# Chapter 13
# The Structure and Geography of Collaboration Networks in the European GNSS Industry

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**Abstract** The concentration and dispersion of innovative activities in space have been largely 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 R&D collaboration networks. This paper contributes to this challenge focusing on the 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 EU Framework Programs, and apply social network analysis. We study the properties both of the network of organisations and the network of collaborative projects. We show that the nature of the knowledge involved in relationships influences the geographical and structural organisations 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.

## 13.1 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 evidence this process, focusing on the structural dimensions of R&D collaboration networks. The literature on geography of

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innovation has provided important empirical evidence showing that firms learn more easily from each other when they are located within the same place (Feldman 1999). The economics of innovation literature has also early recognized the central role of networks in the development of new products, new processes and new knowledge (Freeman 1991; 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).

To understand better the role of geography and networks in innovation activities, scholars have often investigated the type of knowledge which is actually exchanged between actors. The conceptualization of the nature of knowledge has been a central debate in the field (Cowan et al. 2000) and especially the reference to tacit knowledge has increasingly been used to explain the spatial patterns of innovative activities. 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), and little is said about the links between the nature of knowledge and the structural organisations 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.

This paper aims at contributing to this challenge 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) in Europe. 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.

The paper is organized as follows: Sect. 13.2 recalls the challenging introduction of structural properties of collaboration networks into the traditional parameters of the geography of innovation. Section 13.3 discusses a set of testable propositions that link cognitive and geographical dimensions of networks to their purely structural dimensions, stressing on the particular case of technological fields in which standardization influences the structuring of networks. Section 13.4 presents the data set of R&D collaborations in the European technological field of GNSS. Section 13.5 proposes an original network analysis developed for both identifying the nature of knowledge involved in relationships and the structural properties of the R&D collaboration network. Section 13.6 tests separately each proposition and discusses the formal results. Section 13.7 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 idea to be turned into a mass market standard.

## 13.2 Theoretical Context

The geography of innovation exhibits structures that result from localization and knowledge externalities. One of the main 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 (Audretsch and Feldman 1996). But for Breschi and Lissoni (2001), what is hidden behind knowledge externalities could be more the result of the intentional effort of organisations to exchange and combine knowledge than a simple corridor effect. The geographical extent of knowledge spillovers does not depend only on distance but also on the ability of knowledge to flow across relational structures.

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). The key parameters for the valuation of these risks and opportunities are the degree with which the knowledge bases of partners complement each other and the degree of openness of their model of knowledge valuation. Organisations decide to form a knowledge partnership only when each one assumes that the benefits of knowledge accessibility will exceed the risks of under appropriation. Structural properties will be not purely physical, but the result of the strategic behavior of organisations to deal with their own knowledge trade-off. Geography matters for the micro-motives of organisations for shaping knowledge relations. Indeed, geographical proximity between organisations involved in a partnership has ambivalent effects on their respective innovation capabilities (Boschma 2005). 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 are more compatible than proximity.

For a particular knowledge process in a particular technological field, a collaboration network will be defined as the set of organisations that are involved in the field and the set of knowledge ties between them. From this relational matrix and considering the location of organisations, structural properties of the network will be good markers of the channels through which knowledge flows and geography structures itself. The level of connectivity is a good marker to understand the co-existence of arms-length and network relations in a technological field (Uzzi 1997), in particular when compatibility and standardization matter (Cowan et al. 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 (Borgatti and Everett 1999). A network exhibits a core/periphery structure when a highly cohesive structure of knowledge interactions between organisations co-exists with organisations that are poorly connected between themselves and with the core. 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 (Bathelt et al. 2004; Trippl et al. 2009).

## 13.3 The Structural and Geographical Properties of the European GNSS Collaboration Network: Two Propositions

The structural properties of knowledge networks has 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; Scherngell and Barber 2011; Vicente et al. 2011; Balland 2012; Broekel and Graf 2012). These studies concern different industrial sectors and technological fields, different geographical areas, and different sources of relational data. Here we discusse 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 influences the structuring of R&D collaboration networks. GNSS is a standard term for systems that provide positioning and navigation solutions. These technologies were originally developed in the aerospace and defense industries. But nowadays, they find complementarities and integration opportunities in many other socio-economic contexts concerns by mobility. 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 through the Egnos and Galileo programs.

