# Space Vs. Networks in the Geography of Innovation: A European Analysis

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**Summary**

In the last fifteen years, income differences among European Member States have been strongly narrowing while the process has been matched with a widening of the inter-regional variance within single countries. Traditionally, regional economic disparities in Europe have been ascribed to peripherality and/or to a high level of dependence on declining sectors. Nowadays regional disparities can be no longer defined only in terms of statistical differences in the values of standard macroeconomic indicators, but also according to innovative capacities and knowledge endowment. This paper provides an original framework for the interpretation of the existing relationships between innovation process and research activity in Europe and the structural and geographical features shaping the European scientific and technological map. In order to do so, we focus on two knowledge-based relational phenomena: participation in the same research networks (funded by the EU Fifth Framework Programme) and EPO co-patent applications. Using two complementary econometric techniques we try to assess those factors that determine patenting activity, distinguishing structural features, geographical and relational spillovers. Through these variables we measure the intrinsic relational structure of knowledge flows which directly connects people, institutions and, indirectly, regions, across European countries in order to test whether hierarchical relationships based on a-spatial networks between geographically distant excellence centres prevail over diffusive patterns based on spatial contiguity.

**Keywords:** Spatial Distribution, Networks, European Analysis

**JEL Classification:** O31, R12, C21

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## 1. Introduction

European Union has always been concerned about "regional disparities", and this issue became more relevant after the recent Eastward enlargement of the EU membership (Traistaru, Nijkamp, Longhi, 2003; Lackenbauer, 2004; Hapiot and Slim, 2004).

Furthermore, in the last fifteen years, income differences among European Member States have been strongly narrowing, while the process has been matched with a widening of the inter-regional variance within single countries (Quah, 1996; European Commission, 1999a; Martin, 1998, Boldrin and Canova, 2001). Such a dynamic rises a shadow on a whole season of European regional policies, explicitly designed to reduce geographical imbalances and strengthen regional cohesion, and questions on the consequences of the Europe enlargement as the gap is expected to widen.

A very peculiar and worrying aspect of the European context is that the agglomeration process of the economic activity – spontaneously produced by the interaction of economic agents searching for efficiency gains – may become too strong and risky to be socially acceptable in terms of equity.

Traditionally, regional economic disparities have been ascribed to peripherality – measured by the distance from the main centres in terms of population and economic activity – and/or to a high level of dependence on declining industries. Nowadays regional disparities can be no longer defined only in terms of statistical differences in the values of standard macroeconomic indicators (such as GDP a/o unemployment rate), but also according to innovative capacities and knowledge endowment. Knowledge matters more and more in defining both the level and the GDP growth rate of a region.

This paper provides an original framework for the interpretation of the existing relationships between innovation process and research activity in Europe and the structural and geographical features that shape the European scientific and technological map.

Krugman, in his Geography and Trade (1991a), states that "knowledge flows (...) are invisible; they leave no paper trail by which they may be measured and tracked". Jaffe *et al.* (1993) react to the previous statement by suggesting that "knowledge flows do sometimes leave a paper trail, in the form of citations in patents. Because patents contain detailed geographical information about their inventors, we can examine where these trails actually lead" (ibid, p. 578).

We attempt to move the approach a little further by focussing on two knowledge-based relational phenomena: namely, participation in the same research networks (funded by the EU within the Fifth Framework Programme) and EPO co-patent applications. Through these variables we attempt to measure the intrinsic relational structure of knowledge flows, which directly connects people, institutions and, indirectly, regions across the European countries.

The underlying idea of the paper is that knowledge is created and diffused through some crucial nodes (i.e. firms and universities) which tend to co-locate together in specific sites, thus determining the birth and development of high-tech clusters, innovative industrial districts, and excellence centres[1]. However, this geographical selection process leading to a hierarchical structure of the location of innovative activities goes together with an increasing role of knowledge spillovers that, starting from excellence centres, extend their positive effects to other agents (firms, universities, research centres) located in neighbourhood areas. So relevant regions present both an "attractivity" potential and a "diffusive capacity" (Acs, Anselin and Varga, 2002).

Thus, aim of the paper is to verify whether hierarchical relationships based on a-spatial networks between geographically distant excellence centres prevail over diffusive patterns based on spatial contiguity.

To achieve this aim we perform two empirical exercises focussed on a subset of 109 European regions at NUTS 2 level in France, Germany, Italy, Spain and United Kingdom. In the first exercise we consider the process of co-patenting between these regions in order to compare, within a gravity equation model, the influence of geographical distance versus relational distance in shaping these scientific and technological relationships. In the second exercise we analyse the patenting activity of the same subset of European regions in order to measure and compare, through spatial econometric techniques, the relative effects of spatial and relational proximity in determining their innovative performance.

The paper is organised as follows: section 2 includes a brief description of the Fifth Framework Programme, section 3 contains the empirical analyses and section 4 concludes the paper by summarising the main results.

## 2. The 5 Framework Programme (5FP): an overview

Searching for "paper trails" recording evidences of scientific and technological cooperation and networking between institutions and organizations located in five European countries, we focussed on the research contracts (directly and indirectly requiring the creation of research networks) within the Fifth Framework Programmes (henceforth, 5FP).

In this section we briefly depict some essentials of 5FP to understand its structure; therefore we use the EU-CORDIS database, to present some simple descriptive statistics; and finally we illustrate the part of the 5FP, relative to the sample of 109 European regions, used in the empirical analyses in section 3.

The aim of European Framework Programmes is to promote scientific research and technological development within the EU. The mission of such programmes is to solve problems and answering the challenges of the integration process by investigating the socio-economic, technological, industrial economic, social and cultural aspects of the EU (European Commission, 1999b). The 5FP is a five years programme started in 1998 and concluded in 2002. It differentiates from the previous ones for its targets, organisational structure and types of projects, the complementarity among

[1] For a detailed analysis of the emergence of high-tech clusters see Bresnahan *et al*. (2001) and Braunerhjelm and Feldman (2006).

projects, the intention to develop a critical mass of European resources in science and technology, and a slightly higher budget with respect to the previous ones.

FP5 has a multi-theme structure, consisting of seven Specific Programmes, of which four are Thematic Programmes: Quality of Life and Management of living resources (LIFE QUALITY); User-friendly Information Society (IST); Competitive and sustainable growth (GROWTH); Energy, Environment, and sustainable development (EESD); and three are Horizontal Programmes, which underpin and complement the Thematic Programmes by responding to common needs across all research areas: Confirming the international role of Community research (INCO-2); Promotion of innovation and encouragement of SME participation (INNOVATION-SME); Improving the human potential and the socio-economic knowledge base (IMPROVING) (European Commission, 1999b).

According to the EU-CORDIS database, the total number of contracts financed within the 5FP is 16,085 (for a total funding of nearly 12,000 millions euros), out of 60,000 submitted proposals (with a success rate of about 28%) (EU-CORDIS, 2005). Within the 5FP, the contracts are grouped according to the aim of research, as defined by the Thematic and Horizontal Programmes, but are divided into various typologies depending on the type of actors involved.

