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GEOGRAPHICAL AND SECTORAL CLUSTERS OF INNOVATION IN EUROPE

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GEOGRAPHICAL AND SECTORAL CLUSTERS OF INNOVATION IN EUROPE

Abstract
In this paper we attempt to provide empirical evidence on the phenomenon of cluster agglomeration of innovation activities throughout time and space in European regions. More specifically we try to assess whether there are some forces which support the development of technologically specialised regional clusters. In particular we want to determine the spatial extent of these forces, their dynamics along the eighties and nineties and their connection with production clustering. We have started from a mapping of innovation activity in European regions by means of a deep exploratory spatial analysis based on several global indicators of spatial dependence. As a result, in a second step, while controlling for the extent to which the specialization of production in certain sectors influences the specialization of innovation, this paper analyses the role which geographical knowledge spillovers play in innovation concentration in some industries. In other words, after the geographic concentration of production has been controlled for, we address the role that the development of technologically specialised clusters in neighbouring regions may play. The analysis is based on an original statistical databank set up by CRENoS on regional patenting at the European Patent Office spanning from 1978 to 2001 and classified by ISIC sectors (3 digit) and on the Cambridge Econometrics database on production activity.

Keywords: Innovation activity, production specialisation, Spatial analysis, European regions.

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1. Introduction[1]

The "First Action Plan for Innovation in Europe", launched by the European Commission in 1996, clearly states that, in spite of its excellent scientific capabilities, Europe's level of innovation is lower than that of its main competitors. At a time when innovation is the main driving force in economic competitiveness (as asserted also by the tradition of economic growth models starting from Romer, 1986), this has serious implications for employment and economic prosperity in Europe. Innovation has therefore become a priority of European countries in order to start and sustain the engine of economic growth.

In the spatial context such an engine may be fuelled both by the amount of technological activity which is carried out locally and by external technological achievements channeled through information spillovers (Martin and Ottaviano, 2001, Grossman and Helpman, 1991). Spillovers may follow particular patterns depending on economic, technological and geographical distances among firms and regions, that is, on agglomeration phenomena which apply both to production and innovation activities. The extent of spatial agglomeration of technological activities and its relationship with production activities is the main object of analysis in this paper.

As a matter of fact, economic growth, technological change and urbanisation have been, in the past, and are, nowadays, inseparable phenomena (see Baldwin and Martin, 2003). Most importantly, in recent years, an increasing concentration of innovation activities in and around major urban centers has been noticed (Audretsch and Feldman, 1996) while other studies have highlighted that innovation is much more polarized than production (see for example Paci and Usai, 2000, for the case of European regions). The increasing costs of conducting advanced

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applied research, the concentration of large firms, public research centers, top universities, and highly skilled human capital in large urban agglomerations are factors that have contributed to this polarization. Most importantly learning processes may be facilitated when economic actors have the possibility to communicate face to face (Von Hipple, 1994). At the same time, according to the line of research started by Coe and Helpman (1995) and refined by Keller (2002), there may appear important informational spillovers across nations, due to the fact, for example, that the transmission of knowledge in space is becoming less costly as a result of advances in telecommunications. As a matter of fact, Moreno et al. (2004) for Europe and Varga et al. (2003) for the USA have shown that innovative activity in a certain region may be affected by similar activities in contiguous regions. Consequently, the spatial extent of such a process of polarization is an empirical question which should embrace a much more complex picture that one of simple concentration or delocalisation. A picture which is a combination of both phenomena contingent on factors such as countries' institutional context and sectoral characteristics which may affect in different ways, among others, capital and labour mobility and local human capital accumulation (Mariani, 2002).

In particular, in this scenery one has to consider the relationship between the localization process of innovation activities and that of production. There are, as a matter of fact, costs and benefits of doing research close to production and the net result may not compensate the advantages of concentrating it in the areas with strong local technological economies. Again the trade off is contingent on a number of factors which attain, for example, to the scientific content of the research and/or the relative factor intensity of the production process.