### 13.3.1 Structural Properties of Networks and Technological Standard Diffusion

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 et al. 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 network externalities on the demand side, and thus requires a high level of interoperability between competing suppliers (Katz and Shapiro 1994). Firstly, 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. Secondly, 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. 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. One can expect that the maturity of the industry goes with a high level of density and connectedness in the collaboration network, with a high level of closure and triangulation that favors the mutual understanding between partners and prevents opportunistic behaviors (Coleman 1988; Cowan et al. 2004).

Nevertheless, literature shows that highly cohesive structures of knowledge interactions produce conformism and display risks of lock-in (Ahuja et al. 2009). Redundant ties limit access to new information and fresh ideas (Burt 1992), and can sclerose the technological field as a whole. Technological fields characterized by 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 collaboration network. In the exploration phase, technologies are beta tests and compatibility constraints are not as critical as in the integration and exploitation phases. But this pool of fresh and news ideas should be connected to the core of knowledge interactions, 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 organisations 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, an expected core/periphery hierarchy appears as a marker of the increasing maturity of the field.

### *13.3.2 Geographical Properties of Networks and Technological Standard Diffusion*

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). 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.

For instance, Owen-Smith and Powell (2004) highlight structural and geographical patterns along the growing maturity of the biotech sector in Boston. They show that, at the early stage of the cluster, the cohesiveness of the local relational structure rested mainly on the active participation of public research organisations that connect disconnected private organisations in a very open structure of fundamental knowledge dissemination. 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 organisations in any locations that have a tie with local ones. They show that clustered relations depend on the dominance of an academic and open institutional regime, while pipelines relationships 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 in the case of the German co-inventors network and observes a similar pattern of the evolution. From the exploration phase in the 1980s to the exploitation phase in the 1990s, he observes a shift in the network strategies of biotech organisations. While the network grew initially along geographical proximity, the increase of knowledge codification along the maturity process has led companies to use global networks as a resource of triadic closure, which favor trust and knowledge appropriateness.

The geography of R&D collaboration networks is thus dependent on the attributes of the organisations 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. Such a geographical structure corresponds to a particular stage of the growing maturity of the field. Research-based organisations 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. Then he clusters/pipelines structure of knowledge interactions in a particular technological field is typical of the overlap between the phases of its knowledge value chain.

## 13.4 Data

As a relational data source, we use joint R&D projects funded by the Framework Programmes (FP) for research and technological development of the European Union. As such, we follow recent empirical studies emphasizing the advantage of this kind of relational data in economic geography (Autant-Bernard et al. 2007; Breschi et al. 2009; Scherngell and Barber 2011; Balland 2012). For the purpose of this paper, we exploited the GNSS Supervisory Authority[1] (GSA) database on joint GNSS R&D projects funded by the 5th and 6th FP from 2002 to 2007.

This primary database is mainly used to deduce two adjency matrixes: the network of projects and the network of organisations that will be analysed in the empirical section. 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 organisations, we have converted the primary 2-mode matrix into a 1-mode square matrix of collaborations between all the organisations. We assume that each project is fully connected (forming a clique), so that two organisations are linked if they participate to the same project. Descriptive statistics on the network of projects and the network of organisations are presented in Table 13.1. They show that both the network of projects (0,181) and the network of organisations display a relatively high density (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, indicating that only a few nodes have a high probability of having large number of relations (Fig. 13.1). This statistical signature suggests some interesting traits about the industrial structure of the GNSS sector, related to the setting and control of technological standards. Vertical firms and transnational corporations as well as spatial agencies are often representative organisations of this type of market.

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[1] GSA is the European GNSS Agency, in charge of public interests related to GNSS programmes in Europe.

