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Abstract: *This paper contributes to the empirical identification of geographical and structural properties of innovative networks, focusing on the particular case of Global Navigation Satellite Systems (GNSS) at the European level. We show that knowledge bases of organizations and knowledge phases of the innovation process are the critical factors in determining the nature of the interplay between structural and geographical features of knowledge networks. Developing a database of R&D collaborative projects of the 5th and 6th European Framework Programs, we propose a methodology based on social network analysis. Its originality consists in starting from a bimodal network, in order to deduce two affiliation matrixes that allow us to study both the properties of the organization network and the properties of the project network. The results are discussed in the light of the mutual influence of the cognitive, structural and geographical dimensions on knowledge production and diffusion, and in the light of the knowledge drivers that give rise to the coexistence of a relational core-periphery structure with a geographical cluster and pipeline structure.*

Key words: Economic Geography, Knowledge networks, Social network analysis, EU Framework Programs, GNSS
JEL codes: O32, R12

1. Introduction

Technological innovations emerge according to complex micro-macro dynamics in which networks play a critical role in the process that turns an emerging idea into a dominant design. The complexity arises because, from the exploration of novelty to the effective exploitation in markets, fragmented inputs of knowledge are combined in different phases of the knowledge value chain (Cooke, 2006).

The paper aims to introduce a theoretical framework and an empirical assessment that grasps this complexity by supposing that there are three essential dimensions of technological fields.

Firstly, a technological field can be represented by a network structure (Owen-Smith, Powell, 2004; Cowan et al, 2007), i.e the relational matrix that links the organizations that are involved in the field. Secondly, technological fields are the "locus" of a variety of organizations that contribute to the innovation process, each one with its own particular strategies and knowledge bases (Asheim, 2007; Asheim *et al*, 2007). Thirdly, technological innovations emerge and are diffused across geographical space (Boschma, 2005). Therefore, geography has an influence on innovation due to the local dimension of knowledge spillovers (Anselin et al, 1997). Taking the three dimensions into account, knowledge spills over both network structures and geography (Breschi, Lissoni, 2002, Sunley, 2008). Therefore, the way in which organizations manage these knowledge flows at a particular stage of the knowledge value chain influences the structural as well as the geographical features of the network.

All these dimensions will be taken into account in an empirical study of the knowledge process at work in the technological field of the *Global Navigation Satellite Systems* (GNSS). GNSS is a group of systems that provide positioning and navigation solutions. Originating in the aerospace and defence industry, nowadays they are found in a wide range of civilian applications in the context of consumers-driven innovations for mobility. Following Braunschvig *et al* (2003), GNSS can be perceived as *"a fifth utility, on a par with water, gas, electricity and communication"* (p. 158). 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 look at GNSS rather than the "space industry" in general, because network dynamics are more observable in technological fields than in industrial sectors (White et al, 2004). And we chose to look at the Europe (EU-25) since it corresponds to the area of the European Satellite Constellation developed in the *Galileo* project (Rycroft, 2003).

Section 2 develops the above-mentioned theoretical framework and combines the three key dimensions of the structural, geographical and cognitive features of a technological field. Section 3 discusses the context of the study, the relational dataset and some useful preliminary representations of the network. Section 4 introduces the methodology used to study the cognitive, geographical and structural properties of the network. Section 5 presents the results for each property of the network and discusses the main findings. Section 6 focuses on the combination of these properties and discusses 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 particular way.

2. Theoretical background

2.1. Networks, structure and knowledge.

Networks exist because most innovations result from a composite knowledge process that combines fragmented knowledge inputs (Crevoisier, Jeannerat, 2009). Understanding the *structural* properties of networks requires focusing first on the *individual* motives for shaping knowledge relations. The literature in management science and knowledge economics has addressed these motives at the micro level, showing that knowledge 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. The literature on technological alliances shows that a certain amount of cognitive distance between partners produces opportunities of novelty, whereas an excess of cognitive proximity impedes innovation and engenders a risk of unintended knowledge spillovers (Mowery et al, 1998; Nooteboom, 2000). 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 an under knowledge appropriability.

Knowledge networks represent the aggregation of these relations and can exhibit interesting structural properties. First of all, the density of a network, defined as the ratio of the actual relations to the number of possible relations, is a simple but interesting marker of its connectivity. The density of a network and the level of its connectivity thus give a good representation of the coexistence of arms-length and embedded relations in technological fields (Uzzi, 1997). However, the trade-off between accessibility and knowledge appropriability does not enable all connections. Furthermore, high density produces redundancy and, because relations engender costs, a slump in efficiency for some organizations (Burt, 1992).

In addition, the density of knowledge networks can be associated with properties of cliquishness, i.e. when groups of nodes are more closely tied between themselves than with other nodes. These properties can be "presupposed", when cliques strictly represent groups of *n*-lateral relations, for instance when public funded collaborative projects bring together numerous organizations (Autant-Bernard et al, 2007; Vicente et al, 2010). In the latter case, the analysis can focus on a unimodal network, as in most network analysis. However, due to the strong presupposed cliquishness of the network, it would be more relevant to construct and analyze a bimodal network*,* i.e. a network that considers ties between two sets of nodes at two different scales: the ties between organizations and the ties between projects. In doing that, additional properties can be studied by exploring how projects are linked through affiliated organizations and result in a particular structure of interactions. Another interesting structural property concerns the existence of a core/periphery structure, meaning that a network can incorporate nodes that are highly connected between themselves while others remain poorly connected. Such a structure shows that relations are not randomly distributed within a network and can be interpreted as a particular stage of its dynamics.

2.2. Network, institutional & cognitive demography and the knowledge value chain

Networks exist because innovations result from interactions between different institutions involved in composite knowledge processes, with different focuses on knowledge appropriability. Thus, the structural properties of knowledge networks are not independent of the knowledge value chain along which pieces of knowledge are combined in different phases and by different organizations. Following Cooke (2006) and Asheim (2007), the knowledge value chain combines different categories of knowledge introduced in different (and successive) phases of knowledge. Knowledge can be analytic, when it concerns fundamental knowledge and formal models. It can also be synthetic, when fundamental knowledge is turned into practical tests or engineering processes. Finally, it can be symbolic when it concerns marketing, art and design for specific applications.

Identifying "relevant" networks requires identifying all the institutions that bring the knowledge that enables a new idea to be turned into a dominant design or a technological standard. Thus, networks are relational matrixes of various organizations that get involved in different phases of the knowledge value chain. Public research organizations, small and big firms including their R&D departments, but also standardization and regulation agencies and other knowledge intensive business services bring knowledge at different stages of the process and with different rationales of appropriability. In the very upstream phase of knowledge exploration, public research organizations will form partnerships with R&D departments of firms in order to find additional opportunities to promote their analytic knowledge. In the intermediate phase of knowledge integration, firms that have previously developed knowledge will form partnerships, in order for each one to find new market opportunities and enlarge the spectrum of their knowledge tradability, by developing new products or services combining their respective knowledge. This phase requires mainly synthetic knowledge and collaborative engineering for the integration and the compatibility of knowledge modules, and can be supported and coordinated by normalization and standardization agencies. At the last stage of the knowledge value chain, organizations also form partnerships in order to reach mass markets and impose a dominant design. This exploitation phase is based on the relations between competing firms which cooperate in order to reduce market uncertainty, search for scale economies, or increase the consumers' willingness to pay by defining a common standard in relation with agencies. It can also be based on the relations between technological firms and knowledge intensive business services, which bring the symbolic knowledge of marketing and design that favor the diffusion of knowledge in the market.

