on the ability of the suppliers of the field to interact in order to pool together their knowledge and existing technologies around a common standard. Knowledge sharing and collaborative R&D processes are not only dedicated to new ideas, but also to compatibility and interoperability between their own technologies for increasing the potentialities of market exploitation. Second, general-purpose technologies such as GNSS cross different sectors and markets so that their diffusion depends on the variety of applications and new markets they water, and the field is typified by a high level of technological relatedness. Transport, telecommunications, software, safety, tourism, environmental observations, among others, are sectors concerned by GNSS-based innovations, and require a high level of knowledge integration between separated and sometimes cognitively distant knowledge in order to propose viable integrated systems to consumers. This knowledge integration process has two implications for the reinforcement of the core of the network. First, network density and closure in the core of the network favor the buildup of the absorptive capacity, since knowledge distance between partners can be reduced by the connection to other partners who complement their absorptive capacities (Gilsing et al. 2008). Second, interoperability and compatibility in the vertical integration process still remain important so that the knowledge phase of integration needs to be supported by a high level of knowledge exchange and additional collaborative R&D between separated and previously codified knowledge.

The formation of a core of dense knowledge relations in a field concerned by technological standardization and relatedness is then typical of its growing maturity. This structural organization characterized by closure and triangulation favors the mutual understanding between partners, engenders trust, prevents opportunistic behaviors (Coleman 1988), and thus insures a high level of stability. Nevertheless, even if this stability is suitable for favoring incremental innovations in the field, highly cohesive structures of knowledge interactions produce conformism and display risks of lock-in. Redundant ties limit access to new information and fresh ideas (Burt 1992; Barabási and Albert 1999), and can sclerose the technological field as a whole. Technological fields characterized by a structural organization displaying a high level of closure can enter into a phase of inhibition, which is typical of the decline phase of the product life cycle. Technological fields will exhibit a long-term viability and development, when, in parallel to the structuring of the core, a less cohesive but not disconnected pool of explorative knowledge remains at the periphery of the knowledge network. In the exploration phase, technologies are beta tests without consumers or at least very early adopters. Market solutions are not identified and compatibility constraints are not as determinant as in the integration and exploitation phases. But this pool of fresh and news ideas should be connected to the core of knowledge interactions through organizations in order to be turned into tradable innovations in the future. Under such structural conditions, the technological field develops an endogenous capability to grow through its periphery, in particular with the strategic and creative role played by the organizations that connect the core to the periphery (Cattani and Ferriani 2008). Between disconnected structures of knowledge interactions that typify the very early stage of a technological field, and the highly ossified and dense structures of interactions that could typify a lock-in process, a structured core/periphery hierarchy appears as a marker of the increasing maturity of the field. The two following propositions can be deduced:

PROPOSITION 1a *Technological standards are defined and diffused within knowledge networks that display a core/periphery structure.*

PROPOSITION 1b *The core/periphery structure results from the overlapping of the phases of the knowledge value chain.*

3.3. Knowledge network, geographical properties and technological development

We consider that the geographical properties of knowledge networks depend on the degree of maturity of the technological field, and on the specific properties of fields in which technological standardization and relatedness matter for the tradability and diffusion of technologies. Previous research has already demonstrated that industry life cycles are sensitive to geographical changes due to the increasing codification of knowledge along the cycle of a product (Audretsch and Feldman 1996; Audretsch et al. 2008). The clustering of innovative activities corresponds to the early stage of a product, while dispersion occurs when an industry reaches a high level of maturity. If these results have been abundantly evidenced, they failed to investigate the interaction structures that shape these geographical changes. From the very early phase of emerging ideas to the phase from which these ideas are turned into mass-market products, structural as well as geographical properties of knowledge networks evolve. A growing literature on structural and geographical properties of knowledge networks has pointed out these critical parameters (Cowan, Jonard, and Özman 2004; Owen-Smith and Powell 2004; Boschma and Frenken 2010; Balland 2012; Ter Wal 2011). These works consider that networks and attribute-based features interplay along the knowledge value chain of innovations, giving a less abstracted view of the role played by local and non-local knowledge spillovers in the geography of innovation.

Owen-Smith and Powell (2004) highlight structural and geographical patterns along the growing maturity of the biotech sector in Boston. In a comparative approach, they show that at the early stage of the cluster, the cohesiveness of the local relational structure depended mainly on the active participation of public research organizations that connect disconnected private organizations in a very open structure of fundamental knowledge dissemination, while 10 years later, knowledge flowed directly between small science-based firms through formal agreements in a market-oriented regime. At the same time, in a nested analysis of geographical scales, they compare the structural and cognitive properties of the local network to the ones of the network extended to other organizations in any locations that have a tie with local ones. Their findings furnish interesting additional properties: considering the extended network, the ties between private ‘insiders’ and ‘outsiders’ significantly reduce the structural dependence of knowledge flows on local research organizations. Such a result shows how, in the structuring of the knowledge field, clustered relations depend on the dominance of an academic and open institutional regime, while pipelines relations in which private and big firms are involved remain focused on a market regime in which knowledge appropriateness prevails. Ter Wal (2011) proposes a network-based empirical study in the same knowledge field but in the specific case of the German co-inventors network and observes a similar pattern of the evolution of structural properties. From the exploration phase in the 1980s to the exploitation phase in the 1990s, he observes a shift in the network strategies of biotech organizations. While the network grew initially along geographical proximity, the increase in knowledge codification and the maturity stage of commercial applications has led companies to use global networks as a resource of triadic closure, which favor trust and knowledge appropriateness. These empirical studies give well-documented illustrations of the buzz/pipeline model of Bathelt, Malmberg, and Maskell (2004) for whom cluster efficiency in knowledge-based economies arises from a mix of local and global effects of knowledge relations, one of the main discriminatory parameters between them being the degree of formalization of agreements (distance reduces trust and increases control capabilities), and the size of the organizations (managing pipelines requires investments and resources). According to them, if the buzz favors knowledge creation, clusters cannot always be the place of a *vibrant buzz* since outward-looking organizational structures are required for enlarging market access as well as for capturing outside knowledge. Dahl Fitjar and Rodríguez-Pose (2011) go further in the research of the critical determinants of innovations in urban Norwich firms, showing that radical innovations fit better with international pipelines than with local and national relations.

The geography of knowledge networks is thus dependent on the attributes of the organizations and the knowledge value chain of innovations. If clusters remain crucial in the explorative knowledge phase through their ability to connect separated knowledge, they cannot be self-sufficient since diffusion and commercialization require an enlargement of networks in space. For the case of GNSS, as for fields in which technological relatedness and compatibility play a fundamental role, such a geographical structure corresponds to a particular stage of the growing maturity of the field. Research-based organizations are still active in connecting knowledge assets in order to develop new ideas in clusters. At the same time, the incumbents and engineering companies develop pipelines, in parallel to their cluster embeddedness, in order to coordinate the definition of future technological standards and integrate knowledge stemming from other sectors in order to define these standards. Moreover, other knowledge relations, more geographically outward and market-oriented ones, can be developed in order to ensure the availability and tradability of these future applications in dispersed areas and markets. The two following propositions can be deduced:

PROPOSITION 2a *The clusters/pipelines structure of knowledge interactions in a particular technological field is typical of the overlap between the phases of its knowledge value chain.*

PROPOSITION 2b *The geography of knowledge networks is structured by the nature of knowledge involved in research collaborations.*

4. Data

As a relational data source, we use joint R&D projects funded by the Framework Programs (FP) for research and technological development[3] of the European Union (EU). As such, we follow recent empirical studies emphasizing the advantage of this kind of relational data in economic geography (Gambardella and Garcia-Fontes 1996; Autant-Bernard et al. 2007; Breschi et al. 2009; Balland 2012; Scherngell and Barber 2011). For the purpose of this paper, we exploited the GNSS Supervisory Authority[4] (GSA) database on joint GNSS R&D projects funded by the fifth and sixth FP from 2002 to 2007. This section presents the main structural descriptive statistics of both affiliation networks constructed from our database, i.e. the network of projects and the network of organizations.