**Table 1: 5FP by contract type and average membership**

| Type of Contracts | Total Contracts | % | Average dimension per contract | Sub-sample Contracts | Average dimension per contract |
|---|---|---|---|---|---|
| Access to Research Infrastructures | 187 | 1.2 | 1.0 | - | |
| **Bursaries, grants, fellowships** | **1,105** | **6.9** | **1.2** | **29** | **6.9** |
| **Cooperative research contracts** | **620** | **3.9** | **7.9** | **297** | **7.8** |
| **Coordination of research actions** | **170** | **1.1** | **11.4** | **61** | **11.3** |
| **Cost-sharing contracts** | **5,105** | **31.7** | **8.1** | **2,982** | **8.0** |
| **Demonstration contracts** | **67** | **0.4** | **8.9** | **23** | **9.3** |
| Exploratory awards | 997 | 6.2 | 2.0 | - | |
| Exploratory awards (thematic networks) | 3 | 0.02 | 1.0 | - | |
| Joint Research Centre research | 87 | 0.5 | 1.0 | - | |
| **Preparatory, accompanying and support measures** | **3,378** | **21.0** | **2.4** | **514** | **6.2** |
| Research grants (individual fellowships) | 2,855 | 17.7 | 1.1 | - | |
| **Research Infrastructure-Transnational access** | **1** | **0.01** | **5.0** | **1** | **5.0** |
| **Research network contracts** | **333** | **2.1** | **7.7** | **228** | **7.7** |
| **Thematic network contracts** | **524** | **3.3** | **15.5** | **259** | **15.9** |
| **Not defined** | **653** | **4.1** | **6.4** | **172** | **7.0** |
| **TOTAL** | **16,085** | **100** | **4.9** | **4,566** | **8,2** |

Note: only contracts in bold have been considered in the empirical analysis.
Source: our calculations on the EU-CORDIS 5FP database.

Being interested in the existing networks of scientific and technological relationships established between institutions and organisations belonging to the 5 largest EU countries (France, Germany, Italy, Spain and United Kingdom) – which represented about 80% of the GDP and of the population and 77% of the total R&D expenditure[2]. We focus our analysis on a subset of research contracts typologies granted by the EU within the 5FP, whose organisational structure may be better described through a network composed by one coordinator and several participants[3] – as illustrated in table 1.

While the average membership of all 5FP contracts is slightly less than 5, thanks to our selection the same in the sample exceeds 8.

Since we focus our analysis on network-type organisational structure of contracts, it is important to define the networks' nodes: namely coordinators and participants. Coordinators are, in the EU jargon, those legal entities that are in charge of the contracts, in terms of administrative, financial and scientific activities required within the contracts. The coordinator is relevant both in legal and in scientific terms since it is "legally" responsible for the project in front of the Commission; but its role reflects important managing and power skills with respect to the other members of the research project. 5FP research contracts involve different type of actors[4]: single individuals, private firms, universities, research centres, foundations, ONGs, international organisations, etc.

The information relative to the type of coordinator is crucial because it identifies those actors that are more involved in creating new knowledge, and reflects their ability to create research networks. In general research and education institutions coordinate 4,316 contracts (27%), while firms (belonging to the so called "industry sector") only 1,010 contracts (6%). "Other" institutions coordinate more than a half of the contracts (8,512) (53%)[5].

Hence European research networks seem to be mostly managed by subjects not directly involved in the process of creation of new knowledge (i.e. firms, universities and research laboratories). Actually these statistics should be commented very carefully because in many cases, the coordinator of a proposal is a private consultancy that offers its acquired skills to manage the complex EU funding application procedures. Hence these coordinators may not have relevant skills in research and technological development activities, but in the applications procedures and in managing research funding.

A similar analysis, conducted on the categories of participants included in the dataset (62,617 in total), confirms the relative marginality of the industry sector representing only 11% of the total participants, a percentage much smaller if compared with universities and research institutions (44%) and "Other" players (41%). These percentages signal the difficulties of the EU in involving firms in cooperative research and development activities.

Another interesting perspective of analysis of the 5FP research contracts deals with its geographical distribution as illustrated in table 2. The map of coordinators of 5FP contracts is naturally euro-centered (89.4% of the total projects is coordinated by institutions located in Europe 15), although 1.4% of the contracts has a coordinator that is not European. In general coordinators are not evenly distributed across Europe. Larger countries, with well-developed national innovation systems, are over-represented and the presence of EU offices on the national seems to have also a positive impact, both as coordinator and as participants.

[2] There are important differences among them: in fact for example, Germany invests 2,5% of GDP in R&D activities and Spain, less that half, 1,04%.

[3] Thus we selected only those contracts recording an average membership greater than 2. Exception to this general rule was the case of bursaries, grants, fellowships which, in our sample, showed an higher average membership (nearly 7) (table 1).

[4] Formally the EU recognises the possibility to participate to the 5FP to all legal entities (natural persons, legal persons, international organisations and Joint Research Centres) (European Commission, 1999b).

[5] Unfortunately the European Commission-Cordis database does not allow to identify the corresponding sector of these organisations.

## Table 2: 5FP by country

| | Participation as coordinator | | Funds received[a] | | Participation as members | |
|---|---|---|---|---|---|---|
| | Number | % | Total amount (millions euro) | % | Number | % |
| Austria | 399 | 2.5 | 297 | 2.5 | 1,509 | 2.4 |
| Belgium | 694 | 4.3 | 615 | 5.1 | 2,237 | 3.6 |
| Denmark | 403 | 2.5 | 343 | 2.9 | 1,685 | 2.7 |
| Finland | 268 | 1.7 | 233 | 1.9 | 1,516 | 2.4 |
| ***France*** | ***2,094*** | ***13.0*** | ***1,739*** | ***14.5*** | ***7,565*** | ***12.1*** |
| ***Germany*** | ***2,267*** | ***14.1*** | ***2,030*** | ***16.9*** | ***8,694*** | ***13.9*** |
| Greece | 509 | 3.2 | 430 | 3.6 | 2,442 | 3.9 |
| Ireland | 206 | 1.3 | 146 | 1.2 | 804 | 1.3 |
| ***Italy*** | ***1,570*** | ***9.8*** | ***1,091*** | ***9.1*** | ***6,193*** | ***9.9*** |
| Luxembourg | 22 | 0.1 | 14 | 0,1 | 91 | 0.1 |
| Netherlands | 1,195 | 7.4 | 861 | 7.2 | 3,602 | 5.8 |
| Portugal | 212 | 1.3 | 97 | 0.8 | 1,429 | 2.3 |
| ***Spain*** | ***1,157*** | ***7.2*** | ***728*** | ***6.0*** | ***4,618*** | ***7.4*** |
| Sweden | 414 | 2.6 | 383 | 3.2 | 2,295 | 3.7 |
| ***United Kingdom*** | ***2,967*** | ***18.4*** | ***2,133*** | ***17.7*** | ***7,722*** | ***12.3*** |
| ***EU-5 (our sample)*** | ***10,055*** | ***62.5*** | ***7,721*** | ***64.2*** | ***34,792*** | ***55.6*** |
| EU-15 | 14,377 | 89.4 | 11,140 | 92.6 | 52,402 | 83.7 |
| 10 EU New Members (post 2004) | 517 | 3.2 | 159 | 1.3 | 3,717 | 5.9 |
| Rest of Europe | 438 | 2.7 | 302 | 2.5 | 3,530 | 5.6 |
| Other Countries | 228 | 1.4 | 135 | 1.1 | 2,961 | 4.7 |
| NOT defined | 525 | 3.3 | 298 | 2.5 | 7 | 0.0001 |
| **TOTAL** | **16,085** | **100** | **12,035** | **100** | **62,617** | **100** |

[a] These values refer to total funds assigned to projects whose coordinator is located in the country.
Source: our calculations on the EU-CORDIS database.