2.3. Network and geography

Network geography exists because the fragmented pieces of knowledge are disseminated across different points of geographical space. The geographical extent of knowledge spillovers is the critical parameter that determines the spatial organization of networks. Geographical proximity between institutions 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, the risk of unintended spillovers is so high that geographical distance and temporary proximity are more compatible with cooperative agreements. In summary, knowledge partnerships between public research organizations and firms in the explorative knowledge phase are compatible with geographical proximity, since (i) the singular mode of knowledge promotion of the research organization favors knowledge spillovers, and (ii) there is a cognitive gap to be reduced between analytic/abstracted knowledge and engineering/synthetic knowledge. Geographical proximity facilitates the integration phase when the partners are cognitively distant so that the combination of previous codified knowledge requires additional R&D. Along the same lines, knowledge interactions between technological SMEs and big firms can be compatible with geographical proximity when the former concentrate their capabilities on technology and the latter on the market, and when property rights are specified so as to prevent opportunism. But geographical proximity can also have negative effects on knowledge partnerships when cognitive proximity between partners increases the risks of unintended knowledge spillovers (Breschi, Lissoni, 2001; Boschma, 2005), engenders a distrust climate (Suire, Vicente, 2009) and conflicts on the local matching of cognitive resources (Torre, 2008).

Networks in technological fields will thus display a geographical structure that reflects these ambivalent effects of geographical proximity on knowledge partnerships. Obviously, one of the most regular structures one could expect is the cluster structure. Since Porter's research (Porter, 1996), 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. Thus, starting from the identification of a technological field should permit a better understanding of how networks are spatially organized. Moreover, if clusters exist, they are generally embedded in larger geographical structures, and connected through pipelines and knowledge gatekeepers (Bathelt *et al*, 2004; Moodyson, 2008; Rychen, Zimmermann, 2008; Trippl *et al*, 2009). Thus, the geography of networks will correspond to the aggregation of relational strategies for geographically distant or close knowledge along the knowledge value chain. For instance, Autant-Bernard *et al* (2007) find that both local and distant connections interact in the European network of micro and nanotechnologies, the respective effect of each one depending on individual variables such as the size and the absorptive capabilities of the nodes of the network. Owen-Smith and Powell (2004) compare the same bio-technological field dynamics on two different geographical scales. They show that the local cohesive structure in the Boston cluster is dependent on the active participation of public research organizations, whereas large companies and venture capitalists are the central nodes of the geographically extended network.

3. Data

We will now deal with these ideas through an empirical assessment of the structural, cognitive and geographical properties of networks in the particular case of the European GNSS technological field. This section gives an overview of the main characteristics of the field, and presents the process of data collection and some preliminary descriptive statistics on the bimodal relational database. More details are given about the secondary databases, i.e. the affiliation databases, with the network of projects and the network of organizations.

3.1. The GNSS technological field

GNSS is a standard term used to describe systems that provide positioning and navigation solutions. These technologies were mainly developed in the aerospace and defence industry. Nowadays, in the consumers-driven technological paradigm of mobility, GNSS are technologies that find complementarities and integration opportunities in many other socio-economic contexts and have a large number of civilian applications (Braunschvig *et al*, 2003). 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, telecommunication, etc (Vicente *et al.* 2010).

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, SMEs, research centres, spatial agencies, and even non-profit organizations. Among them, big companies such as Thales Alenia Space and EADS Astrium, national space agencies CNES (France) and DLR (Germany), and the European Space Agency, collaborate on innovation projects with a large array of other organizations. Governmental institutions are also involved in the knowledge process, in particular when applications are dedicated to health, emergency and other public utilities. In addition, the Egnos and Galileo programs are key political issues for the European independence on navigation satellite systems, especially considering the American GPS. The geography of the GNSS industry is typified by research collaborations among organizations from different European countries, originally from France and Germany, and more recently from Spain, England, the Netherlands or Italy.

3.2. The (primary) bimodal database

The first step consisted in gathering all the collaborative projects in the GNSS technological field that are funded by the European Union during the period under study (2002-2007). Relevant information about knowledge collaborations can be found in the Framework Programs (FPs) on research and technological development[1].

Two reasons legitimize the choice of collaborative projects. Firstly, since the end of the 1950s, space organizations are used to working on projects. Each satellite is a project in itself and a unique product that cannot be produced in a standardized production chain. Secondly, space organizations are accustomed to working under funded programs, since space exploration has always been a very strategic issue for countries. Data were directly collected from the database of information services of the European Commission, available on the Cordis[2] website for all EU-supported R&D activities, and on the GNSS Supervisory Authority[3] website for FP dedicated to the GNSS. Some projects, often the big ones, are described in more detail than others, which led us to collect more precise information on the project and partner's websites: communication documents, work package reports. This additional work was particularly useful for improving the identification of the knowledge phase of the projects.

We assume that two organizations are linked when they participate in the same project. For the construction of the relational database, it is assumed that ties are active from the beginning to the end of each project. *Table 1* displays descriptive statistics about the cumulated number of projects and organizations during the overall period.

Projects		**Organizations**	
Number of projects	72	Number of organizations	360
Average of organizations by project	8.2	Average of projects by organization	1.7

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[1] Since 1984, FPs aim to fund transnational and collaborative R&D projects, in order to promote a European research area

[2] http://cordis.europa.eu/home_en.html

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

Standard error	6.6	Standard error	1.7
Minimum	2	Minimum	1
Maximum	32	Maximum	17

Table 1. Descriptive statistics of the bimodal network

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).