This paper aims at studying the phenomenon of agglomeration and specialisation of innovative activities and its relationship with the agglomeration of production activities starting from a mapping of innovative performance in European regions by means of an exploratory spatial investigation. The analysis is carried out for different time periods starting from the early eighties up to the beginning of the 21st century and it is implemented for different sectors in order to evaluate differences and similarities across them. Accepting and finding evidence in favour of the presence of common specialization patterns in production and innovation does not exclude that spillovers may also occur across other than within borders. We neither believe that externalities are nor totally localized neither totally global and we expect them to depend on the geographical distance among regions. Following these lines, in a second step, while controlling for the extent to which the specialization of production in certain sectors influences the specialization of innovation, this paper analyses the role which geographical knowledge spillovers play in innovation concentration in some industries. In other words, after the geographic concentration of production has been controlled for, we address the role that the development of technologically specialised clusters in neighbouring regions may play. Econometric techniques are going to allow us to assess the presence and strength of such phenomena.

The analysis is performed at the regional level given that, on the one hand, innovation policies are often implemented at this territorial level (even though within a national framework); on the other hand because, as noted above, technological activities appear strongly localized into clusters of innovative firms. As argued by Storper (1995, p. 896) this is, as a matter of fact, the geographical level "at which technological synergies are generated and to which any national technology policy must therefore be addressed". As a result, even accepting that there is need for a global approach to innovation, we try to handle it by considering important diversities across nations, regions, sectors and time. This aspect is addressed directly thanks to an original and updated statistical databank on regional patenting at the European Patent Office spanning from 1978 to 2001 and classified by ISIC sectors (up to 3 digits). This database allows the analysis of the spatial distribution of innovative activity across 175 regions of 17 countries in Europe (the 15 members of the European Union plus Switzerland and Norway) in a set of 7 manufacturing sectors.

The paper is organised as follows. In the following section we provide a discussion on the quality of the indexes used in this paper. The third section analyses the spatial distribution of innovative activity and specialization patterns throughout Europe along the eighties and nineties. In the fourth section we estimate a model of specialization patterns in which knowledge interactions are included. Final remarks are in the last section.

2. Some issues about technology measurement

Several contributions in the past have made extensive use of patent statistics in order to analyse the spatial distribution of innovation activity. In particular, in the case of European regions Breschi (2000) and Caniels (2000) have provided an articulated and extensive analysis of the spatial distribution of innovation in European regions until the nineties whilst Paci and Usai (2000) have tried to address the same issue of agglomeration of innovation and production for a smaller set of countries. These precedents should not let one forget that the use of patents as indicators of innovative activity implies some inconveniences and shortcomings which ought to be kept in mind while interpreting the outcome of the analysis, both descriptive and econometric.

Several economists (for instance, Pavitt, 1982 and Griliches, 1990, among others) have been debating about the issue of measuring innovative activity and technological progress, but no universal solution has been found. Based on the concept of knowledge production function two types of indicators are usually identified: technology input measures (such as R&D expenditure and employees) and technology output measures (such as patents and new product announcements).

The main drawback of the former indicators is that they embrace firms' efforts for invention and innovation together with imitation activities. Moreover, they do not take into account informal technological activity and, as a consequence, may underestimate the amount of innovative activity. On the contrary, the latter represents the outcome of the inventive and innovative process even though there may be inventions which are never patented as much as patents which are never developed into innovations. However, the patenting procedures require that innovations have novelty and usability features and imply relevant costs for the proponent. This implies that patented innovations, especially those extended in foreign countries, are expected to have economic value, although highly heterogeneous.

With respect to the object of our research[2], that is to study innovative activity across regions, sectors and time, patent statistics seem particularly suitable, due to some useful properties with respect to R&D data which are summarised below:

(a) They provide information on the residence of the inventor and proponent and can thus be grouped regionally (potentially at different territorial units starting from zip areas), whereas R&D statistics are available just for some regions or at the national level

(b) They record the technological content of the invention and can, thus, be classified according to the industrial sectors whilst R&D data is usually aggregated, especially at the regional level3

(c) They are available year by year for a long time span and this allows for a dynamic analysis, on the contrary

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[2] Note that since 2000 there is an important initiative called European trend chart on innovation which provides several indicators on innovation (based on input and output data and on the CIS survey) at the regional level and a synthetic measure of them. Unfortunately, the time and the sectoral dimension of such a database are rather limited. Nevertheless for the time being this database is going to become more and more a crucial point of reference for the analysis in this field.