4.1. Relational data source

Among other data sources,[5] the choice of R&D projects is especially relevant for two reasons. First, since the end of the 1950s, space organizations used to work under publicly funded programs, since space exploration has always been a strategic issue for governments. A disadvantage of using FP as relational data is related to the influence of the European research policy on collaboration choices, leading for instance to geographical dispersion (Autant-Bernard et al. 2007). A possible bias in our results could be to observe a lower degree of collaborations intra-cluster and a higher degree of collaborations inter-clusters that one could expect without the EU funding criteria. However, our study should not suffer from this issue, as our objective is not to explain collaboration choices, but to compare the geographical and relational structures of knowledge exploration, integration and exploitation. Indeed, we are only interested in the proportion of each type of knowledge flowing within clusters or between clusters, and there is no particular reason to assume that the three kinds of knowledge are influenced in a different way by the EU research policy.

As pointed out above, data have been mainly collected from the GSA database, which provide information about all joint R&D projects (including the partners in the projects) funded by European GNSS programs. Some additional information required for the empirical study has been collected from information services of the European Commission,[6] as well as on the project and partner's websites, using communication documents or work package reports. This additional work was particularly important for the classification of the different projects in exploration, integration and exploitation. Table 1 displays descriptive statistics about the cumulated number of projects and organizations involved in the overall period (2002–2007).

Figure 1 gives a bimodal visualization of the GNSS collaboration network. Blue squares represent projects and red circles represent organizations. The bimodal network is a rectangular data matrix of organizations (360 rows) by projects (72 columns).

4.2. The affiliation networks

This primary database is mainly used to deduce two adjacency matrixes the *network of projects* and the *network of organizations* that will be analyzed in the empirical section. Relatively few network analyses focus on networks of projects in economic geography. This is an originality of our approach that will allow us to study interesting structural properties of knowledge creation. Indeed, we consider that similar to networks of patents (Verspagen 2007), networks of projects contain very rich knowledge-related information.

Table 1. Descriptive statistics (2002–2007).

Projects		Organizations	
Number of projects	72	Number of organizations	360
Average of organizations by project	8.2	Average of projects by organization	1.7
Standard error	6.6	Standard error	1.7
Minimum	2	Minimum	1
Maximum	32	Maximum	17

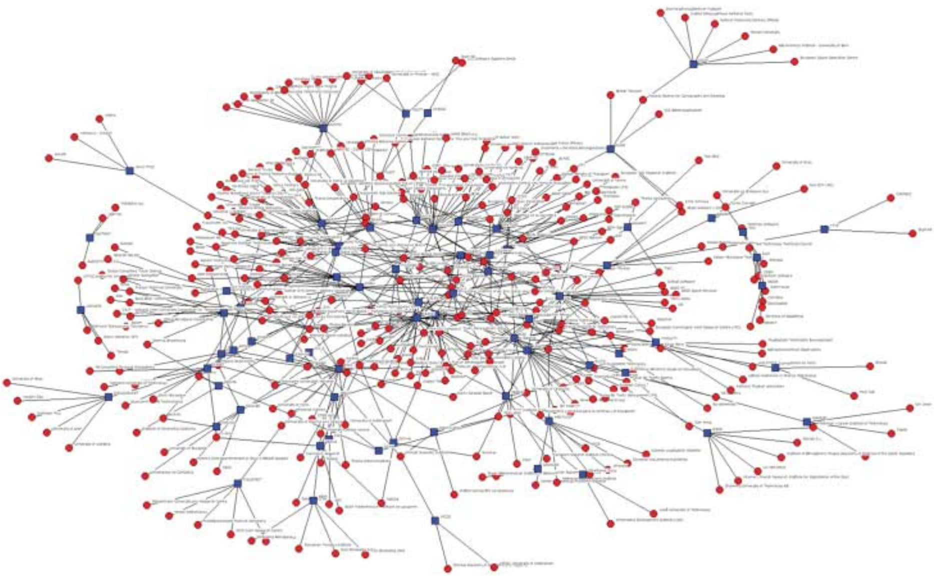

Figure 1. The GNSS bimodal network, 2002–2007.

Table 2. Structural characteristics.

Statistics	Network of projects	Network of organizations
No. of nodes	72	360
No. of links (valued)	1512	7842
No. of links (dichotomized)	914	7144
Density	0.181	0.055
Main component	66	339

To construct the network of projects, it is assumed that two projects are linked if at least one organization participates in these two projects. To construct the network of organizations, we have converted the primary bimodal matrix into a square matrix of relations between all the organizations. We assume that each project is fully connected (forming a clique), so that two organizations are linked if they participate to the same project. Descriptive statistics on the network of projects and the network of organizations are given in Table 2. They show that both the network of projects (0.181) and the network of organizations display a relatively high density[7] (0.055) and a high connectivity. Considering the network of projects in particular, we identify a principal component of 66 projects, meaning that only 6 projects are isolated during the period of study.

The degree centrality distribution exhibits an asymmetrical shape,[8] indicating that only a few nodes have a high probability of having large number of relations (Figure 2). This statistical signature suggests some interesting traits about the industrial structure of the GNSS sector, related to the setting and control of technological standards as well as efficient cost strategies. Vertical firms and transnational corporations are often representative organizations of this type of market. In our case, these hubs are mainly firms of big corporate groups (Thales, Finmeccanica, and EADS) and spatial agencies (European and national) that develop orbital and ground infrastructure.

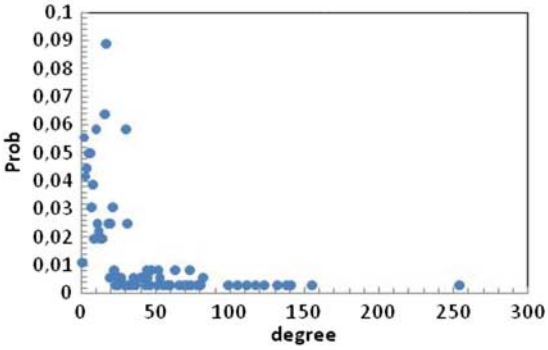

Figure 2. Degree centrality distribution among the 360 organizations.

5. Methodology

In this section, we describe the method we used to capture the nature of knowledge, in order to proceed to the social network analysis of both the network of organizations and the network of projects[9] (Ter Wal 2011; Broekel and Graf 2012). The exploration–integration–exploitation taxonomy is discussed as well as the robustness of the final classification of projects we obtain. In addition, we explain the methodology for the empirical identification of clusters and pipelines in Europe.

5.1. Exploration–integration–exploitation: a taxonomy

Joint R&D projects refer to a large variety of knowledge processes, ranging from exploration (fundamental research) to exploitation (applied focus) to follow the distinction proposed by March (1991). In the context of the GNSS industry, we also consider the integration category, for projects combining different existing technologies because this kind of project is concerned with specific standard and compatibility issues.