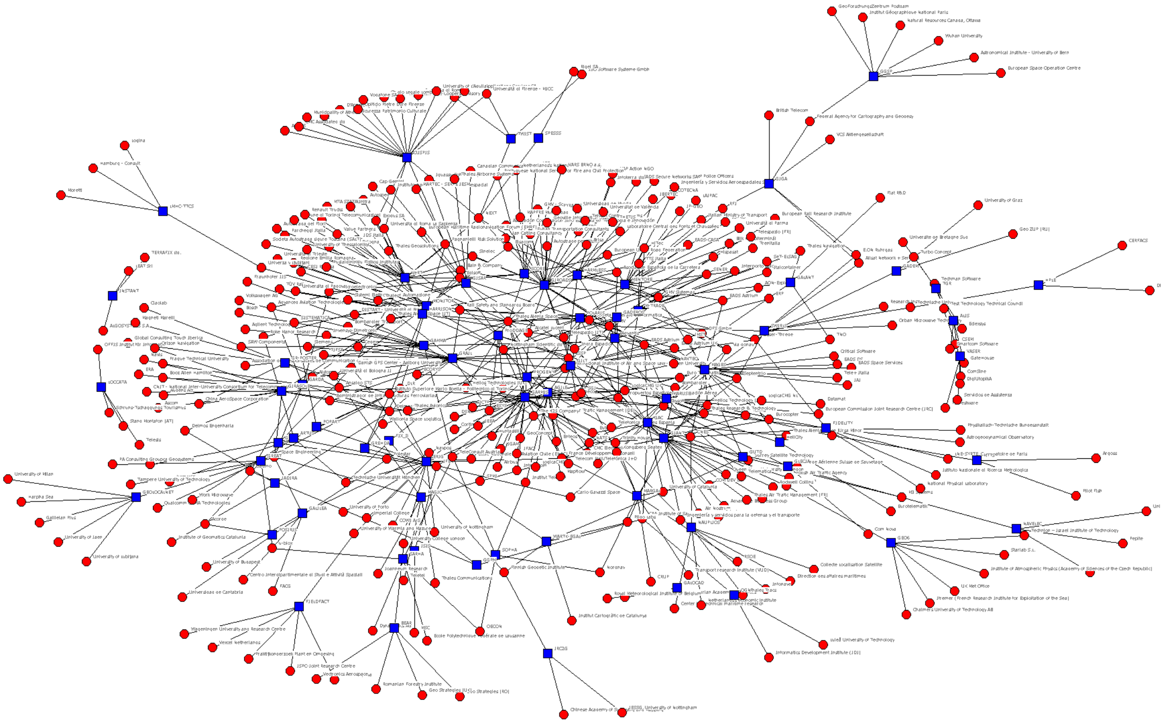

Figure 1. The GNSS bimodal network

3.3. *The (secondary) affiliation database*

This primary database is mainly used to deduce two affiliation matrixes: The *network of projects*, and the *network of organizations*. For the former, it is assumed that two projects are linked when at least one organization participates in these two projects. Relatively few network analyses focus on networks of projects. However, we consider that it can be very useful, in particular when technological fields are considered to incorporate different knowledge phases. Moreover, our purpose is still focused on the analysis of relations between organizations. So for the latter, 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. The network of organizations gives valuable information on the geographical features of the knowledge network.

4. Methodology

Structural characteristics were investigated using social network analysis tools. We use Ucinet (Borgatti et al. 2002) software in order to study structural properties, roles and positions of organizations and projects. For that, the focus on cognitive and geographical patterns requires determining additional factors. Thus, precisions are given concerning the critical parameters discussed in the theoretical background: (i) the knowledge phases of the collaborative projects (exploration, integration, exploitation), (ii) the knowledge bases of organizations, defined according to the SAS model (synthetic, analytic, symbolic), (iii) their location, following the NUTS2[4] classification of European regions.

4.1. Nature of the relations

R&D collaborative projects refer to a large variety of knowledge processes. In order to provide a better understanding of the process of knowledge creation and diffusion, we focus on the cognitive nature of these projects, and so on the cognitive nature of the relations, by considering the following typology (*table 2*) that typifies the knowledge phases of the collaborative projects according to their final goal and their distance to the market.

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

Table 2. Knowledge phase of the projects

This typology is an adaptation for R&D collaborative projects of an already existing classification of the phases of the Knowledge Value Chain (KCV) (Cooke 2006, Asheim *et al*, 2007; Gisling, Nooteboom, 2006). Explorative projects consist in 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 the research of models of synchronization and

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[4] 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

optimization of the GPS signal can be considered as belonging to this early phase. On the contrary, a project where the dominant knowledge phase is exploitation uses existing knowledge to develop a relatively new and specific technological application that corresponds to a demand on the market. Collaborative projects that develop and design applications for transport regulation or air fleet management belong to this knowledge phase. Finally, a project classified under the integration phase is situated between the two. It can be defined by the opportunity to create a new technology by combining two already existing technologies in order to create a new market opportunity for each organization. For instance, in the database, most of the integrative projects are dedicated to the convergence and interoperability between the WIFI and the GPS signal. The integration of the two technologies requires additional R&D in order to insure the compatibility between the two. Obviously, for some projects, operating a classification was not easy, particularly for projects in which the three phases can be identified. In this situation, we have focused on the dominant phase of the project. We obtain the following distribution: 23 projects are dedicated to exploration, 25 projects to integration, and 24 projects to exploitation.

4.2. The knowledge bases of the organizations

The study of knowledge creation and innovation processes often requires information about the kind of knowledge developed by the different organizations. In order to improve the empirical identification of the cognitive features of the GNSS technological field, we use the SAS model (Asheim *et al*, 2007) discussed above. This standard classification allows us to distinguish between the knowledge bases of the different organizations involved in the GNSS FP 5 & FP 6. A large proportion of organizations developing synthetic knowledge are found (192), with a balanced distribution of organizations developing analytic (84) and symbolic (84) knowledge.

4.3. Identification of clusters and pipelines

Recall that this contribution aims to provide a better understanding of the geographical patterns of technological fields. The first step consisted in locating the organizations in the database. Unfortunately, the database of the Cordis and the GSA did not provide a sufficient level of information. The only systematic information was the country of the organizations and the name of a contact person. However, the size of the network permitted us to find postal addresses for the organizations on their web sites, on the documents and work packages of their projects or on specialized GNSS websites. Their location was often immediately clear, especially for research centres and SMEs, but a doubt sometimes remained for multi-establishment firms. In that case, more thorough research was undertaken in order to find the establishment of the engineers involved in the work packages we were considering. If doubt still remained, the location of the organization was considered as missing data (less than 5%). The second step was the identification of geographical clusters. Starting from the square matrix of organizations (360X360), we aggregated all the organizations according to region. This methodology is close to the blocks models of White *et al.* (1976). Here, blocks are constructed on the basis of geographical regions the NUTS2 level. 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"* (p.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 that the organizations be "*interconnected*", and thus defines the number of relations between organizations. *Figure 2* represents the distribution of organizations among the 88 NUTS II 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 in this case is quite similar to 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 seventh values. Conformably to a Zipf like relation, it appears that few regions (7/88) concentrate 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. These clusters are located in the regions of Community of Madrid, Ile de France, Midi-Pyrenees, Lazio, Inner London, Lombardy, and Upper Bavaria.