[3] It should be noted that R&D statistics provide other interesting information concerning the origin of the expenditure. R&D statistics are, as a matter of fact, usually divided into categories such as business, university and government.

regional R&D data is available only for recent years and discontinuously

Our proxy for innovative activity refers to patents applications at the European Patent Office over the period starting from 1978 until 2001 classified by the inventor's region in Europe. Applications at EPO should provide a measure of sufficiently homogenous quality, due to the fact that applying to EPO is difficult, time consuming and expensive. This indicator, in other words, should prove particularly effective in order to take into account potentially highly remunerative innovations which for this reason are patented abroad. The use of the inventor's residence, rather than the proponent's residence, is preferred in order to attribute the spatial localisation of each innovation (Paci and Usai, 2000, Breschi 2000). Indeed, the latter generally corresponds to firms' headquarters and therefore it might lead to an underestimation of peripheral regions' innovative activity whenever the invention has been developed in a firm's subsidiary located in another area.[4] Moreover, differently from previous research (Bottazzi and Peri, 2003) we do not assign patents just to the first inventor, given that this may bias our result as inventors are usually listed in alphabetical order. For the case of patents with more than one inventor, therefore, a proportional fraction of each patent is assigned to the different inventors' regions of residence.

As for the territorial break up we have only partially followed the classification provided by EUROSTAT through

[4] For instance, the headquarter of Enichem, the Italian petroleum and chemical multinational, is located in Milan (Lombardia) but the innovative activity (as indicated by the residence of the inventors) is much more dispersed due to the presence of several plants in other regions (e.g. Veneto, Sicilia, Liguria and Sardegna).

NUTS (*Nomenclature des Unités Territoriales Statistiques*)[5]. For some countries, this classification turns out to be artificial, based mainly on statistical concerns while failing to identify uniform regional areas in terms of economic, administrative and social elements. In fact, we have tried to select, for each country, a geographical unit with a certain degree of administrative and economic control.[6] The result is a division of Europe (15 countries of the European Union plus Switzerland and Norway) in 175 sub-national units (which, from now on, we will simply call, *regions*) which are a combination of NUTS 0, 1 and 2 levels (see Appendix for details).

As far as the sectoral classification is concerned, it is known that patent data are still of minimal use for economic analysis due to their mode of classification: innovations are recorded for administrative purposes using the International Patent Classification (IPC) system, which categorizes inventions by product or process. On the contrary, most economic analyses are interested in the particular sectors of the economy originating the invention or implementing it. For this reason patent data, originally classified by means of the IPC, have been converted to the industry of manufacture thanks to the Yale Technology Concordance[7] [see in Evenson (1993) and Evenson and Johnson (1997)]. Such a concordance uses the probability distribution of

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[5] Eurostat classification list four categories of territorial units: 15 NUTS 0 nations; 77 NUTS 1 regions, 206 NUTS 2 regions and 1031 NUTS 3 regions.

[6] The perfect territorial unit is difficult to be found since administrative units do not necessarily reflect economic phenomena. Better territorial units used in the empirical literature are the functional urban region just for main urban centres at the European level (Cheshire, 1990 and Cheshire and Magrini 2000), the local labour system in Italy (Paci and Usai, 1999) or the *basin d'emploi* in France (Combes, 2000).

[7] The original YTC was conceived by Evenson, Kortum and Putnam. Updates to the YTC have been programmed by Daniel Johnson who kindly provides downloadable conversion tables and detailed explanations on the procedures at the Internet address: http://faculty1.coloradocollege.edu/~djohnson/jeps.html.

each IPC or product code across industries of manufacture in order to attribute each patent proportionally to the different sectors where the innovation may have originated.

3. The geography of innovative activity

3.1 Mapping of innovation in Europe

At the beginning of the period under consideration (early eighties) a strong central-periphery distribution of innovation activity is observed (Map 1a).[8] Innovation activity is mainly concentrated in the very core of Europe, a cluster of regions which includes the whole of Switzerland, West Germany, Luxembourg and most regions of Austria. There are also some other dark spots of innovation in the North and East of France, the South-East part of United Kingdom, in the Netherlands and in some Scandinavian countries, mostly in Sweden. None or modest technological activity is documented in most regions of the South of Europe: Spain, Greece, Portugal and South of Italy. Innovative backwardness is also documented for some northern countries such as Norway and Ireland.

This picture is confirmed looking at the innovative activity at the country level (Table 1) and among the twenty most innovative regions at the beginning (Table 2a) and at the end of the period under analysis (table 2b). At the beginning of the eighties the most innovative country is by far Switzerland, with 14.5 patents per 100.000 inhabitants, followed by Germany (8.3) and Luxembourg (7.2). A similar picture appears at the regional level, where, among the top performers, we find six Swiss regions, nine German regions, two Swedish regions, Luxembourg and Ile de France (which hosts Paris) and Zuid Nederland (where Philips HT research center is located).