To proceed with the classification of the different projects into these three categories, we developed an approach making use of three criteria. First, we analyzed the main goal of the project, as expressed in the title of the project, or in the abstract. It generally already gives a clear overview of whether projects are oriented from general concern for GNSS to very specific applications. Second, we used a criteria based on the redundancy of specific related key words (Table 3) in the abstract and in other available project documents (work-package reports for instance). Third, we also observed the distance to the market in the different documents, because an important strategic issue for EU is to prepare the commercialization of the European navigation satellite systems. Then, projects express more or less explicitly the extent to which they contribute to achieving such an objective. By consequence, we classified in ‘exploration’ a set of projects that do not develop direct applications, but aim at improving general knowledge for navigation and positioning. This consists of knowledge production far from clear market opportunities, even if prototypes or beta tests can sometimes result from fundamental research and models. For instance, projects that focus on research for accuracy and reliability of Galileo/Egnos signals, synchronization or calibration of atomic clocks can be considered as belonging to this early phase as it will generate a large scope of further applications. On the other hand, we classified as ‘exploitation’ the projects proposing to develop well-defined GNSS applications, for instance a sensor-augmented receiver-specific environment, or development of applications specifically required for transport regulation, air fleet management or emergency services.

Table 3. Knowledge phase of the projects.

	Exploration	Integration	Exploitation
Main goal	New knowledge for future applications	Combine pre-existing technologies	Develop GNSS-based applications and services
Keywords	Concepts/theory	Technological standard	Market
	Research	Interoperability	Use
	Investigation	Combination	Applications
	Simulations	Satellite + ICT	Design
	Mathematical model	PDA	Development
	Study	Wireless	Services
Distance to the market	***	**	*

*Represents weak.
**Represents medium.
***Represents strong.

Assistance tools for users or market analysis also belong to this category. Finally, we found relevant to distinguish a third category: 'integration', for projects proposing technical integration of two technologies. For instance, in the database, most of the integrative projects are dedicated to the convergence and interoperability between GNSS, Wi-Fi and mobile phones, PDA, mp3 players or computers. The integration of two technologies requires additional R&D in order to ensure the compatibility between them. For a few projects, operating such a classification was not straightforward because the three phases were identified. In this particular situation, we focused on what we considered as the dominant phase, i.e. the most important contribution of the project, assuming that it corresponded to the largest proportion of knowledge flows.

5.2. Robustness of the classification

We analyzed which type of organization is involved in which kind of project. Broekel and Graf (2012) directly used this kind of approach to distinguish between projects dedicated to basic and applied research, arguing that public research organizations and universities are more likely to be involved in the former, while firms are more likely to be involved in the latter. Following this reasonable assumption, we distinguish among research, engineering and market-related types of organization. We considered that public research organizations and universities belong to the 'research' category. Firms specialized in satellite or telecommunications infrastructure, hardware or software belong to the 'engineering' category. 'Market-related' category is a very important residual one for the GNSS industry, involving final users, designers, associations and business consultants (Vicente, Balland, and Brossard 2011). A large proportion of organizations developing engineering knowledge are found (192), with a balanced distribution of organizations developing research (84) and market-related (84) knowledge. This straightforward typology of knowledge bases of organizations allows us to control for our projects' classification by combining the distribution of the knowledge types of the organizations with the knowledge nature of the projects. Each project displays a number of knowledge bases equal to its number of partners. We studied the distribution of the knowledge bases in the different projects, according to their knowledge phases (Table 4).

Table 4. Types of organizations and cognitive nature of collaborations.

	Exploration	Integration	Exploitation	Total
Research				
No. of organizations	62	37	25	124
%	52.5	15.9	9.2	20
Engineering				
No. of organizations	46	163	169	378
%	39	70.3	62.4	60.8
Market-related				
No. of organizations	10	32	77	119
%	8.5	13.8	28.4	19.2
Total				
No. of organizations	118	232	271	621
%	100	100	100	100

The exploration phase requires mostly research knowledge bases, since 52.5% of the organizations involved in the exploration phase develop research knowledge, but less engineering knowledge (39%) and only little market-related knowledge (8.5%). Then, the integration phase requires mostly engineering knowledge (70.3%) and very little research (15.8%) or market-related knowledge (13.9%). Finally, the exploitation phase also requires mostly engineering knowledge (62.4%), but organizations that produce market-related knowledge are mainly involved in the exploitation phase (28.4%), while the share of research knowledge decreases dramatically in this category (9.2%). This test confirms the robustness of our classification, as research organizations are more involved in exploration, engineering firms in integration, and market-related actors are more involved in exploitation.

5.3. Identification of clusters and pipelines

The GSA and Cordis databases provide systematic information on the country of the organizations and the name of a contact person, but information concerning postal addresses of organizations is not always indicated. However, the small size of the network allowed us to find missing postal addresses of organizations on their web sites, work packages of the projects or specialized GNSS websites. When a doubt still remained, especially for multi-establishment firms, more thorough research was undertaken in order to find the establishment of the engineers involved in the work packages we were considering. At the end, less than 8% of the postal addresses are missing. On this base, we proposed a method to identify clusters and pipelines from the global network of organizations. Starting from the square matrix of organizations (360 × 360), we aggregated all the organizations belonging to the same region, taking NUTS2[10] regions as the spatial unit of analysis. Most empirical research on innovation performance and knowledge spillovers in Europe use the NUTS2 level of spatial aggregation (Autant-Bernard et al. 2007; Cassi et al. 2008; Scherngell and Barber 2011), because it corresponds to real administrative units with a local identity and a policy authority (Bottazzi and Peri 2003). Moreover, GNSS clusters are often accredited by policy-makers and such an accreditation, generally defined at the NUTS2 level, influences the eligibility for public funding and incentives for local collaborations. A finer spatial scale (NUTS3) is sometimes adopted in the literature but it does not correspond to the geographical organization of the cluster policy in the GNSS industry. Such a territorial breakdown would artificially exclude and isolate organizations even though they are officially members of the cluster. Reflecting at the same time the concentration of the activity, cluster policies,

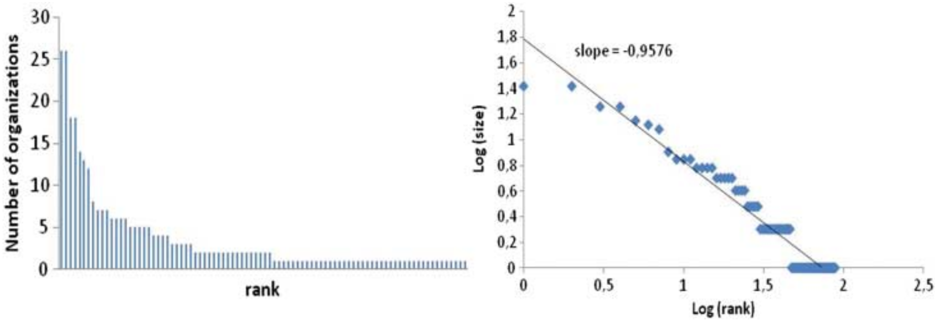

Figure 3. Distribution of organizations among 88 NUTS2 European regions.

and labor market dynamics, NUTS2 regions represent a relevant spatial unit in the case of the GNSS industry.

Then we obtained a new matrix of relations between regions, with the diagonal indicating the number of relations within the region. Close to the definition of Porter (1998), we defined a cluster as the 'geographic concentration of interconnected companies and institutions in a particular field' (78). Thus, three criteria were taken into account. The first one, the 'particular field', is obvious because we already focused on the particular technological field of GNSS. The second one refers to a 'concentration of companies and institutions', i.e. the number of organizations in the regions. The third one requires organizations to be 'interconnected', and thus defines the number of relations between organizations. Figure 3 represents the distribution of the number of organizations of the 88 NUTS2 European regions in which at least one organization is involved in the GNSS collaboration network. If we plot the regions against their rank with a log-log scale, it appears that this distribution follows a power law which is quite similar to the Zipf law with a slope of −0.9576 obtained with a least-square estimation. It is interesting to note the non-monotonic shape of the plot for the first seven values. In confirmatory with a Zipf-like relation, it appears that only very few regions (7/88) concentrate on a high number of organizations (more than 10) and a relational density higher than the average density of the network as a whole (see below). We considered that the main GNSS clusters are located in these seven regions. Then we drew a relational matrix for each of these clusters (i.e. we removed all organizations outside of the clusters) in order to study their cognitive structure. Pipelines were studied according to the block matrix of relations between regions.