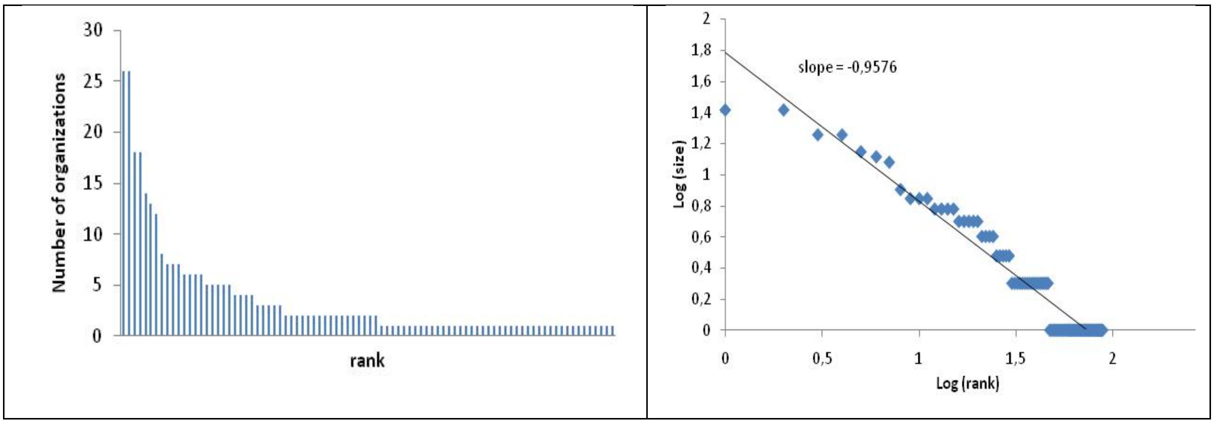

Figure 2. Distribution of organizations among 88 NUTS II European regions

5. Main empirical results

This section presents the main empirical results and aims to distinguish structural from cognitive and geographical properties of the GNSS network. Both the network of organizations and the network of projects are used in a complementary way. We first begin by describing the structural features of the GNSS collaboration network, emphasizing the core/periphery structure. Then we introduce the cognitive dimension, using the SAS model, in order to characterize the knowledge bases of the organizations, and the KVC, in order to typify the knowledge phases of the projects. Finally, the geography of the GNSS technological field is studied, with a particular interest dedicated to the cognitive structure of clusters and pipelines. The following section will introduce these findings in an overall discussion on the interactions and feedback between these three dimensions.

5.1. Structural properties

Descriptive statistics on the network of projects and the network of organizations are presented in *Table 3*. They show that both the network of projects (0,181) and the network of organizations display a relatively high density (0,055). Density level is calculated by dividing the proportion of actual ties (number of links dichotomized) by the sum of all possible ties. However, the most interesting observation is that they display high connectivity. Considering the network of projects, it displays a principal component of 66 projects, and only 6 projects are isolated on the overall period. In order to go beyond this simple finding*, Table 3* also uses the core/periphery model (Borgatti, Everett 1999)[5]. The core is formed by a group of densely connected projects. Inversely, it displays another group of projects more loosely connected and forming the periphery of the overall network of projects.

Structural characteristics		
Statistics	**Network of projects**	**Network of organizations**
Nb of nodes	72	360
Nb of links (valued)	1512	7842
Nb of links (dichotomized)	914	7144
Density	0.181	0.055
Main component	66	339
Core/Periphery		
Core	19	-
Periphery	53	-

Table 3. Structural characteristics of the network of projects and the network of organizations

A second major finding concerning the structural dimension of the network is the degree distribution of the organizations. Degree centrality indicates the number of relations of each organization, and the

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[5] The core/periphery partition is obtained thanks to a genetic algorithm. 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

distribution (*Figure 3*) shows that few nodes have a high number of relations. On the left figure we compute the probability for a node to have a degree. As the distribution exhibits an asymmetrical shape, we test for a possible scale free network property (Barabasi, Albert 1999). A scale free network is a graph following a power law distribution defined by $P(k) \sim k^{-\gamma}$. On the right figure and with a log-log scale, it can be approximated by a straight line thanks to least square estimation. The parameter γ usually range from 2 to 3 in order to characterize a power law distribution of degree as representative of a scale-free network. In our case we estimate a $\gamma=0{,}577$, quite far away the acceptance interval. By consequence, the usual explanations of Barabasi and Albert to justify the scale free network should be taken carefully, since our data are "cross-sectional like" and do not permit to deal with behavior of new entrants. Nevertheless, this statistical signature suggests some interesting traits about the industrial structure of the GNSS sector. Indeed, the European GNSS collaboration network exhibits a hub and peripheral structure (few organizations with a high degree while mainly are poorly connected). This is in coherence with the maturity degree of GNSS technological field and more generally with oligopolistic markets. According to Klepper (1996), a mature market is, among other variables, defined by the settings and control of technological standards as well as efficient cost strategies. Vertical firms and transnational corporation are often representative actors 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 (Vicente et al. 2010). More details are given in *table 4*, where the twenty more central organizations are presented, according to the degree centrality, but also according to the closeness and the betweenness centralities.

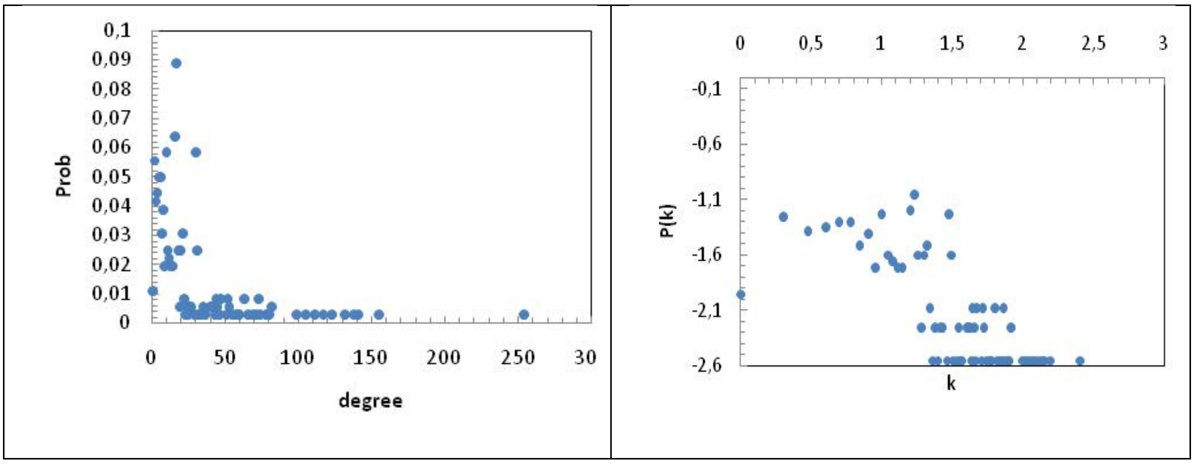

Figure 3. Degree centrality distribution among the 360 organizations

The third structural result gives more precisions about the centrality of organizations. In *Table 4*, the centrality of organizations is presented according to degree centrality, but also according to closeness and betweenness centrality. Closeness centrality indicates the geodesic distance of a given node from all others, and betweenness centrality measures the number of times each node connects to others. Basic degree centrality highlights the key organizations of a network: Thales Alenia Space, Telespazio, GMV, Nottingham Scientific Ltd and the European Satellite Services Provider. TAS and Telespazio are both subsidiaries of Thales and Finmeccanica, and are the main European satellite constructors, with EADS Astrium. GMV develops critical subsystems[6], and Nottingham Scientific Ltd is a SME that provides reliability solutions for GNSS. European Satellite Services Provider (ESSP) is a company with multiple European Air Traffic Control shareholders and set up to operate EGNOS. A comparative analysis of degree centrality and betweeness centrality provides an interesting result. Research institutions or space agencies, such as DLR, ISMB and the University of Warmia score higher in betweeness than in degree centrality. This result confirms previous findings mentioned in the theoretical background on the intermediary role of research institutions, and their ability to connect disconnected organizations (Owen-Smith, Powell, 2004; Vicente et al. 2010).