**Table 13.1** Structural characteristics

| Statistics | Network of projects | Network of organisations |
|---|---|---|
| Nb of nodes | 72 | 360 |
| Nb of links (valued) | 1,512 | 7,842 |
| Nb of links (dichotomized) | 914 | 7,144 |
| Density | 0.181 | 0.055 |
| Main component | 66 | 339 |

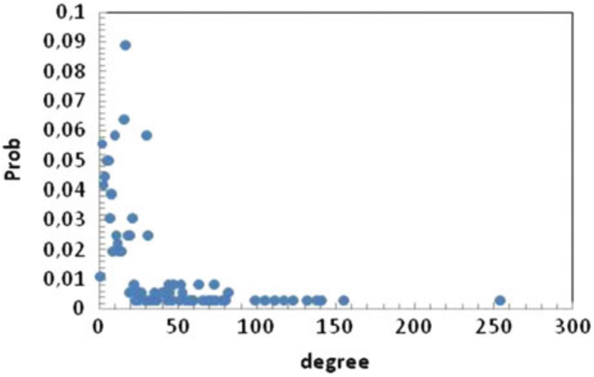

**Fig. 13.1** Degree centrality distribution among the 360 organisations

## 13.5 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 organisations and the network of projects. 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.

### *13.5.1 Exploration – Integration – Exploitation: A Taxonomy*

Joint R&D collaborative 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 to 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 13.2) in the abstract and in other available project documents (work-package reports for instance). 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. On the other hand, we classified as “exploitation” the projects proposing to develop well defined GNSS applications, for instance the development of applications specifically required for transport regulation, air fleet management or emergency services. 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, telecommunication and computer industries. The integration of two technologies requires additional R&D in order to ensure the compatibility between them.

### *13.5.2 Robustness of the Classification*

We analyzed which type of organization is involved in which kind of project. Broekel and Graf (2012) directly use this kind of approach to distinguish between projects dedicated to basic and applied research, arguing that public research organisations 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 organisations 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 an important residual one for the GNSS industry, involving final users, designers, associations and business consultants (Vicente et al. 2011). A large proportion of organisations developing engineering knowledge are found (192), with a balanced distribution of organisations developing research (84) and market-related (84) knowledge. This straightforward typology of knowledge bases of organisations allows us to control for our projects’ classification by combining the distribution of the knowledge types of the organisations 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 13.3).

**Table 13.2** 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 |
| Key words | Concepts/theory | Technological standard | Market |
| | Research | Interoperability | Use |
| | Investigation | Combination | Applications |
| | Simulations | Satellite + ICT | Design |
| | Mathematical model | PDA | Development |
| | Study | Wireless | Services |

**Table 13.3** Types of organisations and cognitive nature of collaborations

| | Exploration | Integration | Exploitation | Total |
|---|---|---|---|---|
| *Research* | | | | |
| | 62 | 37 | 25 | 124 |
| (%) | 52,5 % | 15.9 % | 9.2 % | 20 % |
| *Engineering* | | | | |
| (Nb of organisations) | 46 | 163 | 169 | 378 |
| (%) | 39 % | 70.3 % | 62.4 % | 60.8 % |
| *Market-related* | | | | |
| (Nb of organisations) | 10 | 32 | 77 | 119 |
| (%) | 8.5 % | 13.8 % | 28.4 % | 19.2 % |
| *Total* | | | | |
| (Nb of organisations) | 118 | 232 | 271 | 621 |
| (%) | 100 % | 100 % | 100 % | 100 % |

This test confirms the robustness of our classification, as research organisations are more involved in exploration, engineering firms in integration, and market-related actors in exploitation.

### 13.5.3 Identification of Clusters and Pipelines

The GSA and FP databases provide systematic information on the country of the organisations and the name of a contact person, but information concerning postal addresses of organisations is not always indicated. However, the small size of the network allowed us to find missing postal addresses of organisations 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 organisations. Starting from the square matrix of organisations (360 × 360), we aggregated all the organisations belonging