Table 2 shows that United Kingdom is the most involved country in the 5FP, with British institutions coordinating about 18% of total financed contracts, followed by Germany (14.1%) and France (13%). These 3 countries manage about one half of all 5FP contracts. Italy and Spain are lagging behind, being involved as contract coordinators respectively in 9.8% and 7.2% of the EU total. These five countries account for more than 62.5% of the coordinators.

Similar results can be drawn considering the memberships: the members are mostly from European countries (83.7%), although non-EU share increased (4.7%) respect to the coordinator (1.4%). The five countries listed before represent 55.6% of total members, but there is a change in the classification. In fact Germany is most involved (13.9%) followed by United Kingdom and France (12.3% and 12.1%) are more or less equally involved, while Italy and Spain show similar percentages as before (9.1% and 6.1%).

Similar percentages characterise the distribution of funds (table 2)

To summarise, in order to carry out the empirical analysis described in section 3, we select those 5FP contracts that respond to some geographical, structural and information criteria. First of all we select those contracts that involved (directly or indirectly) the creation of a "network", and whose coordinator was an organisation/institution localised in one of the 109 European regions belonging to the above mentioned 5 large countries, irrespective to the type of coordinator. Finally we selected only those applications whose record was complete (i.e containing information on region's coordinator; on typology of coordinator and on the total amount of EU funds). This selection process produced a final number of 4,566 contracts, about 28% of all contracts financed within the 5FP (table 1) and 64% of the total funding.

## 3. The empirical analyses

Scientific and technological knowledge, leading to patents (and, partly, embedded in), is both created and diffused through some crucial nodes (i.e. universities, research institutions, firms, etc.), which tend to spatially concentrate within excellence centres and high-tech clusters (Swann *et al.*, 1988; Bresnahan *et al.*, 2001; Maggioni, 2002; Braunerhjelm and Feldman, 2006). However, this co-location process may have two distinct effects on the "geography of innovation" at the regional level.

On one hand, each cluster may extend its influence on the neighbouring territories through a trickling down process of spatial diffusion (underlining the role of face-to face contacts, labour force local mobility, and other forms of localised knowledge spillovers). According to this perspective, space matters most.

On the other hand, technological and scientific knowledge developed in the cluster may be diffused and exchanged through a set of a-spatial networks (often structured in formal and contractual agreements between institutions) connecting each cluster with other clusters, irrespectively of the geographical contiguity. According to this perspective, relational networks matter most.

Thus knowledge may either diffuse homogenously through space following an inverse relationship with the distance from the cluster's centre or flows through a complex network of privileged channels.

The aim of these two empirical exercises is therefore to verify the relative importance of the two above mentioned phenomena in order to test whether formal relationships based on a-spatial networks between geographically distant clusters prevail over diffusive patterns based on spatial contiguity.

In order to do so we focus on two knowledge-based phenomena: the participation in a research network (funded within the 5FP) and the patent application at EPO. Through these variables we attempt to measure the intrinsic relational structure of knowledge flows, which directly connects people, institutions and, indirectly, regions across the European countries. In particular the first one detects the impact of networking activity as an input of the innovative process, and the second one measures the networking activity as output.

### 3.1. A gravity model of co-patenting

Patents (and patent applications) are one of the most established output indicators of innovative activities[6]. Since the seminal contribution of Scherer (1965), patents have been used in the economic literature[7] (Grilliches, 1981, 1990), in order to measure knowledge spillovers and other spatial externality effects which, in contrast to what argued by Krugman (1991a), "do leave a paper trail" (Jaffe *et al.*, 1993).

The constitution of the European Patent Office in Munich in 1977 allowed researchers to use a common dataset to analyse the innovative performance of different European countries and regions. In particular Paci and Usai (2000) and Breschi and Lissoni (2004) have developed systematic analyses of patenting activity throughout Europe at different NUTS levels, showing the existence of significant clustering phenomena (whose agglomeration indexes are even higher than those registered by high-tech manufacturing) within a core-periphery geographical pattern.

Later studies investigate patent data as relational variables Breschi and Lissoni (2004 and 2006) use patent citations in order to compare the relevance of spatial proximity as opposed to social proximity in determining the spillover effect of scientific research. Maggioni and Usai (2005) look at patents as a relation between inventors and applicants at NUTS 2 level and study the distributions of these relationships within different European countries searching for industry-specific patterns and testing the hypotheses of a diffused "brain-drain" dynamics.

In Maggioni and Uberti (2005) and in this paper another relational aspect of patents is considered: the co-invention process. Out of a total of more than 170,900 patent applications belonging to every IPC sections (coming from inventors located in the above mentioned 5 countries in the period 1998-2002) – extracted by the CRENOS files based on the original EPO database – we selected only those patents whose applications were recorded by more than one inventor.

Next we split each patent into equal shares attributed to each inventor; and we added these data for each NUTS2 regions in order to build a matrix in which a generic cell *ij* represents the share of patents recorded jointly by inventors located in region *i* and region *j* (where region *i* and region *j* could belong to different nations)[8]. Finally a total of nearly 30,000 co-patents was identified.

Co-invention (and thus co-patenting) is a process involving both tacit and codified knowledge exchanges. For this reason it implies a series of both "face to face" and "over the distance" relationships between inventors. That is why it is interesting to analyse the relative importance of "geographic" versus "functional" distance as forces shaping the interregional (international) structure of knowledge flows networks (Maggioni and Uberti, 2005).

The gravity equation model is an extremely successful tool of empirical analysis to explain social interactions (for example international trade, foreign direct investment, migration, tourism) according to the existence of "attractive" and "impeding" forces.

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[6] "The measure of patented innovations provides a fairly good, although not perfect, representation of innovative activity. This supports the use of patent counts in studies examining technological change" (Acs *et al*., 2002, p. 1070).

[7] Not to forget the wide economic geography and regional science literature.

[8] For example a patent registered by three inventors located in three distinct regions *i*, *j*, and *z*, would be split in $n*(n-1)$ cells and respectively in *i* with *j* and *z*, *j* with *i* and *z*, and *z* with *i* and *j*. Hence a invention co-patented by three individuals in three different regions and is registered with a value of 0.1666 in the cells corresponding to 6 different couplets.

This range of models is derived from the “Law of universal gravitation” proposed by Newton in 1687 stating that “gravitational force between masses decreases with the distance between them”, according to an inverse-square law.