6. Main empirical results: structural and geographical organization of the GNSS technological field

This section presents the main empirical results concerning the influence of the nature of knowledge on structural and geographical properties of the GNSS technological field. Both the network of organizations and the network of projects are analyzed in a complementary way to provide empirical evidence for the proposition previously discussed. We first begin by describing the structural features of the GNSS collaboration network, emphasizing the existence of a core/periphery project structure. Then we introduce the geographical dimension, with an emphasis on the identification of the kind of knowledge flowing in clusters and pipelines. The results are discussed in Section 7, with particular attention paid to the interaction between the two propositions.

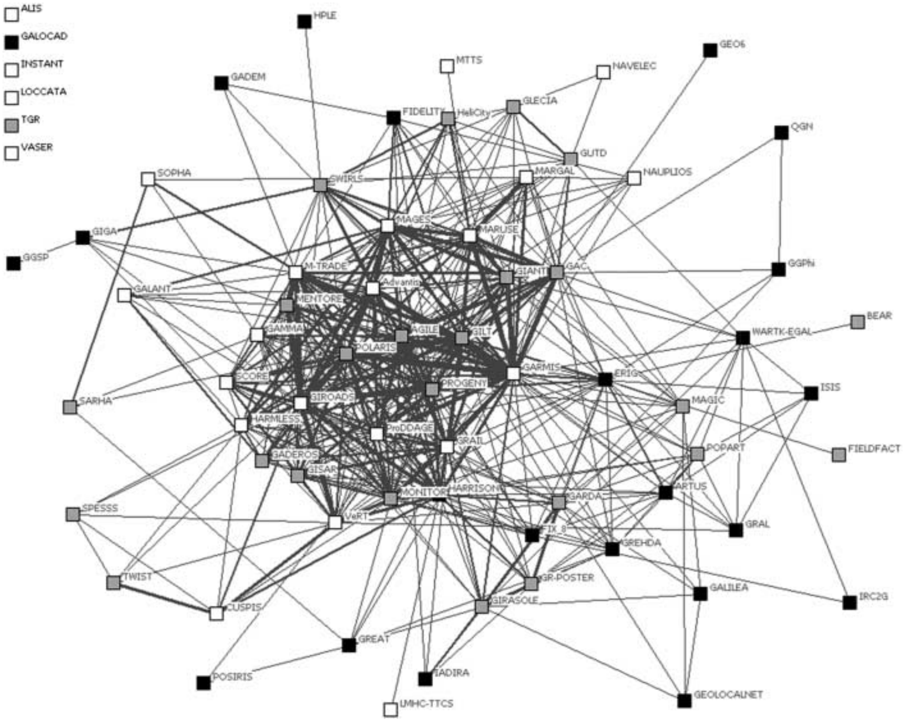

Figure 4. Core and periphery structure and nature of knowledge. Black squares represent projects dedicated to exploration, gray squares to integration, and white squares to exploitation. The line strength represents the number of organizations that tie projects, from 1 to 5 ties.

6.1. Structural organization: core and periphery

First, we study the connectivity of the different R&D projects according to their knowledge features. We use the core/periphery model developed for social network analysis by Borgatti and Everett (1999). The core/periphery partition is obtained by using a genetic algorithm (Goldberg 1989). It maximizes the correlation between the observed core/periphery partition matrix and an ideal core/periphery pattern matrix where only core nodes are fully connected, while all peripheral nodes are isolated. Applying this model to the network of projects, we empirically identify a core formed by a group of densely connected projects, while another group of more loosely connected projects constitute the periphery (Figure 4). Table 5 presents the results of the model. Projects in the exploration phase are mostly peripheral, since only 4.4% of the projects that are in the exploration phase are in the core. On the contrary, 32% of integrative projects and 41.7% of exploitative projects belong to the core. As a consequence, the closer the projects are to the market, the more they are interconnected. On the contrary, the very upstream phase of knowledge value chain remains ‘located’ at the periphery of the network.

This result can be strengthened by an econometrical test in order to control for the size of the projects. Recall that we have shown above that organizations are not randomly distributed along the knowledge phases (exploration, integration and exploitation). Thus, we will perform an econometrical test in order to estimate whether the knowledge profile of the partners (research, engineering or market-related) influences the probability of the project belonging to the core of the network, with the size of the project as a control variable. To that end, for each of the 72 projects we distinguish the respective level of organizations

Table 5. Core and periphery.

	Core	Periphery	Total
Exploration			
No. of projects	1	22	23
%	4.4	95.6	100
Integration			
No. of projects	8	17	25
%	32	68	100
Exploitation			
No. of projects	10	14	24
%	41.7	58.3	100
Total			
No. of projects	19	53	72
%	26.4	74.6	100

Table 6. Probit estimation and marginal effect.

Explained variable = belonging to the core	Probit estimation	Marginal effect
Size	0.925***	0.0044***
	(0.204)	
Size^2	−0.019***	−0.0000908***
	(0.004)	
Research	0.713	0.003393
	(0.725)	
Engineering	1.604*	0.0076339*
	(0.758)	
Market-related	1.206*	0.0057391*
	(0.620)	
Constant	−23.962**	
	(9.497)	
N	72	
Log pseudolikelihood	−9.888918	
Pseudo R^2	0.7620	

Note: Robust standards errors in the parenthesis.
*Mean significant at the level of 10%.
**Mean significant at the level of 5%.
***Mean significant at the level of 1%.

belonging to research, engineering and market-related categories. Then, we use a continuous variable range from 1 to 10 regarding the level of the presence of each knowledge base.[11] For instance, a project of size 19 with 2 'research' organizations, 16 'engineering' organizations and 1 'market-related' organization is coded (2, 9, 1). This means that respectively 10.53%, 84.21% and 5.26% of organizations are research, engineering and market-related ones. We define $Y_{i\in\{1,72\}}$, as a binary variable taking the value 1 if the project i belongs to the core and the value 0 otherwise. The probability of belonging to the core is assumed to be related to the size of the project and the knowledge profile of the partners. The relationship is specified as

$$Pr[Yi = 1|X] = \Phi(\beta_0 + \beta_1 \text{ size} + \beta_2 \text{ size}^2 + \beta_3 \text{ research} + \beta_4 \text{ engineering} + \beta_5 \text{ market}),$$

with $\Phi(.)$ representing the cumulative normal distribution function and X is the vector of regressors. We also estimate the marginal effect which is the slope of the probability curve to each regressor X to $Pr[Yi = 1|X]$, holding other variables constant.[12]