Looking at the evolution over time of the innovative activity, it is possible to remark some important elements. First, the intensity to innovate has increased considerably over the two decades in all

[8] Throughout the paper patents per capita are used, even though main results do not change if one uses the absolute value of patents.

countries: the average innovative output was 3.6 patents per 100,000 inhabitants in the early eighties and it was almost three times bigger (10.4) at the end of the nineties.[9] As regards the level of inequality in the spatial distribution of the innovative activity, this is clearly very high: the ratio between the most innovative country (Switzerland) and the least (Portugal) is equal to 245. The coefficient of variation reported in the last columns of table 1 both for nations and regions shows that the former has gone from 1.05 to 0.71 and the latter from 1.46 to stabilize around 1.04 in the last period. Most importantly, the innovations have been spreading to some more regions starting from the core described above. It is clear that such a phenomenon has involved mainly the whole of France, Belgium, Denmark, the North of Italy, a few Northern regions in Spain and most importantly the South Finland and almost the whole of Sweden (see Map1b, c, d).

Figure 1 allows having some detail concerning the process of divergence/convergence of innovative activity across the 175 regions both for the total of manufacturing and for some sectors. In general, the coefficient of variation in the patenting activity among the 175 regions for the Manufacturing and the energy sector is around 1.6 in 1981 but descends gradually to around 1.00 at the end of the period (see the top-left panel in figure 1). Such a regular decline in the geographical concentration of innovative activity is a common feature of some macro-sectors, such as Electronics and Fuels, chemical and rubber. In some other sectors, such as Food, beverages and tobacco, Mining and energy supply and Transport equipment, there appear to exist some changes along time, although with a common feature of lower values for dispersion at the end of the period, while the residual sector of Other manufacturing (together to the one of Construction) shows a rather constant pattern throughout the period.

One other way to look at the dynamics of spatial diffusion of technological activity is to analyse the distributions of the patents per capita through the kernel density functions for the four periods under examination, as reported in Figure 2. It is clear that the distribution is

[9] This phenomenon is partly due to a shift of patent applications by European firms from National patenting offices to the European one.

skewed to the lower values of patents during all the period under consideration, whereas the outliers are in the upper band of patents (basically some regions in Switzerland and Germany). However, the kurtosis is much clearer at the beginning of the 80s, with a clear smoothing process in late 80s and mid-90s, so that the right-hand tale becomes thicker, in other words, more regions are obtaining output in the innovative activity.

This pattern is the result of different performances by countries and regions: there has been some catching up as much as some falling behind. For example among the catching up process, it is worth highlighting the most brilliant one shown by Finland, which in the nineties manages to reach the fourth position in the country ranking (Table 1) and to put its capital region among the first producers of innovation in Europe. The Finnish region Uusimaa was 49th at the beginning of the eighties and sixth at the end of the nineties, originating one of the most remarkable catching up performance in Europe in the last twenty years (see table 2b) .

The comparative examination of table 2a and 2b, moreover, is rather informative about the relatively great reshuffle of regions. Table 2a for example tells us that even though 14 out of 20 innovative regions have managed to keep a ranking among the twenty most innovative regions from 1981-83 to 1999-01, there have been some remarkable declines (that of Luxembourg which goes from the 20th place to 44th). Most interestingly, table 2b tells us that 15 regions which are in the top20 in the latest period were already there in the early eighties. However there are some interesting stories to pinpoint, other than that of Uusimaa. Stutgart and Zuid Nederalnd, for example, were in the 13th and 18th position and are now second and fourth. Voralberg (that is the most western Austrian region in between Switzerland and Germany) was 64th and it is now 14th.. All in all, table 2 illustrates that among the top regions the German leadership has been strengthened (11 regions out of 20 are German) whilst the Swiss regions have lost some ground (they were 6 and they are now 4).

Among the declining countries the most remarkable cases are the one of the United Kingdom which goes from the seventh to the eleventh position and the one of France which moves from the sixth to the tenth ranking. It should be, however, noted that the two cases are different since in the latter there are still one champion region, that of Ile de France which has the 23rd rank. On the contrary the first British region in the ranking is Eastern which features in 39th position. Finally, no notable dynamics is shown by the followers, in other words, countries such as Italy, Norway, Spain, Portugal and Greece.