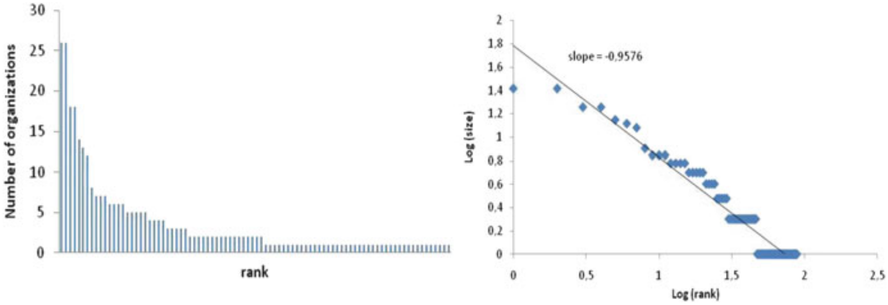

**Fig. 13.2** Distribution of organisations among 88 NUTS II European regions

to the same region, taking NUTS2 regions as the spatial unit of analysis (Autant-Bernard et al. 2007; Scherngell and Barber 2011). Then we obtained a new 1-mode matrix of relations between regions, with the diagonal indicating the number of relations within the region.

Figure 13.2 represents the distribution of the number of organisations 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 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. Conformably to a Zipf like relation, it appears that only very few regions (7/88) concentrate a high number of organisations (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 organisations outside of the clusters) in order to study their cognitive structure. Pipelines were studied according to the block matrix of relations between regions.

## 13.6 Main Findings

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 organisations and the network of projects are analyzed in a complementary way to provide empirical evidence for the proposition previously discussed.

### 13.6.1 Structural Organization of the Collaboration Network: A Core/Periphery Structure

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 constitutes the periphery (Fig. 13.3). Table 13.4 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. In contrast, 32 % of integrative projects and 41.7 % of exploitative projects belong to the core. The closer projects are to the market, the more they are interconnected. On the contrary, the upstream phase of knowledge value chain remains "located" at the periphery.

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 organisations are not randomly distributed along the knowledge phases (exploration, integration, exploitation). Thus, we 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 organisations belonging to research, engineering, and market-related categories. Then, we use a continuous variable range from 1 to 10 regarding the level of presence of each knowledge base.[2] For instance, a project of size 19 with 2 "research" organisations, 16 "engineering" organisations and 1 "market-related" organization is coded (2, 9, 1). This means that respectively 10.53 %, 84.21 %, 5.26 % of organisations 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:

$$Pr[Y_i = 1|X] = \Phi\left(\beta_0 + \beta_1 size + \beta_2 size^2 + \beta_3 research + \beta_4 engineering + \beta_5 market\right),$$

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

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[2] For each project we code 1 if the project exhibits between 0 % and 10 % of organisations with a knowledge profile, 2 if the project exhibits between 10 % and 20 % … to 10 if the project exhibits between 90 % and 100 %.

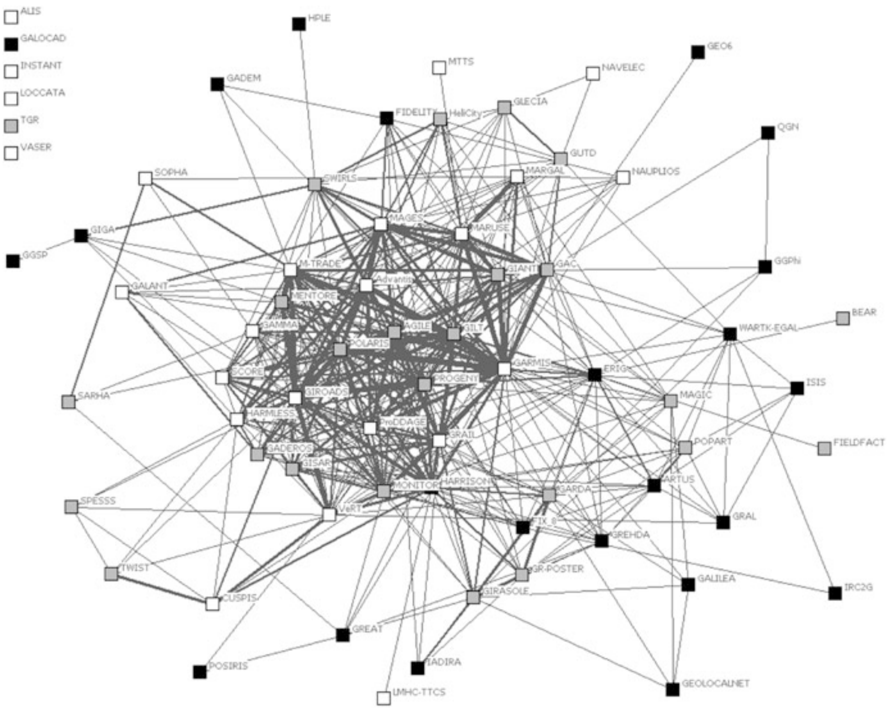

**Fig. 13.3** Core & Periphery structure and nature of knowledge (*Black squares* represent projects dedicated to exploration, *grey squares* to integration, and *white squares* to exploitation. The *line* strength represents the number of organisations that tie projects, from 1 to 5 ties)