Centrality of the top 20 organizations

Organizations	Degree	Organizations	Closeness	Organizations	Betweenness
Thales Alenia Space	254	Thales Alenia Space	4.430	Thales Alenia Space	15.412
Telespazio [IT]	155	Telespazio [IT]	4.400	FDC	6.197
GMV	141	GMV	4.390	Skysoft	5.768
NSL	138	Nottingham Scientific Ltd	4.389	Nottingham Scientific Ltd	4.965
ESSP	132	ESSP	4.389	Telespazio [IT]	4.880
Skysoft	123	Skysoft	4.384	DLR	4.498
FDC	117	FDC	4.382	GMV	4.433
GMV Sistemas	111	EADS Astrium DE	4.378	HiTec	4.278
EADS Astrium DE	105	LogicaCMG UK	4.377	ISMB- Politecnico di Torino	3.937
LogicaCMG UK	99	GMV Sistemas	4.372	NEXT	3.858
Indra Espacio	82	DLR	4.371	Space Engineering	3.334
DLR	82	Alcatel Lucent	4.365	Pagnanielli Risk Solution	3.323
Pagnanielli Risk Solution	80	ISMB - Politecnico di Torino	4.364	ESSP	3.175
ESYS	79	Indra Espacio	4.363	Atos Origin	3.100
NEXT	78	ESYS	4.360	FACG	3.100
Septentrio	74	IIASL - Leiden University	4.359	Thales Alenia Space [IT]	2.767
Kongsberg Seatex	73	Thales Alenia Space [IT]	4.358	University of Warmia	2.591
HiTec	73	Pagnanielli Risk Solution	4.357	Deimos Space	2.519
Alcatel Lucent	73	Kongsberg Seatex	4.354	Kongsberg Seatex	2.452
AENA	71	Deimos Space	4.351	GMV Sistemas	2.368

Table 4. Centrality measures

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[6] Integrity Processing Facility, Orbit Synchronization Processing Facility, Flight Dynamics Facility, Service Product Facility, Mission Data Dissemination Network Element.

5.2. Cognitive properties

Our review of the theoretical background emphasized the need to introduce a cognitive dimension into structural mechanisms in order to provide a better understanding of knowledge networks. Following the theoretical arguments of Cooke (2006), *Table 5* statistically combines the distribution of the knowledge bases (of the organizations) with the knowledge phases (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. We found that different phases of knowledge require different types of knowledge bases. The exploration phase requires mostly analytic knowledge bases, since 52,5% of the organizations involved in the exploration phase develop analytic knowledge, some develop synthetic knowledge (39 %) and few develop symbolic knowledge (8,5%). On the other hand, the integration phase requires mostly synthetic knowledge (70,3%) and very little analytic (15,8%) or symbolic knowledge (13,9%). Finally, the exploitation phase also requires mostly synthetic knowledge (62,4%). Organizations that produce symbolic knowledge are mainly involved in the exploitation phase (28,4%), while the share of analytic knowledge decreases dramatically in this phase (9,2%).

Knowledge bases and cognitive nature of collaborations

SAS & KVC	Exploration	Integration	Exploitation	Total
Analytic				
(Nb of organizations)	62	37	25	124
(%)	52,5 %	15.9 %	9.2 %	20 %
Synthetic				
(Nb of organizations)	46	163	169	378
(%)	39 %	70.3 %	62.4 %	60.8 %
Symbolic				
(Nb of organizations)	10	32	77	119
(%)	8.5 %	13.8 %	28.4 %	19.2 %
Total				
(Nb of organizations)	118	232	271	621
(%)	100 %	100 %	100 %	100 %

Table 5. Knowledge bases and cognitive nature of collaborations

In order to describe the cognitive features of the network, it is useful to assess whether or not the network reveals the presence of preferential attachments between organizations sharing similar or complementary knowledge bases. We computed the E-I index, which was proposed by Krackhardt and Stern (1988), in order to measure "group embeddedness", through a comparison of the numbers of within-group ties with the number of between-group ties. This E-I index is defined as follows:

$$-1 \leq E - I \equiv \frac{Nb - Nw}{N} \leq +1 \text{ with } Nb = \sum_i N_b^i \text{ and } Nw = \sum_i N_w^i$$

With N_b^i being the number of ties of group *i* members to outsiders and N_w^i the number of ties of group *i* members to other group *i* members, and *N* is the total number of ties in the network. The resulting index ranges from -1, when all ties are internal to the group (homophily assumption), to +1, when all ties are external to the group (heterophily assumption). *Table 6* describes the results and shows that organizations developing analytic (0,521) and symbolic (0.476) knowledge bases are highly heterophile. This result means that a large majority of them try to form partnerships with complementary organizations. Conversely, we find that "synthetic" organizations develop a more homophile relational behavior (-0.291).

E-I index	**Internal**	**External**	**Total**	**E-I**
Analytic	24 %	76 %	100 %	0.521
Synthetic	65 %	35 %	100 %	-0.291
Symbolic	26 %	74 %	100 %	0.476

Table 6. E-I index

Finally, *Table 7* uses the core/periphery model again, but now in order to provide information about the connectivity of projects according to their knowledge phase. Using the network of projects, the main result is that 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 of the GNSS network, against 32% of the projects dedicated to the integration phase, and 41,7% of the projects involved in the exploitation phase. As a consequence, the more projects move closer to the market, the more they are connected between themselves, while the very upstream phase of knowledge value chain remains "located" in the periphery of the network, as displayed in *Figure 4*.