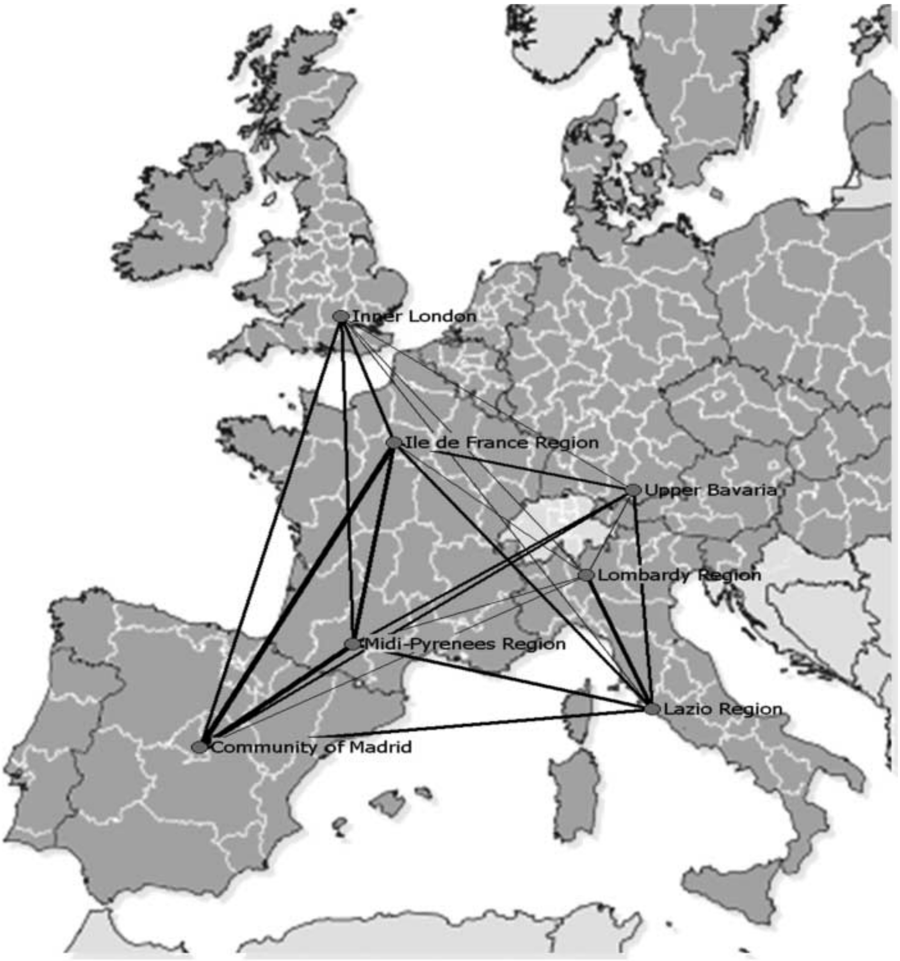

Figure 5. GNSS clusters and pipelines in Europe.

Table 6 displays the result of a probit estimation,[13] as well as the marginal effect of each variable.

As we had suspected, the probability of a project belonging to the core of the network is significantly influenced by engineering and market-related knowledge bases. Conversely, increasing the level of the research component has no effect on the probability of belonging to the core of the network. The marginal effect of the research component has no impact on the probability to belong to the core of the network. It also means that if a collaborative project has to belong to the core for market purpose or standardization consideration, increasing the level of the research base within the project has no effect on the probability of belonging to the core. The engineering component is the more influential determinant: a marginal positive variation[14] of this knowledge base increases the probability of belonging to the core by 0.7%. Finally, an interesting result appears regarding the size of the project. Increasing the size of the project has a positive effect on the probability of belonging to the core of the network but at a decreasing rate, which means the existence of a threshold above which the marginal actors negatively influence the probability of belonging to the core. As previously mentioned, one plausible explanation relies on the limited capabilities of various partners to efficiently manage coordination costs. This hypothesis is sustained in network literature by theoretical research on strategic networks stability (Jackson and Wolinsky 1996).

6.2. Geographical organization: clusters and pipelines

The second set of results concern the way the features of knowledge influence the geographical structuring of the technological field. As previously said, clusters are identified not only on the basis of the number of organizations in the region that are involved in GNSS projects, but also according to the number of relations within the cluster. This methodology allows us to identify the main GNSS clusters and the pipelines between them (Figure 5).[15]

Table 7 presents descriptive statistics concerning the seven main GNSS clusters. Considering the number of relations, the biggest cluster is located in the Community of Madrid (132 ties within the cluster), the second one in the Lazio Region (74) and the third one in the Midi-Pyrenees Region (52). We can see that these three clusters include the three main organizations (according to their degree centrality): Thales Alenia Space (Toulouse), Telespazio (Roma) and GMV (Madrid).

In order to provide information about the cognitive structure of the GNSS clusters, each cluster's relational matrix has been divided into three matrixes (nodes are still organizations), according to the nature of relations: exploration, integration and exploitation. Table 8 shows how the nature of knowledge influences the geographical organization of the GNSS technological field.

Table 7. Clusters and pipelines interaction structure.

	Community of Madrid	Lombardy region	Upper Bavaria	Midi-Pyrenees region	Lazio region	Inner London	Ile de France region
Clusters							
Country	Spain	Italy	Deutschland	France	Italy	UK	France
Main city	Madrid	Milan	Munich	Toulouse	Roma	London	Paris
Main organization	GMV	PRS	Astrium	TAS	Telespazio	Logica	FDC
No. of organizations	26	13	12	18	18	14	26
Internal degree[a] (dichotomized)	132	20	18	52	74	14	38
Density (dichotomized)	0.203	0.128	0.136	0.169	0.241	0.076	0.058
Exploration	86	2	6	32	24	10	18
Integration	32	6	12	14	28	2	22
Exploitation	34	14	0	6	28	2	0
Internal degree (valued)	152	22	18	52	80	14	40
Pipelines							
Community of Madrid	–	22	34	74	57	37	79
Lombardy Region	22	–	8	13	47	5	11
Upper Bavaria	34	8	–	27	23	14	20
Midi-Pyrenees Region	74	13	27	–	40	30	57
Lazio Region	57	47	23	40	–	11	28
Inner London	37	5	14	30	11	–	25
Ile de France Region	79	11	20	57	28	25	–
External degree[b]	303	106	126	241	206	122	220
Cluster openness[c]	1.99	4.81	7	4.63	2.57	8.71	5.5

[a] Internal degree refers to the number of relations within the cluster.
[b] External degree refers to the number of relations across the cluster, i.e. within the pipelines.
[c] Cluster openness = external degree/internal degree.

Table 8. Nature of knowledge flows in clusters and pipelines.

	Exploration	Integration	Exploitation	Total
Within the clusters				
No. of links	178	116	84	378
%	47	31	22	100
Within the pipelines				
No. of links	462	588	274	1324
%	35	44.5	20.5	100
Clusters/others				
No. of links	1482	1610	890	3982
%	37	40.5	22.5	100
Others/others				
No. of links	210	376	478	1064
%	20	35	45	100

Indeed, 48% of the relations within the clusters belong to the exploration phase, 30% to the integration phase and only 22% to the exploitation phase. This result is in line with the literature, according to which geographical proximity is more important in the exploration phase (Audretsch and Feldman 1996). Similarly, the pipeline relational matrix has been divided into three matrixes (the nodes are still the seven clusters), according to the nature of relations: exploration, integration and exploitation. Table 8 reveals a radically different distribution than the one found for local knowledge relations. Indeed, now 35% of the relations across the clusters belong to the exploration phase, but 44.5% to the integration phase and only 20.5% to the exploitation phase. This result shows that organizations are more likely to collaborate with others located in another dominant cluster when collaborating on a project in the integration phase. Thus, we have shown that the phases of knowledge, i.e. exploration, integration or exploitation, are not randomly developed in clusters and pipelines, but that exploration tends to require more geographical proximity.[16]

7. Discussion: how do clusters/pipelines and core/periphery structures work together in knowledge processes?

First, the study of connectivity between projects suggests that organizations that are not directly tied in a project can be tied through intermediaries that connect separated projects, so that knowledge can potentially flow into the network. If arms' length relations exist, knowledge diffusion and exchange seem to prevail in a cohesive structure of relations. This means that most of the organizations are aware that GNSS are general-purpose technologies that require a high level of interoperability and compatibility between applications. Such a result is typical of the 'industry of networks', for which development and diffusion require standardization. This relatedness is also the result of the European Commission strategy that makes sure that research in the field depends on the setting of standards, in order that innovations turn into mass-market technologies. Moreover, *Proposition 1a* is validated, since the overall connectivity of the GNSS network exhibits an interesting structural property of core/periphery, meaning that beyond the average level of connectivity between collaborative projects, some of them are highly interconnected while some others remain poorly connected. Following the *Proposition 1b*, this structure is appropriate for the viability and development of the field. On one hand, it is necessary for technologies that are integrated to be connected to a standard, and the development of the market will be all the more extensive if organizations exchange knowledge in order to set and stabilize the standard.