3.2 Innovation clusters in Europe

All the evidences gathered in the tables and maps analysed in the previous section show that innovative activity is relatively concentrated in few areas in Europe. There are some spatial agglomerations which have grown over time, others which have started, and others which have lost their strength. In order to have some more detailed idea of the relative strength of such processes it is possible to use some formal indicators of spatial dependence. As a matter of fact, the degree of spatial association can be analysed by means of the Moran's I statistic, which is defined as:

$$I = \frac{N}{S_0} \frac{\sum_{i}^{N} \sum_{j}^{N} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{N} (x_i - \overline{x})^2}$$

where x_i and x_j are the observations for region *i* and *j* of the variable under analysis, patents in our case; $\overline{x}$ is the average of the variable in the sample of regions; and w_{ij} is the *i-j* element of the row-standardised *W* matrix of weights. $S_0 = \sum_i \sum_j w_{ij}$ is a standardisation factor that corresponds to the sum of the weights. The most general specification for the weight matrix is the physical contiguity one, given rise to a binary and symmetric matrix where its elements would be 1 in the case of two regions sharing a boundary and 0 otherwise. In the case of a row-standardised *W* matrix, in which each element in a row is divided by the total sum of the row, S_0 equals the number of observations, *N*, so that N/S_0 is equal to 1.

The use of the Moran index for the entire economy (see first rows in Table 3) shows a clear rejection of the null hypothesis with a positive value of the statistic: there appears a strong positive spatial autocorrelation, confirming the visual impression of spatial clustering given by the maps. If one also considers the spatial correlogram, this rejection is observed till the third order of contiguity--1st, 2nd and 3rd order neighbours--, as reported in Table 3. Nonetheless, there also appears a pattern of decreasing autocorrelation with increasing orders of contiguity typical of many spatial autoregressive processes.

We have also constructed the scatter maps in order to assess the sign of the spatial association in the different areas and its evolution along time (see Map 2, panel a and b). The scatter maps show that there is a clear association of high-high values in the centre, and low-low values in the South. This positive association remains true throughout the period, with few exceptions: some regions in the North of Italy presented initially high value of patents surrounded by low values whilst in the nineties became a cluster of high values. Additionally, Finland has performed remarkably well along this period, presenting low values at the beginning surrounded by low values, but changing to high values. This pattern shows almost no difference along time.[10]

The presentation of the aggregate geographic distribution of innovative activity in Europe does not give detail of the propensity for innovation to cluster spatially within specific sectors. However, the database on patenting allows one to investigate the geographical distribution of innovative activity also sector by sector in order to see if agglomeration forces depend on sectoral characteristics. In Map 3 the sector with the highest revealed technological advantage index is used to define the specialisation in European regions at the beginning of the eighties (panel a) and at the end of the nineties (panel b). The mapping, among other interesting evidences, shows that there seem to be some clusters of common technological specialisation patterns: Textiles and clothing in Italy, Fuels, chemicals and rubber in Germany, Food and beverages in Northern Europe.

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[10] Scatter (and also LISA) maps for other periods not reported in the paper are available on request.

Also, the distribution of innovative activity for the seven macro-sectors under analysis is given in Table 3 where we have reported the Moran tests for spatial autocorrelation in each of them. The sectoral results confirm the presence of spatial association up to the third contiguity order for all sectors considered. Another interesting result is that the spatial concentration of innovation in particular sectors is considerably greater than for all manufacturing. So, the sectors of Mining and energy, Food, Textile and clothing and Transport equipment present a higher value of the Moran's statistic than for the sector of Total manufacturing, that is, concentration in space in these sectors is very important. The opposite is obtained in the cases of Chemicals and plastic and Electronics, although the spatial autocorrelation encountered in those cases is also significant. All in all, this means that patenting activity in a certain sector tends to be correlated to innovation performed in the same sector in contiguous areas, determining the creation of specialised clustering of innovative regions in different sectors. This suggests that the analysis of technological spillovers and sectoral interdependences across regions is a promising way forward. In the next section a first attempt in this direction is done by means of an empirical model.

4. Model and results

In this section we investigate the phenomenon of cluster agglomeration of innovation activities throughout time, space and sectors in European regions. We try to assess which are the forces which support the development of technologically specialised regional clusters. In particular we would like to assess the spatial extent of these forces, their dynamics along the eighties and nineties and their connection with production clustering.