Core & Periphery	**Core**	**Periphery**	**Total**
Exploration			
Nb of projects	1	22	23
%	4.4%	95.6%	100%
Integration			
Nb of projects	8	17	25
%	32%	68%	100%
Exploitation			
Nb of projects	10	14	24
%	41.7%	58.3%	100%
Total			
Nb of projects	19	53	72
%	26.4%	74.6%	100%

Table 7. Core & Periphery

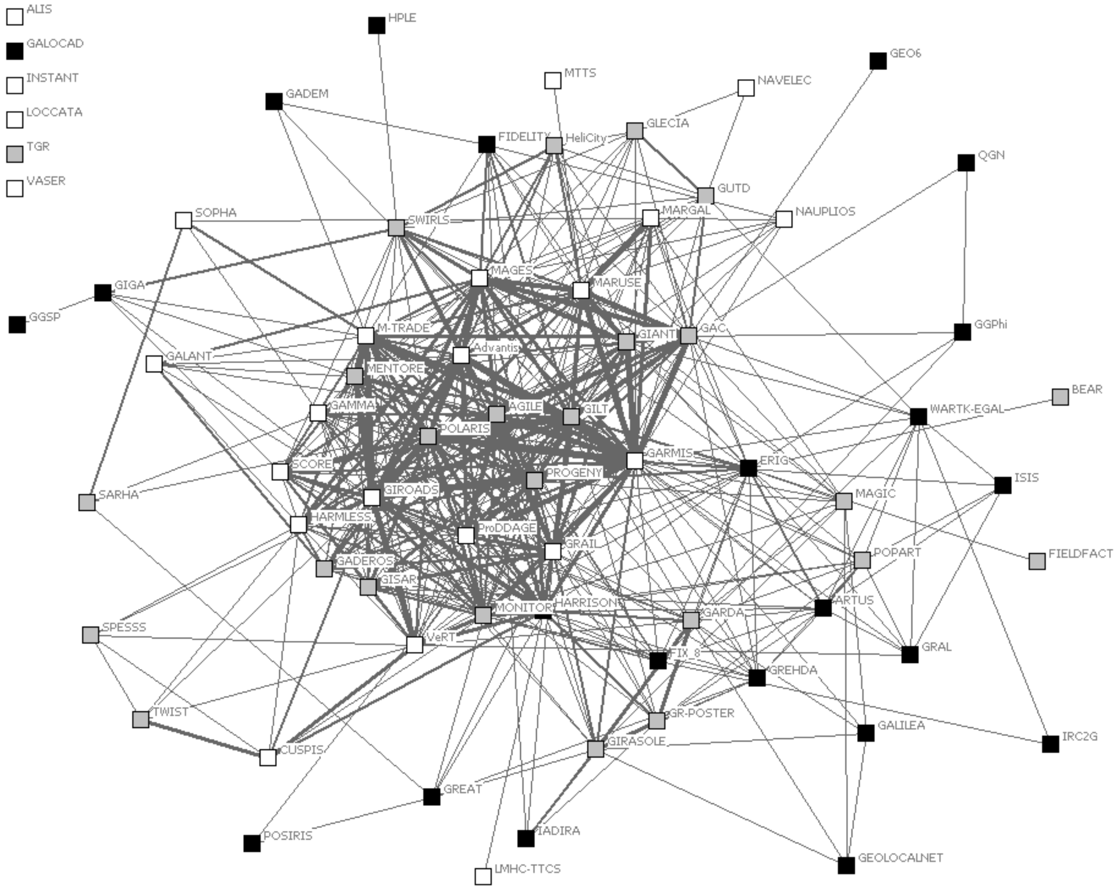

Figure 4. Core & Periphery structure and knowledge phases[7]

This result can be strengthen by an econometrical test. Recall that we have shown above that organizations have not similar preferences for cognitive nature of collaboration (exploration, integration, exploitation) according to their knowledge bases. Thus, we will perform an econometrical test in order to estimate if the knowledge profile of the partners (analytic, synthetic, and symbolic) influences their probability to belong 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 belonging to analytical, symbolic and synthetic categories. Then, we use a continuous variable range from 1 to 10 regarding the level of presence of each knowledge base[8]. For instance, a project of size 19 with 2 "analytical" organizations, 16 "synthetic" organizations and 1 "symbolic" organization is coded (2, 9, 1). It means that respectively 10.53%, 84.21%, 5.26% of organizations are analytical, synthetic or symbolic oriented ones. The following table displays the result of a probit

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[7] Black squares represent projects dedicated to exploration, grey squares to integration, white squares to exploitation. The line strength represents the number of organizations that tie projects, from 1 to 5 ties.

[8] 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%.

estimation[9] with an explained variable which takes the value 1 if the project belongs to the core or 0 else, as well as the marginal effect of each variable[10].

Explained variable = belonging to the core	**Probit estimation**	**Marginal effect**
Size	0.925*** (0.204)	.0044***
Size^2	-0.019*** (0.004)	-.0000908***
Analytic	0.713 (0.725)	.003393
Synthetic	1.604* (0.758)	.0076339*
Symbolic	1.206* (0.620)	.0057391*
Constant	-23.962** (9.497)	
N	72	
Log pseudolikelihood	-9.888918	
Pseudo R2	0.7620	

Note: ***, **, * mean significant at the level of 1%, 5%, and 10% respectively robust standards errors in the parenthesis

Table 8 - Probit estimation and marginal effect

As we suspected, the probability of a project to belong to the core of the network is significantly influenced by synthetic and symbolic knowledge bases. At the opposite, increasing the level of analytical component has no effect on the probability to belong to the core of the network. The marginal effect of analytical 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 analytical base within the project has no effect on the probability to belong to the core. The synthetic component is the more influential determinant, as soon as a marginal positive variation[11] of this knowledge base increases the probability of belonging to the core of 0.7 point of percentage. Finally, an interesting result appears regarding the size of the project. Increasing the size of the project has a positive effect on the probability to belong to the core of the network but at a decreasing rate, which means the existence of a threshold above which the marginal actors influence negatively the probability to belong to the core. As previously mentioned, one of plausible explanation relies on the limited capabilities of various partners to manage efficiently

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[9] We control for Heteroscedasticity with White correction. .

[10] Formally, we test the following specification: Pr(Core=1)=F(size, size^2, analytic, symbolic,synthetic)+e. The marginal effect is the slope of the probability curve relating each variable X to Pr (Core=1|X), holding other variables constant. Detailed about the econometric test can be found in Cameron and Trivedi (2005).

[11] Reminder 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.

coordination costs. Once more, if the project has to belong to the core for strategic and market considerations, an excessive size could have a counterproductive effect.

5.3. Geographical properties

The third category of features we highlight concerns the geographical properties of the network. As previously said, clusters are identified 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*).