Nevertheless, a full cohesive structure can engender some risks of lock-in. That is why, on the other hand, exploration activities enter the network gradually through the periphery, in order to maintain research and upstream technological solutions that can diffuse to the core when market opportunities and demand conditions are favorable.

Second, considering *Propositions 2a* and *2b*, it is noteworthy that the main geographical clusters of the GNSS network are typified by a high level of explorative relations and a decreasing share of relations from exploration to exploitation (Table 8). This is not really a surprising result since the literature shows that exploration phases compel a high level of fundamental and tacit knowledge that requires proximity between organizations and social network effects. If we turn to pipelines, Table 8 shows that pipelines gather a large part of knowledge relations in the integration phase. An efficient integration and combination process requires cooperation between complementary as well as competing companies located in different clusters in order to set up a technological standard as widely as possible. The 'space alliance' being composed of a couple of clusters in Europe (Figure 5), the existence of these pipelines in the engineering process confirms the usefulness of the Galileo project. This project intends to organize the viability of the technological field by creating incentives for cooperation, in order to guarantee the diffusion of GNSS-based applications. Finally, knowledge relations in the exploitation phase are poorly represented in the main clusters as well as in pipelines. A large share of exploitation relations involves organizations that are dispersed in Europe. This result is not a surprise since the main purpose of collaborations in this phase concerns market tradability and diffusion of technological applications. Nevertheless, the relational structure through which innovations are turned from very early knowledge into mass-market products requires paying close attention to this geographical dimension. These dispersed networks are all the more necessary given that GNSS diffusion, as well as ICT demand, is influenced by network externalities and thus by a wide geographical availability of applications.

Finally, considering the combination of *Propositions 1a* and *1b*, and *2a* and *2b*, new findings in economic geography and knowledge economics emerge. Table 9 summarizes these findings, crossing the knowledge phases with the cognitive, structural and geographical statistics of the GNSS network.

The most noteworthy result is the negative linear relationship between the geographical and structural concentration of knowledge interactions (Figure 6). This means that the more the projects are embedded in a highly cohesive structure, the less knowledge relations are clustered in particular locations. The fact that geographically clustered relations are 'located' in the periphery of the network of projects does not mean that clusters

Table 9. Cognitive/geographical/structural properties and the phases of the knowledge value chain.

	Knowledge exploration	Knowledge integration	Knowledge exploitation
Cognitive properties	Research and fundamental knowledge	Engineering knowledge	Market-related knowledge
Geographical properties	Highly clustered in a couple of places	Pipelines, cluster relatedness	Dispersed and covering the European area
Structural properties	Periphery	Core and periphery	Core

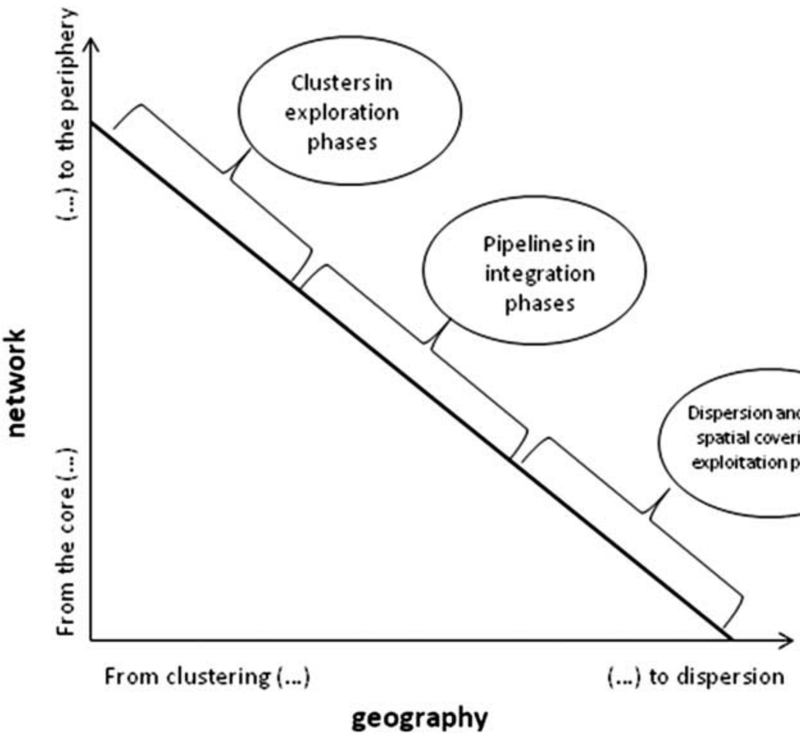

Figure 6. Geographical cluster/pipeline and network core/periphery structure.

host organizations that are poorly connected among themselves. Recall that Table 7 showed that the seven main clusters display an internal density higher than the average density of the network as a whole. On the contrary, clusters are highly cohesive substructures of knowledge relations focused mainly on explorative projects that are poorly connected to the core of projects of the European network. At the other extremity, the core of collaborative projects hosts organizations that are scattered across the European area. Between these two extremes, an intermediate level of geographical dispersion corresponds to the interconnection between clusters that supports the integration knowledge processes.

This negative linear relationship can be explained by the industrial and spatial organization that supports the viability of the GNSS technological field. If we suppose the GNSS network in the period under investigation to be in a particular stage of its endogenous dynamics, its core/periphery and cluster/pipeline structure will reflect its particular stage of maturity. If clusters have been considered in the literature as efficient structures of knowledge production, their existence and their high performance are not sufficient conditions of high performance in the technological field as a whole. To reach maturity, a technological field needs to be supported by a high level of spatial diffusion supported itself by the existence of norms, compatibility and interoperability. The existence of pipelines and the spatially dispersed core of the network is thus the illustration that the GNSS technological field has reached a certain level of maturity during the period under study. Nevertheless, an excess of cohesion in the network can be interpreted as a lock-in condition that excessively scleroses the knowledge dynamics at work within the network. That is why, as previously said, the periphery of the network is a condition of its viability, because it can introduce fresh ideas and new knowledge in order to strengthen and extend the increasing part of the curve of the technological life cycle, part in which clusters play a critical role.

8. Concluding remarks

The paper aimed to contribute to research on the geography of innovation by introducing the study of the structural properties of knowledge networks into the centripetal and centrifugal forces of innovation activities. Our results highlight how knowledge spills over geography and relational structures, and how a particular technological field structures itself along its knowledge value chain. Such results have been obtained using network analysis standard tools, which constitute nowadays a powerful method for investigating relational structures in innovation processes. But structural properties by themselves do not permit us to perfectly understand the channels of knowledge spillovers and their geographical extents. These structures depend on a set of cognitive attributes, related to the organizational demography and the knowledge phases of the value chain. So the introduction of these attributes into the structural properties of knowledge networks, at the level of organizations and at the level of knowledge projects, is particularly suited to go beyond the standard tacit/codified knowledge classification as a source of agglomeration and dispersion of innovation activities.

The salient outcome is the negative linear relationship found between geographical cluster/pipeline and structural core/periphery structures in the European GNSS technological field. We have shown that clusters are critical loci for exploration processes in the upstream phase of the knowledge value chain and contribute to the growth of the technological field. But clusters, in spite of the focus they constitute for innovation policies, do not contribute alone to the market success of technologies. At the periphery of the knowledge network, clusters play a critical role by preserving a pool of new and upcoming exploitable knowledge. But the new ideas in a technological field will be turned into mass-market products if, in the downstream knowledge phase of integration and exploitation, tradable goods and technologies remain on a high level of spatial diffusion and technological standardization. So the viability of the technological field will depend on the existence of a cohesive structure of relations in the core of the network of knowledge projects that involve dispersed and distant organizations.