In the economic literature gravitational models are commonly used to explain the actual pattern of international trade flows. Bilateral trade between two countries is proportional to their economic mass (i.e. GDP or population) and inversely related to their geographical distance. These models are successful tool for empirical analysis since the ’60s: the signs of parameters of importing and exporting countries’ GDPs are positive, roughly equal to unity and significant, and the sign of geographical distance is negative and significant (Tinbergen, 1962; Poyhonen, 1963). More recently this empirical success has found solid theoretical bases within different analytic frameworks: from Hecksher-Ohlin-Samuelson, to monopolistic competition, to national (Armington) product differentiation (Anderson, 1979; Bergstrand, 1985; Helpman, 1988; Deardorff, 1998; Feenstra, 2002; Dalgin, Mitra and Trindade, 2004).

In this paper we build a gravitational model which explains knowledge flows embedded in the realisation of a patentable innovation by two inventors living in two generic regions *i* and *j* as a function of a series of attributional and relational variables.

The dependent variable is $CO\_PAT_{ij}$, co-patenting between the period 1998 and 2002, the independent variables are defined as follows.

The set of independent variables includes 2 different sources of R&D expenditure (as percentage of GDP): business R&D expenditure (*BizRD*) and government R&D expenditure (*GovRD*)[9].

Secondly, being a gravity equation framework, we include a variable to measure the role played by geographical distance (between the regions and from the regions to the European “centre”).

We use geographical distances ($GEODIST_{ij}$) among 109 European regions, calculated according to the shortest road distance (in kilometres) between regional “capitals”. In this paper the notion of “regional capital” is arbitrary since NUTS2 level are administrative meaningful entities in Italy, Germany, Spain and France, but not in the UK. In this last case we used population as the selecting criteria to identify the most relevant city (which we called “capital”), irrespective to the presence of an administrative capital[10].

Another important geographical aspect is related to the centrality or peripherality of a region respect to a geographical European centre identified with Brussels: regions distant from Brussels are much more disadvantaged and show worst economic performance. Hence we included the $PERIPH_{ij}$ variable to detect this aspect. This variable considers at the same time the distance of each couplet of regions (11,772 couplets) from Brussels and we consider the minimum value between the two to detect the central advantage played of the most advantaged region[11].

The similarity of the innovative specialisation of two regions ($TECHSIMIL_{ij}$) is measured as the correlation coefficient between the sectoral composition of patent application registered by region *i* and those registered by region *j* at EPO in the same period 1997-2000 (Moreno, Paci, Usai, 2005).

The relational aspect is captured by the co-membership in the same 5FP project. The variable $MEMB_{ij}$ counts the number of joint memberships of regions within the considered subset of 5FP contracts. This variable captures the influence of research networks on the co-patenting activity.

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[9] Due to data availability, either *BizRD* and *GovRD* are calculated as averages for years 1995, 1997, 1999 and 2001. These variables are calculated for region *i* and region *j*, but in table 3 we present only one coefficient for each R&D source due to the symmetry of the database.

[10] For example for Scotland we selected Glasgow instead of Edinburgh.

[11] We replicated the estimation with alternative measures of peripherality (namely the maximum distance and the sum of the distances from Brussels) and obtained almost identical results.

Finally we add some dummy variables: $CONTIG_{ij}$, the geographical contiguity which takes value 1 for contiguous regions (i.e. which share a border), 0 elsewhere; and $d_I$, a dummy variable which is used to control for fixed national effects both on the "emitting" and the "receiving" regions.

We use a double-log specification of the following OLS regression equation so that estimated coefficients can be interpreted as elasticities and is defined as follows:

$$Co\_PAT_{ij} = a_0 + a_1 BizRD_i + a_2 BizRD_j + a_3 GovRD_i + a_4 GovRD_j + a_5 TECHSIMIL_{ij} + \\ + a_6 GEODIST_{ij} + a_7 CONTIG_{ij} + a_8 PERIPH_i + a_9 MEMB_{ij} + d_I + e_{ij} \qquad (1)$$

where $d_I$ indicates country dummies variables and $\varepsilon_{ij}$ is the standard error term.

The independent variables used in the regression presented in table 3 thus measure the role played by private and public R&D, by the degree of technological similarity, by the geography and, finally by the participation to joint research networks in determining the co-patenting activity between two European regions.

The results (illustrated in table 3) show that business R&D is more relevant than government R&D in explaining the variance of the co-patenting activity and that the co-patenting activity of two regions is positively correlated to the degree of technological similarity of their innovation systems.

**Table 3: The gravity equation of co-patents**

Dependent variable: $\text{Co-patenting}_{ij}$ - OLS estimation

| variables | model |
|---|---|
| BizRD | 0.393*** |
| | (0.029) |
| GovRD | 0.042*** |
| | (0.020) |
| $TECHSIMIL_{ij}$ | 0.321*** |
| | (0.154) |
| $GEODIST_{ij}$ | - 1.001*** |
| | (0.040) |
| $CONTIG_{ij}$ | 0.701*** |
| | (0.091) |
| $PERIPH_{ij}$ | -0.591*** |
| | (0.047) |
| $MEMB_{ij}$ | 0.315*** |
| | (0.023) |
| Number of observations | 4,518 |
| F-Test | 383.43 |
| $Adj\text{-}R^2$ | 0.5153 |

Robust standard errors in parenthesis; *** significant at 1%. Country dummies and a constant term were included in all regressions. Their coefficients are always significant but not reported in the table.

In particular a 1% increase of private R&D in region *i* and *j* influences co-patenting activity of about half of a percentage point, but the same increment in government R&D affects co-patenting activity 10 times less (about 0.04%).

The technological similarity of innovation systems of two counties affects positively co-patenting activity. This significance and the sign of this coefficient confirm that innovation and "innovative" relational activities go in the same direction following a path where similar regions match with similar regions.

Although these first results, the analysis confirms that space is an important part of the innovation activity: geographical distance between regions is negatively related to co-patenting (doubling the distance between two regions, reduces the co-patenting activity by one half); and contiguous regions[12] show a higher propensity to co-invention. Furthermore, geographical peripherality does influence negatively the co-patenting activity: two equally distant couplets of regions are likely to have different co-patenting figures according to their distance from Brussels.

Finally, research networks (as proxy of the existence of relational activities) play a, smaller but significantly positive, role in the co-patenting activity. In fact a 1% increase the co-membership affects the co-patenting activity by 0.3%. This confirms that relational innovative activities, as being part of a European research network, affect positively the innovative capacity of a region.

Comparing the coefficients of geographical variables and relational variables emerges relations and distance play important role on the co-patenting activity, but there are important differences. We can therefore conclude that this first empirical exercise may suggest the prominence of spatial spillover dynamics over formal relational networking in determining the knowledge exchange and interactions needed to jointly produce a patentable innovation.