**Table 13.4** 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 13.5** Probit estimation and marginal effect

| Explained variable = belonging to the core | Probit estimation | Marginal effect |
|---|---|---|
| Size | 0.925*** | .0044*** |
| | (0.204) | |
| Size^2 | −0.019*** | −.0000908*** |
| | (0.004) | |
| Research | 0.713 | .003393 |
| | (0.725) | |
| Engineering | 1.604* | .0076339* |
| | (0.758) | |
| Market-related | 1.206* | .0057391* |
| | (0.620) | |
| Constant | −23.962** | |
| | (9.497) | |
| Number of observations | 72 | |
| Log pseudolikelihood | −9.889 | |
| Pseudo R2 | 0.7620 | |

Note: ***, **, * mean significant at the level of 1 %, 5 %, and 10 % respectively. Robust standard errors in parenthesis.

constant.[3] The following table displays the result of a probit estimation,[4] as well as the marginal effect of each variable (Table 13.5).

As we 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 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 on strategic networks stability (Jackson and Wolinsky 1996).

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[3] Detailed about the econometric specification can be found in Cameron and Trivedi (2005).

[4] We control for Heteroscedasticity with White correction.

**Fig. 13.4** GNSS clusters and pipelines in Europe

### 13.6.2 Geographical Organization: A Clusters/Pipelines Structure

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 on the basis of the number of organisations 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 (Fig. 13.4).

Table 13.6 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 organisations (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 organisations), according to the nature of relations: exploration, integration and exploitation. Table 13.7 shows how the nature of knowledge influences the geographical organization of the GNSS technological field.

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

**Table 13.6** Clusters and pipelines interaction structure

| Clusters | Community of Madrid | Lombardy Region | Upper Bavaria | Midi-Pyrenees Region | Lazio Region | Inner London | Ile de France Region |
|---|---|---|---|---|---|---|---|
| Main organization | GMV | PRS | Astrium | TAS | Telespazio | Logica | FDC |
| Nb of organisations | 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 13.7** Nature of knowledge flows in 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 | 1,324 |
| % | 35 % | 44.5 % | 20.5 % | 100 % |
| *Clusters/others* | | | | |
| Nb of links | 1,482 | 1,610 | 890 | 3,982 |
| % | 37 % | 40.5 % | 22.5 % | 100 % |
| *Others/others* | | | | |
| Nb of links | 210 | 376 | 478 | 1,064 |
| % | 20 % | 35 % | 45 % | 100 % |

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 13.8 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 organisations 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.

## 13.7 Discussion: How Do Clusters/Pipelines and Core/Periphery Structures Work Together in R&D Collaboration Networks?

Firstly, the study of connectivity between projects suggests that organisations 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 organisations 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

**Table 13.8** 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* |

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 rests on the setting of standards, in order that innovations turn into mass-market technologies. 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. On one hand, the development of the market will be all the more extensive if organisations 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 occur.

Secondly, 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 13.7). 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 organisations and social network effects. If we turn to pipelines, Table 13.7 shows that pipelines gather a large part of collaborations 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 by a couple of clusters in Europe (Fig. 13.4), 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 organisations 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. 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 the structural and geographical dimensions, new findings in economic geography and knowledge economics emerge. Table 13.8 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. 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 organisations that are poorly connected among themselves. Recall that Table 13.6 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 organisations 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.

## 13.8 Conclusion

Our results highlight how knowledge spills over geography and relational structures, and how a particular technological field structures itself along its knowledge value chain. 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 organisations.

In terms of policy perspectives, our findings suggest that networks and geography matter 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 towards 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).

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