In terms of policy perspectives, our findings suggest that networks and geography need to be considered for innovation. Policy-makers have to deal with these two dimensions jointly. Indeed, on the one side, nations have progressively targeted their policies from an industrial policy focus, generally governed at the national level, to a more decentralized and regional emphasis, with the development of clusters policies. Such a move toward the increasing role of regions in knowledge-based economies is consistent with the necessity to support leading places in technological domains. On the other side, the creation of the European research area has certainly participated to a better dissemination of knowledge in Europe and then an increasing capacity to integrate separated pieces of knowledge to foster innovation. But our findings suggest that these two sides need to be strongly related and more coordinated at the European level. If regional or national clusters policies have definitely increased the capacity of regions to explore new technological domains, the chance to transform them into future dominant designs depends on the ability of clusters to be connected to largest networks (Frenken et al. 2009). An *ex ante* diagnosis of growing clusters in particular technological fields could serve as a guide for European policy-makers to better promote the development of future technological standards. Moreover, our findings confirm the previous observations of Foray and Steinmueller (2003). According to us, policies aimed at stimulating research collaboration at the European level must take into account of the nature of knowledge that is to be exchanged. When public incentives focus on very emergent and explorative knowledge domains, a targeting of complementary organizations in a limited set of clusters can be more efficient than a general watering of public funds in the whole of the European area. Here again, an *ex ante* diagnosis of emerging clusters based on the location of scientific publications or patent data can work as a guide to promote such policies. On the contrary, for technological domains that have reached a higher level of maturity, the aims of European policy-makers should be to change and focus on public incentives for a largest diffusion of knowledge in networks, in order to extend the possibilities of technological exploitation for different markets and in different places.

Acknowledgements

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Notes

1. In this paper, we consider that cluster-type relations differ from pipeline-type relations since the former imply relations between co-located organizations in a region, while the latter imply relations between distant organizations at the national or international level. In the following empirical study, we will consider the NUTS2 level of the European classification of regions for distinguishing cluster and pipeline-type relations. Moreover, along the lines of the empirical study by Dahl Fitjar and Rodríguez-Pose (2011), and considering that our dataset is based on formal consortiums (collaborative R&D projects of the fifth and sixth Framework Programs), cluster-type relations differ from the 'buzz' (Bathelt et al. 2004), since they refer to formal local knowledge interactions rather than informal and face-to-face interactions. Pipelines are considered as non-local or global interactions, also in a formal way, with a particular attention, in the following study, to the global relations between organizations located in the identified European clusters of the GNSS industry.
2. http://www.gsa.europa.eu/.
3. Since 1984, FPs aim to fund transnational and collaborative R&D projects to promote a European research area.
4. GSA is the European GNSS Agency, in charge of public interests related to GNSS programmes in Europe
5. In economic geography, Ter Wal and Boschma (2009) also emphasize the relevance of using co-patents or survey for relational data. While patenting is not common in the GNSS industry, conducting surveys at the European level can lead to serious problems in homogeneity and completeness of relational data.
6. Publicly available on the Cordis website for all EU-supported R&D activities (http://cordis.europa.eu/home_en.html).
7. Density level is calculated by dividing the proportion of actual ties (number of links dichotomized) by the sum of all possible ties.
8. Precisely, as the distribution exhibits an asymmetrical shape, we test for a possible scale-free network property (Barabási and Albert 1999). A scale-free network is a graph following a power law distribution defined by $P(k) \sim k - \gamma$, with the parameter γ usually ranging from 2 to 3. Thanks to a least-square estimation, we estimate a $\gamma = 0.577$, quite far away from the acceptance interval of a scale-free property.
9. We used the Ucinet statistical tool for social network analysis and the Netdraw software for the visualization (Borgatti, Everett, and Freeman 2002).
10. The Nomenclature of Territorial Units for Statistics (NUTS) was established by the European Union (Eurostat) to provide a standard classification of European spatial units.
11. For each project, we code 1 if the project exhibits between 0% and 10% of organizations with a knowledge profile, 2 if the project exhibits between 10% and 20% …to 10 if the project exhibits between 90% and 100%.

12. Detailed information about the econometric specification can be found in Cameron and Trivedi (2005).
13. We control for Heteroscedasticity with White correction.
14. We remind that following our codification of knowledge bases, it is difficult to interpret the marginal variation in terms of percentage. In that case, marginal variation refers to a switch from one interval to another one.
15. The thickness of ties corresponds to the number of inter-clusters relations, from]0, 20] for the slender ties to]60, 80] for thick ties.
16. Ter Wal (2011) found out a similar result, showing that geographical proximity is a more important driver of network formation in exploration stages than in exploitation ones.

References

Antonelli, C. 1996. Localized knowledge percolation processes and information networks. *Journal of Evolutionary Economics* 6, no. 3: 281–95.

Antonelli, C. 2006. The business governance of localized knowledge: An information economics approach for the economics of knowledge. *Industry & Innovation* 13, no. 3: 227–61.

Audretsch, D., O. Falck, M. Feldman, and S. Heblich. 2008. The lifecycle of regions. *CEPR discussion paper DP6757*, Centre for Economic Policy Research, London.

Audretsch, D., and M.P. Feldman. 1996. Innovative clusters and the industry life cycle. *Review of Industrial Organization* 11: 253–73.

Autant-Bernard, C., P. Billand, D. Frachisse, and N. Massard. 2007. Social distance versus spatial distance in R&D cooperation: Empirical evidence from European collaboration choices in micro and nanotechnologies. *Papers in Regional Sciences* 86, no. 3: 495–520.

Balland, P.A. 2012. Proximity and the evolution of collaboration networks: Evidence from research and develoment projects within the GNSS industry. *Regional Studies* 46, no. 6: 741–756.

Balland, P.A., M. de Vaan, and R. Boschma. 2011. The dynamics of interfirm networks along the industry life cycle: The case of the global video games industry 1987–2007. *Papers in Evolutionary Economic Geography* 11.14, Section of Economic Geography, Utrecht University.

Barabási, A.L., and R. Albert. 1999. Emergence of scaling in random networks. *Science* 286: 509–12.

Bathelt, H., A. Malmberg, and P. Maskell. 2004. Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography* 28, no. 1: 31–56.

Borgatti, S.P., and M.G. Everett. 1999. Models of core/periphery structures. *Social Networks* 21: 375–95.

Borgatti, S.P., M.G. Everett, and L.C. Freeman. 2002. *Ucinet 6 for Windows*. Harvard: Analytic Technologies.

Boschma, R.A. 2005. Proximity and innovation: A critical assessment. *Regional Studies* 39, no. 1: 61–74.

Boschma, R.A., and K. Frenken. 2006. Why is economic geography not an evolutionary science? Towards an evolutionary economic geography. *Journal of Economic Geography* 6: 273–302.

Boschma, R.A., and K. Frenken. 2010. The spatial evolution of innovation networks. A proximity perspective. In *Handbook on evolutionary economic geography*, ed. R.A. Boschma and R. Martin, 120–35. Cheltenham: Edward Elgar.

Boschma, R.A., and A. Ter Wal. 2007. Knowledge networks and innovative performance in an industrial district: The case of a footwear district in the south of Italy. *Industry and Innovation* 14, no. 2: 177–99.

Bottazzi, L., and G. Peri. 2003. Innovation and spillovers in regions: Evidence from European patent data. *European Economic Review* 47: 687–710.

Braunschvig, D., R.L. Garwin, and J.C. Marwell. 2003. Space diplomacy. *Foreign Affairs* 82, no. 4: 156–64.

Breschi, S., L. Cassi, F. Malerba, and N. Vonortas. 2009. Networked research: European policy intervention for information and communication technologies. *Technology Analysis and Strategic Management* 21: 833–57.