However one may suspect that research contracts are established between contiguous (or proximate) regions, thus weakening the above-mentioned results by blurring the difference between spatial spillovers and relational exchange of knowledge. This suspicion proves to be wrong as shown by the correlation coefficient between $GEODIST_{ij}$ and $MEMB_{ij}$ which is almost null (-0.0744) and the average distance between two randomly selected members of a research network, which is equal to about 800 Km.

### 3.2. Spatial dependence vs. relational dependence in patenting activity

The previous econometric exercise focussed on co-patenting which account for a minimal part of all patenting activity in the 5 largest European countries (30,000 out of 170,900, nearly 18%). The sample is certainly small but not biased, since the "co-patenting" and the "patenting" activity are similarly distributed across European Regions[13].

However in order to have a more complete description of the relevance of relational vs. spatial proximity, we model a second econometric exercise whose object is patenting activity of European regions looking for evidence of spatial and relational dependence in the data.

In doing so we follow a stream of literature, which, based on the seminal contribution of Griliches (1979), examines the knowledge production function from a spatial perspectives. Jaffe (1989) analyses the existence of spatial knowledge spillovers originated by universities and finds that these positive externalities are intrinsically local (i.e. limited in their geographical extent) due to relevance of tacit knowledge in academic relations, which makes scientific and technological knowledge transmissible only through face to face contacts.

This relevance of localised knowledge spillovers has been confirmed by a series of empirical analyses (either at the state or at SMA level) on the US case (Acs *et al.*, 1994; Audrestsch and Feldman, 1996; Anselin *et al.*, 1995). However these papers do not model explicitly the mechanism of knowledge transfer and therefore, as highlighted by Breschi and Lissoni (2001), run the risk of mixing together local knowledge spillovers with other sources of pecuniary externalities.

[12] By using both distance and contiguity variables we are somehow able to take into account the large variance in the size of regions existing within our sample.

[13] The rank correlation between the variables distributions is equal to 1.

Recent papers such as Varga *et al.* (2003), Bottazzi and Peri (2003), Greunz (2003), Bode (2004), Abreu *et. al.* (2005) and Moreno, Paci e Usai (2005) investigate the mechanisms and determinants of the process of creation and diffusion of innovative knowledge, taking explicitly into account both temporal and spatial dynamics through a full set of spatial econometrics techniques.

In order to do so we use a knowledge production function where the dependent variable is the number of patents application per million labour force registered by inventors located in 109 European Regions in year 2002, while the set of independent variables is composed by various types of Research and Development expenditures (R&D), different measures of the specialisation in patenting and production, and different measures of spatial and relational dependence.

Due to the fact that there exists a time lag between inputs and outputs in the knowledge production function (i.e. between R&D expenditure and patent applications), we consider the number of patent application registered at EPO in 2002 while for the independent variables we calculated the average value of the period 1995-2001[14].

The use of different sources of R&D funding (private and public) makes us able to detect which sector (private or public) is mostly involved in the process of creating potentially "marketable" knowledge (leading to an active patenting activity). In particular in the regression we include business R&D expenditure ($BizRD_i$) and government R&D expenditure ($GovRD_i$) expressed as percentage of the regional GDP.

We want also to test whether specialisation (in the regional innovation and production system) influences the patenting activity in general and we calculated both absolute (denoted by SP) and relative (denoted by LQ) specialisation indexes.

$SP\_INN_i$ corresponds to the share of high-tech patents of region *i* respect to the total number of high-tech patents in the nation[15] as follows:

$$SP\_INN_i = \frac{Pat_i^{HT}}{Pat_I^{HT}}$$

where *i* identifies the region, *I* the nation, *HT* the patents in high-technology industries.

Secondly, in order to test the influence of the relative specialisation of the regional innovation system, as compared to the national one, we calculated a traditional location quotient for high-tech patents ($LQ\_INN_i$) as follows:

$$LQ\_INN_i = \frac{Pat_i^{HT}}{Pat_i^{TOT}} \bigg/ \frac{Pat_I^{HT}}{Pat_I^{TOT}}$$

where *i* identifies the region, *I* the nation, *HT* the patents in high-technology industries and *TOT* the total number of patents in all sectors.

In order to measure the relevance of the specialisation of the production structure of each region included, we calculated an absolute and a relative specialisation index: $SP\_PROD_i$ and $LQ\_PROD_i$ by measuring economic activity in terms of the number of local units[16].

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[14] The time series derived from Eurostat database contain some missing data, and this procedure partially allowed us to include valuable data.
[15] Similarly to R&D expenditures, all specialisation indexes are based on the average of the period 1995-2001.
[16] Similarly we compute both absolute and relative specialization index relative to employment, obtaining very similar results (not presented in the paper).

The first index ($SP\_PROD_i$) is the absolute specialisation in high-tech activity of regions in the nations, and is calculated as the share of the number of local units in high-tech sectors[17] in region *i* respect to the total number of local units in high-tech sector in nation *I*. Formally:

$$SP\_PROD_i = \frac{LU_i^{HT}}{LU_I^{HT}}$$

where *i* identifies the region and *I* the nation, $LU^{HT}$ identifies the total number of local units in high-tech sector.

The relative specialisation of the regional production system in high-tech industries is calculated as a location quotient relative to local units in high-tech sectors ($LQ\_PROD_i$) is calculated as follows:

$$LQ\_PROD_i = \frac{LU_i^{HT}}{LU_i^{MAN}} \Big/ \frac{LU_I^{HT}}{LU_I^{MAN}}$$

where all variables are as above except $LU^{MAN}$ which identifies the total number of local units in manufacturing in the region (*i*) (or in the nation if *I*)[18].

Further we include an attributional quantitative variable relative to the Fifth Framework Programme, $MEMB_i$ that corresponds to the total number of 5FP networks a region *i* was involved as member.

Finally to detect not only the role of geographical distance, but most of all the role by the peripherality, we included a geographical variable, $PERIPH_i$, that indicates the distance of a region from Brussels.

In order to measure the relative importance of spatial versus relational dependence in the patenting dataset we use spatial econometrics techniques based on two different contiguity matrices: a geographical/spatial (spa) and a relational one (rel).

The geographical matrix, in spatial econometrics is called the contiguity matrix $W^c$, whose elements $w^c_{ij}$ are 1 if regions *i* and *j* share a common border and 0 otherwise.

The relational matrix is built on the scientific relations among regions participating on 5FP. In the relational matrix $W^r$ the elements $w^r_{ij}$ are one 1 if regions *i* and *j* share a relevant level of research programmes and 0 otherwise. The relational matrix was built according to a network, as defined within the 5FP. This binary matrix was created following a complex procedure. Once labelled each coordinator and members according to the region of localisation, we defined a squared matrix of relations containing the number of relations between each couplet of regions and we symmetrised it. Since the resulting matrix was too dense (almost each region had scientific relation with nearly every other region) we decided to dichotomise the matrix by taking as threshold value the average number of partners each region had in all the contracts in the dataset (equal to 7).

With spatial error models[19] we tested two equations that contain different measurements of innovative and production specialisation.

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[17] In this analysis the high-tech sector includes the following sectors of NACE classification Rev. 1.1: DL30 (Manufacture of office machinery and computers); DL32 (Manufacture of radio, television and communication equipment and apparatus); DL33 (Manufacture of medical, precision and optical instruments, watches and clocks).