In the paper by Jaffe et al (1993) it is highlighted that one possible explanation why innovation is some sectors tends to cluster geographically more than in other sectors is that the location of production is more concentrated spatially. This being true, whenever one analyses why the propensity for innovative activity to cluster geographically changes across sectors, it is needed to control for the geographic concentration of the location of production activity. However, even after accounting for the geographic concentration of the production specialisation, an interesting point to be analysed is to what extent the specialization of innovative activity in one region is influenced by the specialization pattern in neighbouring regions. In other words, which is the role played by interregional knowledge spillovers in sectoral specialization in the geographical space.

Following the ideas above, we want to analyse the extent to which the innovation specialization of a given sector in a given region is influenced by the level of specialization in the production activity in the same region and sector and the level of specialization in the same region in the neighbouring regions. The model to be estimated is therefore as follows:

$$\mathrm{IST}_{ijt} = \alpha_0 + \alpha_1 ISP_{ijt-1} + \alpha_2 W(r) IST_{ijt-1} + \sum_{N=1}^{17} \delta_N NAT_N + \sum_{S=1}^{7} \lambda_S SECT_S + \varepsilon_{ijt} \qquad (1)$$

where IST_{ij} represents the relative technological specialization index of region *i* in sector *j*. As a measure of sectoral specialisation we use the usual location quotient, or revealed technological advantage index, which is the result of a double weighting of the regional sectoral innovation activity, with respect to the total innovation in the region and with respect to the European quota of that sector.

As outlined above, such an indicator is considered to be a function of the presence of production specialization in the same sector within the same region by means of ISP_{ij} which is the relative production specialization index of region *i* in sector *j*. The same indicator as described above is used to measure the production specialization index. It is only after the geographic concentration of production has been controlled for, that the degree to which interregional knowledge spillovers in the same sector can be addressed. So, the specialization in the same sector of nearby regions ($\mathrm{W(r)IST}_{ij}$) is introduced, where r indicates different order of lags for the weight matrix.

Moreover, our general framework given in (1) introduces an additional vector of factors which may also have a significant effect on the specialisation of the innovative activity and that take into account potential omitted variables. So, firstly we attempt to control for institutional environment and other structural factors common to all the regions belonging to a nation, which may affect innovation specialisation, through the use of a set of national dummies, *NAT*. Additionally, with the aim to control for the different technological opportunities of the sectors under consideration, a set of sectoral dummies is also included. In this sense, the sectoral breakdown of the patent data is not matched by data on production[11]. This is why the econometric analysis on the geographical specialisation patterns in European regions is referred to just seven macro sectors.

The analysis is performed for three periods, that is *t* is equal to 1989-91, 1994-96 and 1999-01, so that one can assess the evolution of the parameter under examination, if any. The availability of time series data, furthermore, permits to avoid endogeneity problems by considering independent variables at time *t-1*, which refer to periods 1981-83, 1989-91, 1994-96 respectively.

Table 4 summarises econometric results. We have estimated three equations for each period corresponding to different sets of lags for W: from first order to third order lag. The final set up refers to an estimation model with 1225 observations.

Some results are interesting to highlight. First of all the relationship between production and innovation specialisation proves positive and significant. Most importantly such a link is getting stronger along time indicating that research labs tend to stay closer to production plants. This result confirms previous one on Europe (Paci and Usai, 2000) and as a consequence discord with those obtained by Audretsch and Feldman (1996) for the case of US states.

Secondly, it is clear that the innovation specialization of one region is related to the specialization of close-by regions. The empirical evidence thus suggests that, even after controlling for the influence of sectoral specialization in production in the same region, innovation tends to cluster more in sectors in which the neighbouring regions are also technologically specialized. In other words, knowledge spillovers play a decisive role in the geographical configuration of industrial specialization patterns.

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[11] The data on production is provided by the Cambridge Econometrics database which only partially the problem of availability and reliability of data at the regional level in Europe (see Combes and Overman, 2003).

Since we have considered second- and third-order lags of the variable reflecting the interregional effect on specialisation, it is observed that such a relationship is significant until the second order of contiguity. So, technological specialisation in one region depends not only on the technological specialisation of first-order neighbouring regions but also on the technological specialisation of the regions sharing a border with these first-order neighbours, although with a slightly lower magnitude of this influence. Spillovers stop at this level given that the third-order contiguity lag is non significant.