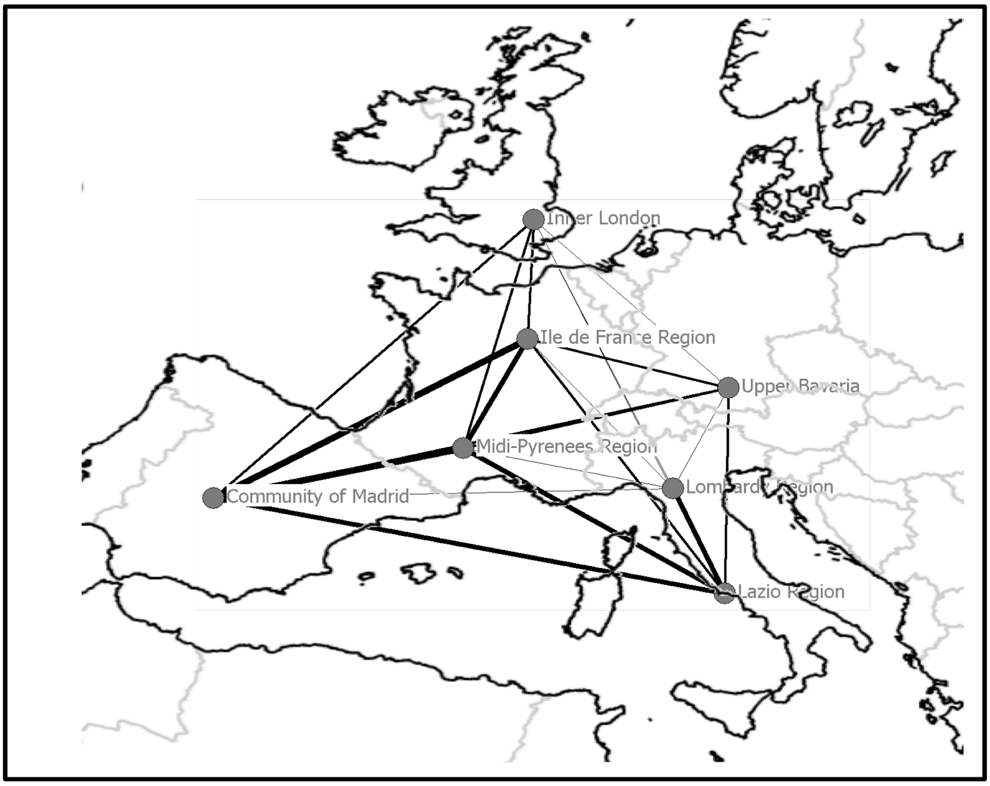

Figure 5. GNSS clusters and pipelines in Europe[12]

Table 9 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).

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[12] The thickness of ties correspond to the number of inter-clusters relations, from]0, 20] for the slender ties to]60, 80] for thick ties.

Clusters and pipelines

Clusters	**Community of Madrid**	**Lombardy Region**	**Upper Bavaria**	**Midi-Pyrenees Region**	**Lazio Region**	**Inner London**	**Ile de France Region**
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
Nb of organizations	26	13	12	18	18	14	26
Internal degree[*] (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[**]	303	106	126	241	206	122	220
Cluster openness[***]	1.99	4.81	7	4.63	2.57	8.71	5.5

[*] Internal degree refers to the number of relations within the cluster
[**] External degree refers to the number of relations across the cluster, i.e. within the pipelines
[***]Cluster openness = External degree / Internal degree

Table 9. Geographical patterns

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 10* shows that 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 confirms the literature, according to which geographical proximity is of more benefit to projects in the exploration phase.

Similarly, the pipeline relational matrix has been divided into three matrixes (nodes are still the seven clusters), according to the nature of relations: exploration, integration and exploitation. *Table 10* reveals a radically different distribution than the one found for local interactions. Indeed, now only 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.

Cognitive structure of clusters and pipelines				
	Exploration	**Integration**	**Exploitation**	**Total**
Within the clusters				
Nb of links	178	116	84	378
%	47 %	31 %	22 %	100 %
Within the pipelines				
Nb of links	462	588	274	1324
%	35 %	44.5 %	20.5 %	100 %
Clusters/others				
Nb of links	1482	1610	890	3982
%	37 %	40.5 %	22.5 %	100 %
Others/others				
Nb of links	662	734	762	2158
%	31 %	34 %	35 %	100 %
All				
Nb of links	2784	3048	2010	7842
%	35.6 %	38.8 %	25.6 %	100 %

* Internal degree refers to the number of relations within the cluster
** External degree refers to the number of relations across the cluster, i.e. within the pipelines
***Cluster openness = External degree / Internal degree

Table 10. Cognitive structure

6. Discussion

This set of quantitative results and measures requires an interpretative discussion of the main findings, In particular, the coexistence of a relational core-periphery structure with a geographical cluster and pipeline structure brings interesting and new perspectives

- *Structural properties of the European GNSS technological field: What is new when structural properties are coupled with cognitive features of an innovative network?*

First of all, by using the bimodal network, the study of connectivity between projects instead of the level of connectivity between organizations suggests that organizations that are not directly tied in a project can be tied through intermediaries that connect separated projects, so that knowledge can spill easily over the network. If arms' length relations exist – the network is far from being fully connected – 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 and dedicated services. Such a result is typical of the "industry of networks" (Shy, 2001), 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 rests on the setting of standards, in order that innovations turn into mass-market technologies. This relatedness was previously observed for the development of the GSM in the mobile phone industry.

Moreover, 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 connected between themselves while some others remain poorly connected. The core of the network is thus the locus of a high level of knowledge combination due to organizations that mediate between projects. The other projects, even if they are connected to the core, are more or less "located" at the periphery, with a weaker level of connectivity. This property is typical of many network structures and does not have to be interpreted as a limitation of the structure of the technological field. On the contrary, as observed by Barabasi (2005), many networks such as scientific ones do not evolve at random but following a double trend of core reinforcement and growth through the periphery. The cohesive structure of the core leads to a stabilization and an exploitation of conventions and norms, and the peripheral "players" constitute a pool of more disruptive behaviors that can bring fresh and new ideas into the network (Uzzi, Spiro, 2005; Cattani, Ferriani, 2008). Concerning the European GNSS network, this core/periphery feature can be explained by the structuring of the technological field. Even if the network is analyzed statically over a six-year period, the interaction between the structural properties and the phases of the knowledge value chain confirms this power trend for the considered period. Most of the projects of the core are dedicated to the exploitation and integration phases of the navigation satellite systems while the main part of the explorative projects remains in the periphery, as displayed in *Table 7*. 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. When we study the content of the projects more closely, we observe that many projects located in the core focus on markets which are beginning to be stable, such as navigation systems for transport, mobility, security; while projects located in the periphery are distant from the market and concern research on new generations of more efficient systems which could engender new applications in the future.

- *Geographical properties of the European GNSS technological field in relation to the knowledge bases and value chain: from clusters to dispersed networks.*

Our geographical cluster analysis confirms the coexistence of structural forms observed empirically by others (Storper, Harrison, 1989; Markusen, 1996; Iammarino, McCann, 2006). The respective densities of the seven clusters highlight their different structural forms. Indeed, looking at the geographical patterns of the network (*table 9*), three of them display a relatively high score of internal density, considering that the activation of more than 15% of possible relations represents a high cohesiveness of the clusters. The Madrid, Toulouse and Roma clusters exhibit features typical of Marshallian clusters (Markusen, 1996), meaning that the co-location of organizations is coupled with a structure of knowledge relations and exchange. Moreover, their respective score of openness shows that one of them – the Toulouse cluster – is more "embedded" in the European technological field than the others since it hosts the most central organization (TAS) of the overall network. On the other hand, two clusters display a level of density lower than 7.5% - the Inner London and Ile de France clusters, two metropolitan regions – and so a weaker level of knowledge relations between "insiders", but with higher scores of openness. These two clusters are thus closer to the "satellite platform" of Markusen (1996).