[18] Similarly to R&D expenditures data, these indexes are calculated as average of the available data within the period 1995-2001.

[19] See below tests for the LM test for model specification.

The equation, in double-log, takes into account location quotients and is as follows:

$$PAT_i = b_0 + b_1 BizRD_i + b_2 GovRD_i + b_3 INN_i + b_4 PROD_i + b_5 PERIPH_i + \\ + b_6 MEMB_i + l W_i e + x_i \qquad (2)$$

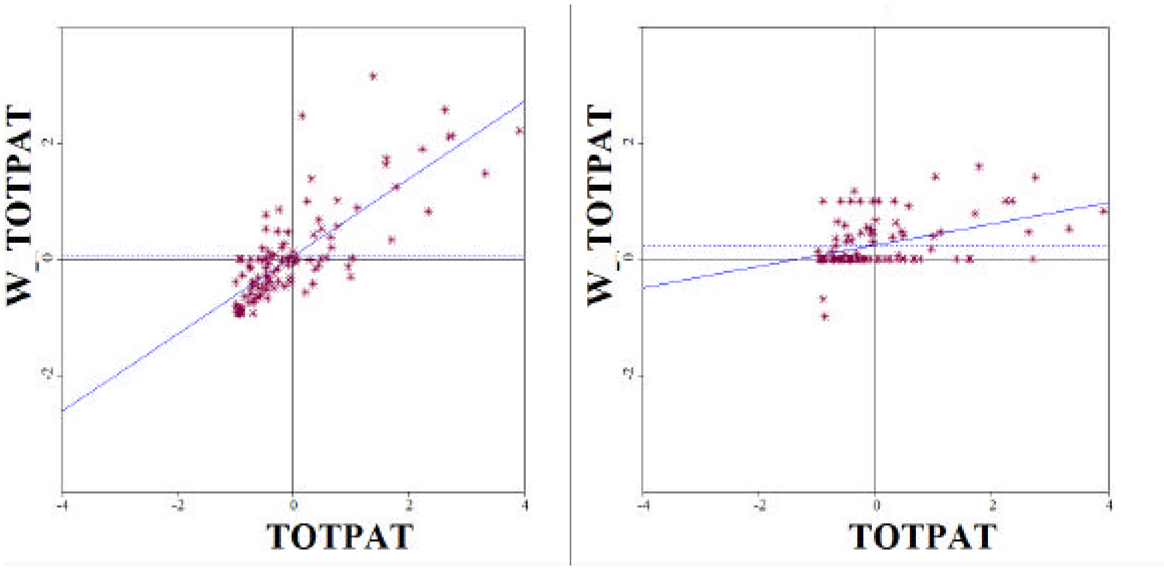
where explicative variables are those defined above, and $INN_i$ is either the absolute ($SP\_INN_i$) or relative index ($LQ\_INN_i$) to verify the specialisation of the innovation system; $PROD_i$ is either the absolute ($SP\_PROD_i$) or relative index ($LQ\_PROD_i$) to verify the specialisation of the production system; spatial effects are accounted through the autoregressive coefficient (λ) and the spatial lag for the errors (Wε). $x_i$ is the standard error term.

Before concentrating on the estimations we analyse the degree of autocorrelation of patents considering spatial and relational matrices. Spatial indexes measure the autocorrelation between the dependent variable and its spatial dimension[20]. In order to detect and test the existence of spatial autocorrelation in our sample, a global (Moran's I) and a local (LISA) indexes are calculated.

The Moran's I, a measure of global spatial autocorrelation or overall clustering, allows estimating the strength of spatial autocorrelation in data distribution. Although Moran's I is very powerful in detecting the degree of spatial autocorrelation, it tends to average local variations, missing the local dimension of spatial autocorrelation. Hence a second local index of spatial autocorrelation is computed: the LISA (Local Indicators of Spatial Association) index which indicates the presence, or absence, of significant spatial clusters or outliers for each location allowing the identification of "hot-spots"[21] areas (Anselin, 1988).

Moran's I statistics show positive and significant (at 1%) coefficients for both matrixes.

**Figure 1: Moran Scatterplot of patenting activity**




Spatial matrix
Moran's I': 0.6672

Relational matrix
Moran's I': 0.1822

[20] In this analysis the autocorrelation is computed between patents (dependent variable) and the geographical/spatial lag and between patents and the relational lag.

[21] As well as "cold-spots".

Looking at the Figure 1, we can see clearly that while high-patent and low-patent tend to form isolated homogenous clusters (suggesting the existence of a polarised structure of the innovation system within our sample), the European scientific networks financed within the 5FP are preferably composed by a mix of high and low patenting regions.

These first results seems to indicate the presence of geographical spillovers and the second put forward that European scientific nets tends (are supposed) to be more heterogeneous.

Looking at local autocorrelation (LISA) maps (figures 2 and 3), we can discriminate again between the result obtained with geographical map and relational map.

**Figure 2: LISA cluster map of patenting activity (Spatial matrix)**

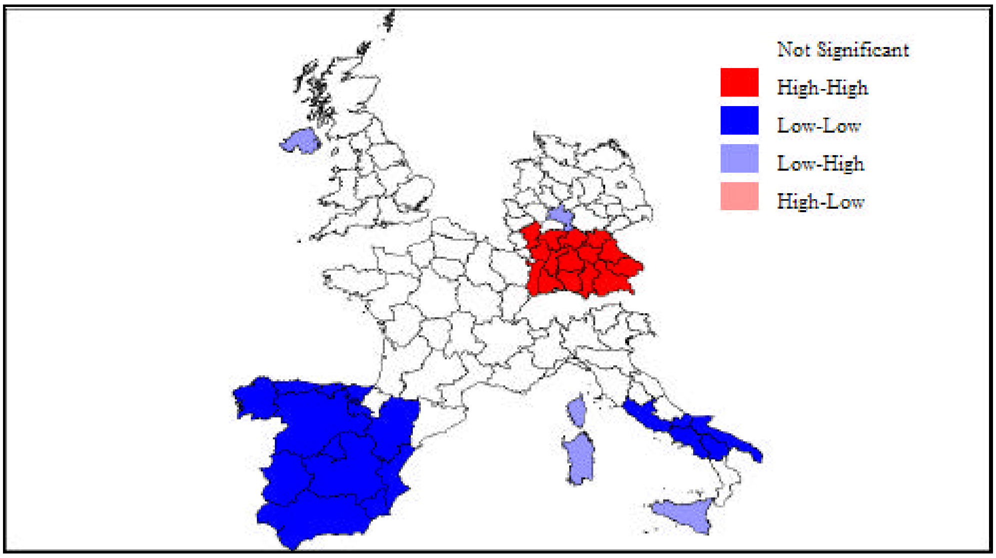
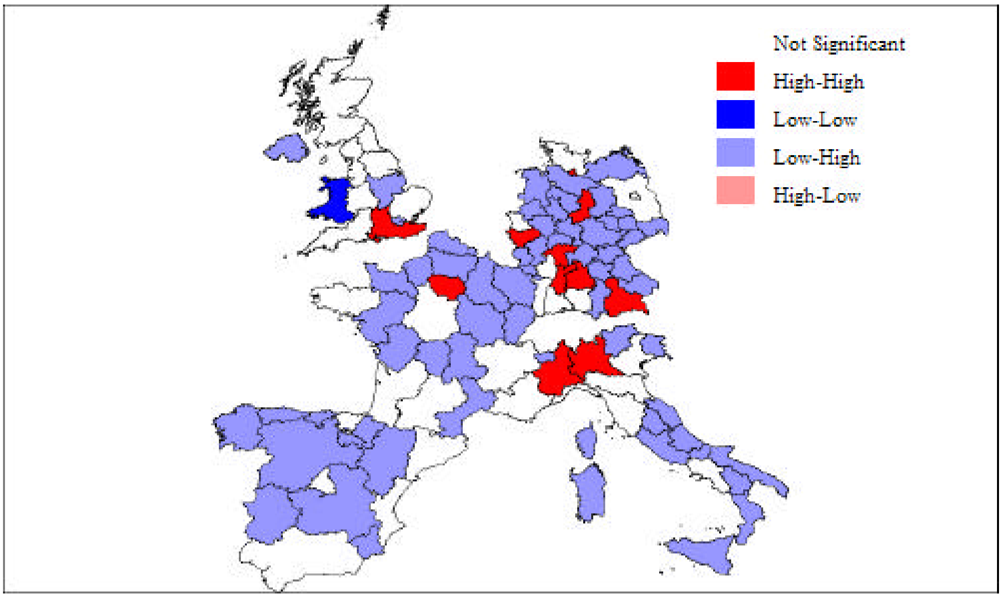