Breschi, S., and F. Lissoni. 2001. Knowledge spillovers and local innovation systems: A critical survey. *Industrial and Corporate Change* 10, no. 4: 975–1005.

Broekel, T., and H. Graf. 2012. Public research intensity and the structure of German R&D networks: A comparison of 10 technologies. *Economics of Innovation and New Technology* 21, no. 4: 345–72.

Burt, R. 1992. *Structural holes*. Cambridge, MA: Harvard University Press.

Cameron, C., and P. Trivedi. 2005. *Microeconometrics*. New York: Cambridge University Press.

Carrincazeaux, C., Y. Lung, and A. Rallet. 2001. Proximity and localisation of corporate R&D activities. *Research Policy* 30, no. 5: 777–89.

Cassi L., Corrocher N., Malerba F., and Vonortas N. 2008. Research networks as infrastructure for knowledge diffusion in European regions. *Economics of Innovation and New Technology* 17: 663–76.

Cattani, G., and S. Ferriani. 2008. A core/periphery perspective on individual creative performance: Social networks and cinematic achievements in the Hollywood film industry. *Organization Science* 6: 824–44.

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

Cowan, R., P.A. David, and D. Foray. 2000. The explicit economics of knowledge codification and tacitness. *Industrial and Corporate Change* 9: 211–53.

Cowan, R., and N. Jonard. 2003. The dynamics of collective invention. *Journal of Economic Behavior and Organization* 52, no. 4: 513–32.

Cowan, R., N. Jonard, and M. Özman. 2004. Knowledge dynamics in a network industry. *Technological Forecasting and Social Change* 71: 469–84.

Cooke, P. 2006. Rational drug design, the knowledge value chain and biosciences megacentres. *Cambridge Journal of Economics* 29: 325–41.

Crevoisier, O., and H. Jeannerat. 2009. Territorial knowledge dynamics: From the proximity paradigm to the muli-location milieu. *European Planning Studies* 17, no. 8: 1223–41.

Dahl Fitjar R., and Rodríguez-Pose A. 2011. When local interaction does not suffice; sources of firm innovation in urban Norway. *Environment and Planning A* 43, no. 6: 1248–67.

Eisingerich, A.B., S.J. Bell, and P. Tracey. 2010. How can clusters sustain performance? The role of network strength, network openness, and environmental uncertainty. *Research Policy* 39: 239–53.

Feldman, M. 1999. The new economics of innovation, spillovers and agglomeration: A review of empirical studies. *Economics of Innovation and New Technology* 8, no. 1: 5–25.

Foray, D., and W.E. Steinmueller. 2003. On the economics of R&D and technological collaborations: Insights and results from the project Colline. *Economics of Innovation and New Technology* 12: 77–91.

Freeman, C. 1991. Networks of innovators: A synthesis of research issues. *Research Policy* 20: 499–514.

Frenken, K., J. Hoekman, S. Kok, R. Ponds, F. Van Oort, and J. Van Vliet. 2009. Death of distance in science? A gravity approach to research collaboration. In *Innovation networks – new approaches in modelling and analyzing*, ed. A. Pyka and A. Scharnhorst, 43–57. Berlin: Springer.

Gallié, E.P., and R. Guichard. 2005. Do collaboratories mean the end of face-to-face interactions? An evidence from the ISEE project. *Economics of Innovation and New Technology* 14: 517–32.

Gambardella, A., and W. Garcia-Fontes. 1996. Regional linkages through European research funding. *Economics of Innovation and New Technology* 4: 123–38.

Gertler, M. 2003. Tacit knowledge and the economic geography of context or the undefinable tacitness of being (there). *Journal of Economic Geography* 3: 75–99.

Gilsing, V., B. Nooteboom, W. Vanhaverbeke, G. Duysters, and A. van den Oord. 2008. Network embeddedness and the exploration of novel technologies: Technological distance, betweenness centrality and density. *Research Policy* 37: 1717–31.

Goldberg, D.E. 1989. *Genetic algorithms*. New York: Addison Wesley.

Hagedoorn, J. 2002. Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. *Research Policy* 31, no. 4: 477–92.

Jackson, M.O., and A. Wolinsky. 1996. A strategic model of social and economic networks. *Journal of Economic Theory* 71: 44–74.

Katz, M.L., and C. Shapiro. 1994. Systems competition and network effects. *Journal of Economic Perspectives* 8: 93–115.

March, J.G. 1991. Exploration and exploitation in organizational learning. *Organization Science* 2: 71–87.

Moodyson, J. 2008. Principles and practices of knowledge creation: On the organization of 'buzz' and 'pipelines' in life science communities. *Economic Geography* 84, no. 4: 449–69.

Nooteboom, B. 2000. Learning by interaction: Absorptive capacity, cognitive distance and governance. *Journal of Management and Governance* 4, nos. 1–2: 69–92.

Owen-Smith, J., and W.W. Powell. 2004. Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science* 15, no. 1: 5–21.

Ozman, M. 2009. Inter-firm networks and innovation: A survey of literature. *Economics of Innovation and New Technology* 18, no. 1: 39–67.

Porter, M.E. 1998. *On competition*. Boston: Harvard Business School.

Rice, J., and N. Martin. 2008. Knowledge-based alliances as a driver of mobile telecommunications convergence: An historical and technical overview. *International Journal of Knowledge Management Studies* 2, no. 1: 4–16.

Rycroft, M.J. 2003. Satellite navigation systems: Policy, commercial and technical interaction. Dordrecht, the Netherlands: Kluwer Academic.

Scherngell, T., and M. Barber. 2011. Distinct spatial characteristics of industrial and public research collaborations: Evidence from the 5th EU Framework Programme. The Annals of Regional Science 46: 247–66.

Schilling, M.A., and C.C. Phelps. 2007. Interfirm collaboration networks: The impact of large-scale network structure on firm innovation. *Management Science* 53, no. 7: 1113–26.

Suire R., and Vicente J. 2009. Why do some places succeed when others decline? A social interaction model of cluster viability. *Journal of Economic Geography* 9, no. 3: 381–404.

Ter Wal, A. 2011. The spatial dynamics of the inventor network in German biotechnology: Geographical proximity versus triadic closure. *Papers in Evolutionary Economic Geography* 11–02, Section of Economic Geography, Utrecht University.

Ter Wal, A., and R. Boschma. 2009. Applying social network analysis in economic geography: Framing some key analytic issues. *The Annals of Regional Science* 43, no. 3: 739–56.

Torre, A. 2008. On the role played by temporary geographical proximity on knowledge transmission. *Regional Studies* 42, no. 6: 869–89.

Trippl, M., F. Tödtling, and L. Lengauer. 2009. Knowledge sourcing beyond buzz and pipelines: evidence from the Vienna software cluster. *Economic Geography* 85, no. 4: 443–62.

Uzzi, B. 1997. Towards a network perspective on organizational decline. *International Journal of Sociology and Social Policy* 17: 111–55.

Uzzi, B., and J. Spiro. 2005. Collaboration and creativity: The small world problem. *American Journal of Sociology* 111: 447–504.

Verspagen, B. 2007. Mapping technological trajectories as patent citation networks: A study of the history of fuel cell research. *Advances in Complex Systems* 10: 93–115.

Vicente, J., P.A. Balland, and O. Brossard. 2011. Getting into networks and clusters: Evidence from the Midi-Pyrenean GNSS collaboration network. *Regional Studies* 45, no. 8: 1059–78.

White, D.R., J. Owen-Smith, J. Moody, and W.W. Powell. 2004. Networks, fields and organizations: Micro-dynamics, scale and cohesive embeddings. *Computational and Mathematical Organization Theory* 10, no. 1: 95–117.