If we now consider clusters in relation to the knowledge value chain, 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 10*). This is not really a surprising result since the literature shows that exploration phases compel a high level of analytic and tacit knowledge that requires proximity between organizations and social network effects between public research organizations, spinoffs and companies. Moreover, as shown in *Table 5*, a large part of explorative knowledge relations involves analytic organizations, which have a highly heterophile profile (*Table 6*), so that they interact mostly with synthetic and symbolic organizations. Geographical clusters are thus suited to fill the cognitive gap between organizations and insure the necessary convergence between their knowledge capabilities. If we turn to pipelines, *Table 10* shows that pipelines gather a large part of knowledge relations in the integration phase. Considering the cognitive nature of collaborations (*table 5*), these relations are mostly shaped by synthetic organizations and concern engineering processes that turn analytic solutions and fundamental research into prototypes and technological goods. Since integration phases involve the combination of existing knowledge, the codification of this knowledge can be sufficiently high for these organizations to be able to interact easily at a distance (Bathelt et al, 2004). *Table 6* confirms this result: "synthetic organizations" have a greater propensity to interact between themselves than with other organizations (knowledge relations of "synthetic organizations" display a weaker E.I index), so that distant knowledge interactions are facilitated by the weak cognitive gap and the opportunities of temporary proximity (Torre, 2008).

Moreover, considering that integration phases are dedicated to an intermediate stage that succeeds when it turns new ideas and research into mass-market products, an efficient integration and combination process requires cooperation between complementary as well as competing companies located in different clusters in order to set up as wide as possible a technological standard. The "space alliance" being composed by a couple of clusters in Europe (*figure 5*), the existence of these pipelines in the engineering process confirms once again 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 and services (Braunschvig *et al*, 2003). Finally, knowledge relations in exploitation phases 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 and services requires paying close attention to this geographical dimension. These dispersed networks are even more necessary when GNSS diffusion, as well as ICT demand, is influenced by network externalities (Shy, 2001) and thus by an availability of applications and services as geographically wide as possible.

- *Geographical and structural properties of the European GNSS technological field: How do core/periphery structures co-exist with cluster/pipeline structures?*

	Knowledge exploration	**Knowledge integration**	**Knowledge exploitation**
Cognitive properties	*Analytic and fundamental knowledge*	*Synthetic and engineering knowledge*	*Symbolic, price and marketing 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*

Table 11: cognitive/geographical/structural properties and the phases of the knowledge value chain

If the analysis focuses now on the links between the core/periphery and cluster/pipeline structures, new findings in economic geography and knowledge economics emerge. *Table 11* summarizes these findings, crossing the knowledge phases with the cognitive, structural and geographical statistics of the GNSS network.

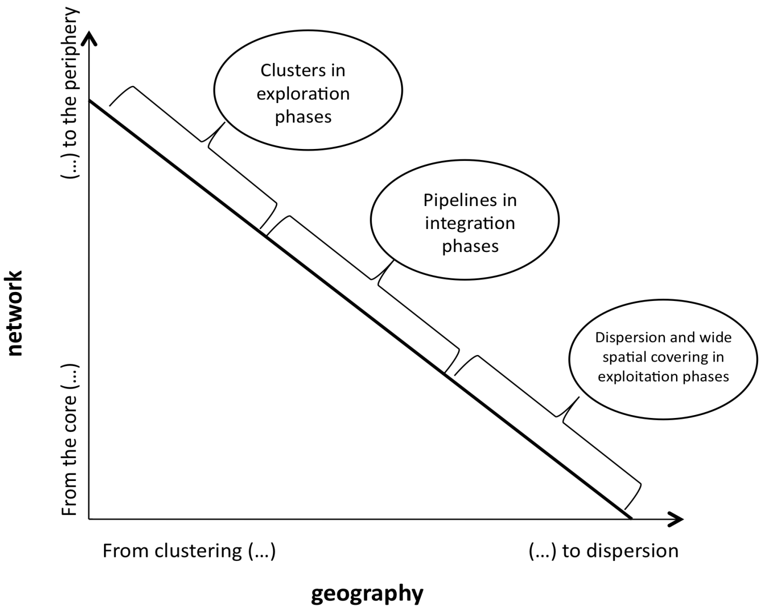

Figure 6: geographical cluster/pipeline and network core/periphery structure

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 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 host organizations that are poorly connected among themselves. Recall that *Table 9* 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 sub-structures 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 (Boschma, 2005). 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. The relationship between these geographical and structural properties is insured by the most central organizations of the network. On the one hand, as displayed in *Tables 4* and *9*, they belong to the main identified clusters in which they coordinate and mediate a large part of explorative relations. Moreover, they posit themselves as geographical gatekeepers (Rychen, Zimmermann, 2008) between clusters by building the main pipelines in order to set up technological standards and integrate applications and services. In doing that, they connect the periphery to the core of the network. On the other hand, these central organizations interconnect and mediate a large range of GNSS collaborative projects dedicated to exploitation in the core of the network, in order to enlarge the potential tradability in the European area.

7. Concluding remarks

Starting from the identification of a technological field has permitted a better understanding of how networks are spatially organized and how clusters are generally embedded in larger geographical structures. Network analysis represents nowadays a powerful method for understanding the interplay between geographical and relational structures in innovation processes (Boschma, Frenken, 2009). This empirical contribution, in a particular technological field and in a particular area, aimed to strengthen this method and confirm its reliability. For this purpose, we have underlined the central role that the cognitive attributes of organizations and knowledge projects play in the structural as well as geographical properties of innovative networks. The salient – almost certainly original – outcome is the negative linear relationship found between geographical cluster/pipeline and structural core/periphery structures.

By distinguishing and linking organizations and projects in the network analysis, we have captured the structural dimensions of the network, by identifying its core, its periphery, and the geographical properties of the network. This methodology has led us to converge with the growing literature that shows that geographical clusters are embedded in larger networks through pipelines, but also to introduce this significant property in the larger perspective of the structural organization of a particular technological field. Thus, 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.

In the periphery of the network of collaborative projects, clusters preserve a pool of new and upcoming exploitable knowledge. But the technological field will display a long-term viability 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. This viability 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.

Obviously, this study concerns a specific technological field, which is far from maturity and displays uncertainty on potential markets. It also concerns a particular area, the European one, in which strategic issues and public funding systems play a central role in the structuring of the technological field. Thus our findings need to be developed in other technological domains. They should also be tested in the future by enlarging or changing the geographical scale.

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