**Figure 3: LISA cluster map of patenting activity (Relational matrix)**




In the first case (Figure 2) a "stronger" cluster characterise some German regions, while the two "weak" clusters involve Italian and Spanish Regions. In the second case (Figure 3) the "stronger" relational clusters regards a subset of advanced European regions which, even if are geographically dispersed, are connected by a very dense relational network constituted by a high number of joint memberships in the same relevant contracts.

Standard spatial econometric theory offers a well consolidated methodology to detect spatial dependence in error terms, which, in particular, captures neighbouring effects on the dependent variable.

Table 4 shows the results of the spatial econometric analysis of the patenting activity of the 109 European regions included in our sample.

## Table 4: Patenting activity: spatial vs. relational dependence

Dependent variable: $Patent_i$ - ML estimation – spatial error technique
rel = relational contiguity matrix; spa = spatial contiguity matrix

| | OLS Specification 1 | | Spatial Error model | | OLS Specification 2 | | Spatial Error model | |
|---|---|---|---|---|---|---|---|---|
| Variables | | | (I rel) | (I spa) | | | (II rel) | (II spa) |
| CONST | 10.82*** | | 10.37*** | 10.94*** | 10.26*** | | 10.20*** | 9.52*** |
| $BizRD_i$ | 0.51*** | | 0.51*** | 0.38*** | 0.63*** | | 0.62*** | 0.52*** |
| $GovRD_i$ | -0.04 | | -0.06 | -0.09 | -0.15 | | -0.17* | -0.22** |
| $LQ\_INN_i$ | | | | | 0.18 | | 0.18* | 0.16 |
| $LQ\_PROD_i$ | | | | | 0.54* | | 0.53** | 0.24 |
| $SP\_INN_i$ | 0.41*** | | 0.41*** | 0.33*** | | | | |
| $SP\_PROD_i$ | -0.28* | | -0.30* | -0.13 | | | | |
| $PERIPH_i$ | -0.58*** | | -0.54*** | -0.64*** | -0.73*** | | -0.73*** | -0.75*** |
| $MEMB_i$ | -0.19 | | -0.17 | -0.13 | -0.04 | | -0.02 | 0.01 |
| Lambda | | | 0.36* | 0.70*** | | | 0.25 | 0.60*** |
| | | | | | | | | |
| Observations | 109 | | 109 | 109 | 109 | | 109 | 109 |
| $R^2$ | 0.68 | | | | 0.53 | | | |
| Log-Likelihood | -125.45 | | -123.32 | -116.57 | -146.75 | | -144.93 | -136.94 |
| | | | | | | | | |
| | (rel) | (spa) | (rel) | (spa) | (rel) | (spa) | (rel) | (spa) |
| Moran's I | 0.11*** | 0.27*** | | | 0.14*** | 0.28*** | | |
| LM Lag | 1.31 | 11.59*** | | | 0.6 | 10.08*** | | |
| LM Error | 7.11*** | 15.76*** | | | 10.46*** | 16.96*** | | |
| Likelihood ratio test | | | 4.27** | 17.76*** | | | 3.64* | 19.63*** |

* significant at 10%, ** significant at 5%, *** significant at 1%.

The coefficient of $BizRD_i$ is always positive and significant (as found in the previous exercise), while the coefficient of $GovRD_i$ is generally negative. If one compares these result with those of table 3 one can derive that publicly funded R&D addresses very basic types of research which rarely produce patentable (or patented) results[22] but which is much more keen on cooperation and collaboration between different institutions.

[22] We should remember that these countries face very different institutional frameworks, concerning the commercial exploitation of academic and public research.

The two sets of specialisation indexes applied to both the innovation and the production systems at the regional level show that both the absolute ($SP\_Pat_i$) and the relative specialisation ($LQ\_Pat_i$) of the regional innovation systems in high-tech sectors produces higher number of patents per head. This result does not hold for the specialisation of the production systems: having a larger share of the national high-tech industries ($SP\_Prod_i$) does not grant a region a higher per capita patenting activity (coefficients are negative or insignificant), while a relative specialisation ($LQ\_Prod_i$) in the same sectors gives a comparative advantages in terms of patent propensity and activities.

The negative and always significant coefficient of $PERIPH_i$ confirms the existence of a polarised "core-periphery" structure of the European innovation system. The farer the region from Brussels, the lower the number of patent per million labour force registered. This confirms the results showed in figures 1, 2 and 3.

The coefficient of the $MEMB_i$ variable is not significant. This shows that it is not really important for a region to be part of a large number of networks in order to be innovative; but, what is important is to be part of the most relevant networks, i.e. to be connected to other relevant regions.

This result is confirmed by the specific spatial econometric analysis, which is performed for each model on two contiguity matrix: a relational and a spatial one.

The first statistics used to achieve this aim is the Moran's I statistics, which detects the general presence of spatial dependence in our model.

From the bottom lines of Table 4 it emerges quite clearly that the Moran's I statistic is significant for all four model specifications, thus signalling both the presence of spatial and relational dependence and the impossibility to use standard OLS estimation techniques[23].

In order to choose the best model for spatial dependence correction we follow Anselin and Florax (1995) considering Lagrange Multiplier (LM) tests for spatial error and spatial lag dependence and their robust counterparts. In Table 4 we presents results for the spatial error specification.

Results on fitting are positive as it is the case of Likelihood ratio tests – provided in Table 3 - which is always significant, suggesting that these estimations presents a better fit than standard regression models. In the same way, AIC (Akaike Information Criterion) and SC (Schwartz Criterion) asses that the spatial error models adopted reveal a better fitting than spatial lag models.

Koenker-Basset and White test exclude the presence of heteroskedasticity in the specifications with the spatial matrix but not for the relational matrix. These results may depend on the very particular nature of the relational weight matrix since one must bear in mind that heteroskedasticity is "frequently encountered in spatial analysis when there are irregular units and relationship being modelled are different in different places" (Law and Heining, 2004, p.37).

Models (I spa) and (II spa) take into account the spatial interaction existing between the value of the dependent variable in a given region and the value of the same variable registered in the neighbouring regions. The *lambda* coefficient (which derives from the spatial error specification of the model) is always positive and highly significant, thus confirming the empirical results of the established literature: patenting activity in a given region benefits from positive performance of its neighbours.

Models (I rel) and (II rel) take into account the relational structure driving from the participation to the same networks within the 5FP in order to test whether there are significant interaction existing between the value of the dependent variable in a given region and the value of the same variable registered in the relationally connected regions. The lambda coefficient is positive but smaller and not significant in one case.

[23] OLS residuals are spatially autocorrelated.

Such a result may be interpreted as a prevalence of spatial spillover effects over the alternative structure based on a-spatial and hierarchical networking, as a prominence of tacit knowledge diffusion with respect to explicit knowledge exchange in the phase of the scientific and technological research process leading to a patentable innovation.

However this may be not necessary the case. Since one of the main objective of EU policies is to reduce geographical imbalances and strengthen the degree of regional cohesion, it may well be the case of a selection bias within the 5FP aimed and supporting research networks involving rich and poor regions, advanced and laggard ones, central and peripherical.

If this is true, then it become easy to understand why data on relational contiguity give feeble signals as compared to spatial contiguity. Two counteracting forces are at play. Autonomous regional decisions will push research institutions located in central and advanced regions to establish exclusive networks, but in order to maximise the probability of being selected, research institutions look for excellent partners located in peripheral and laggard regions.

## 4. Conclusion

Between the end of the '80 and the beginning of the '90, in the field of economic theory endogenous growth literature highlighted the role played by human capital and R&D in determining growth performance of economic systems (Romer, 1986; Lucas, 1988). Similarly, new economic geography showed that market forces may produce heavily polarised spatial distribution of economic activities (Krugman, 1991b).

In addition, European institutions triggered adopting the so-called Lisbon Strategy. In March 2000 the European Council held a special meeting in Lisbon to "agree a new strategic goal for the Union in order to strengthen employment, economic reform and social cohesion as part of a knowledge-based economy" (European Commission, 2000). To achieve this goal, the European Council put forward a threefold strategy whose first and main pillar aimed at preparing the EU for a knowledge-based economy and to adopt the necessary structural reforms to improve competitiveness and innovation.

Nowadays, although the celebrated Lisbon strategy's claim has been seriously criticised and partially reconsidered, it is not possible to deny its merit: having focussed the attention on the relation between scientific excellence, technological primacy, trade and production performance, on the one hand, and the trade-off between internal cohesion and external competitiveness, on the other hand.

Recent empirical literature demonstrates that scientific and technological knowledge, which leads to (and, partly, is embedded in) patents, is both created and diffused through some crucial nodes (i.e. universities, research institutions, firms, etc.), which tend to concentrate spatially within excellence centres and high-tech clusters (Swann *et al.*, 1988; Bresnahan *et al.*, 2002; Maggioni, 2002; Braunerhjelm and Feldman, 2006). However, this co-location process may have two distinct effects on the "geography of innovation" at the regional level: a geographical effect and a relational effect.

On one hand, each cluster might extend its influence on the neighbouring territories through a trickling down process of spatial diffusion (underlining the role of face-to face contacts, labour force, local mobility and other forms of localised knowledge spillovers). According to this perspective, space matters most.

On the other hand, technological and scientific knowledge developed in the cluster may be diffused and exchanged through a set of a-spatial networks (often structured in formal and contractual agreements between institutions) connecting each cluster with other clusters, irrespectively of the geographical contiguity. According to this perspective, relational networks matter most.

This paper investigates both phenomena and tests whether formal relationships based on a-spatial networks between geographically distant clusters prevail over diffusive patterns based on spatial contiguity and two empirical exercises have been performed.

In the first exercise we build a gravitational model which explains knowledge flows embedded in the realisation of a patentable innovation by two inventors living in two generic regions (i.e. co-patents) as a function of a series of attributional and relational variables. According to this test, the significant variables in explaining the structure of co-patents are business and public R&D expenditure and the similarity of innovative structure of the regions. Geography plays a relevant role in this relational activity: spatial proximity and geographical centrality (with respect to Brussels) are always significant in determining the co-patenting activity.

In the second exercise, using spatial econometrics techniques, we tested a knowledge production function, which explains the number of patents application as function of a set variables (i.e. different sources of R&D expenditures and various measures of specialisation of the regional innovation and production system), to measure the degree of spatial and relational autocorrelation of the dependent variable. The estimation confirms the main results of the literature on innovation activity: the crucial role played by the R&D expenditure, although in this exercise the private expenditure is much more relevant in patenting activity (this is probably due to the market oriented activity of industrial sector, opposed to basic research activity performed by public sector) and by the relative specialisation in high-technology sectors.

In both empirical exercises we introduced different variables derived from the 5FP database to measure the influence of scientific networking on regional innovation outcomes. In both cases (when network membership is considered an independent variable and when it is used to build an alternative contiguity matrix), the participation in 5FP research networks have positive impacts in regional innovative activity, despite some crucial limitations.

These research networks may have not fully supported European competitiveness and economic performance. This could be partially explained, on one hand, by the fact that most collaborative research has been undertaken in the “pre-competitive’’ phase of the research process[24] and, on the other, by the fact that the private sector is only marginally involved in the 5FP[25].

But the most relevant function of Framework Programmes lies in the creation of dynamic networks bringing together researchers from laboratories scattered in European firms, universities and other research institutions, providing access to complementary skills, and reducing the degree of excessive competition among researchers and the duplication of research efforts.

We should also consider the incentives structure that affects the choice of partners in a 5FP application. In fact two important and counteracting forces are involved: on one hand actors want to collaborate with institutions located in central and advanced regions to establish exclusive research networks and to create excellence centres; but on the other hand, in order to maximise the probability to be funded, actors look for those partners located in peripheral and laggard regions.

In conclusion the paper has shown that relational networks, here proxied by with 5FP membership, influence the behaviours of regional innovation systems, but that spatial proximity plays a more relevant role in determining their performance.

[24] “Too often successful projects did not produce marketable results, either because they have been isolated from market and social considerations despite their technical excellence, or because the means by which they were to be exploited were not specified or even thought about at the earliest stagesof work’’ (European Commission, 2001).

[25] As confirmed by the percentage of industrial coordinators involved (equal to 6%), a negligible percentage if compared to the incidence of educational and research sector (27%).

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