As for its trend, the relationship among first order contiguous regions has a non monotonic dynamics given that it increases significantly from the first to second period but it decreases in the last one. This result confirms other indirect evidence (within the setting of the knowledge production function) on the relationship among technological activities performed by contiguous regions (see for example Bottazzi and Peri, 2003, and Moreno, Paci and Usai, 2004).

The tests for spatial autocorrelation --LM-ERR, suggested by Burridge (1980), and LM-LAG proposed by Anselin (1988) are computed for a physical contiguity matrix, that is, a binary and symmetric matrix with elements equal to 1 in case of two regions being in contact and 0 otherwise. Thus, the weight matrix has non-zero elements for each observation pair (an observation, row, and its potential neighbour, column) that are assumed to interact. In our case, the magnitude of the non-zero elements is a function of contiguity (the presence of a common border). As observed by the values of these statistics, spatial correlation is a problem which is difficult to eliminate in the first period whilst it is always solved in the last two periods.

In order to assess the robustness of our results to the problem of spatial autocorrelation and to the applied estimation method we have also estimated a second set of regressions. In such a set the lags of the specialization indexes are considered with respect to the same period of the dependent variable. In other words, the estimated equation is as follows:

$$IST_{ijt} = \alpha_0 + \alpha_1 \, ISP_{ijt-1} + \alpha_2 W(r) IST_{ijt} + \sum_{N=1}^{17} \delta_N NAT_N + \sum_{S=1}^{7} \lambda_S SECT_S + \varepsilon_{ijt} \qquad 2)$$

Accordingly, this spatial lag term hast to be treated as an endogenous variable and proper estimation methods have to account for this endogeneity. The most widely used alternative method is Maximum Likelihood (ML) since OLS estimators are biased and inconsistent due to the simultaneity bias.

Results are reported in table 5 and, on the whole, confirm those reported in table 4 while spatial autocorrelation is completely removed. The relationship between the specialization patterns of production and innovation activity within regions is positive and increasing along time. The relationship between innovative activity in contiguous regions is positive and significant even though it seems getting weaker along time. The introduction of second order contiguities, as expected, implies a reduction of the coefficient on the first order lag variable. Moreover it is worth noting that the strength of the relationship among second order contiguous regions is remarkably stable along time.[12]

5. Conclusions

In this paper we attempt to provide empirical evidence on the phenomenon of cluster agglomeration of innovation activities throughout time and space in European regions. More specifically we try to assess whether there are some forces which support the development of technologically specialised regional clusters. In particular we want to determine the spatial extent of these forces, their dynamics along the eighties and nineties and their connection with production clustering.

We have started from a mapping of innovation activity in European regions by means of a deep exploratory spatial analysis based on several global indicators of spatial dependence. The analysis has been carried out for different time periods and sectors in order to evaluate differences

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[12] Other specifications have been estimated to assess for the presence of a relationship between innovative specialization of one region and productive specialization in contiguous regions but results were not significant. Similarly, some attempts to evaluate the presence of different coefficients for each macro-sector by means of interactive dummies have not provided interesting results, probably due to the aggregate nature of our data.

and similarities. Two main outcomes are worth remarking. First, the presence of a strong central-periphery distribution of innovation activity at the beginning of the period. Innovation activity is concentrated in regions in North and centre Europe, while none or modest technological activity is performed in most Southern European regions. Second, this concentration tends to decrease over time while innovation activity has been spreading to some more regions in Scandinavia and in the South of Europe. The analysis of the global indicator of spatial association confirms the presence of a strong and positive spatial autocorrelation process in the innovative activity. This means that patenting activity in a certain region tends to be correlated to innovation performed in contiguous areas. Spatial association is also found at the sectoral level, even at a higher degree than at a aggregated level, determining the formation of specialised clustering of innovative regions in different sectors.

The second step concerns the analysis of the characteristics of the geography of innovation specialization modes across regions and across time. So, we follow the idea that innovation specialization in one region is highly dependent on specialization of production in the same region. However, even after accounting for the geographic concentration of the production specialisation, an interesting point analysed in this paper is to what extent the specialization of innovative activity in one region is influenced by the specialization pattern in neighbouring regions. In other words, which is the role played by interregional knowledge spillovers in sectoral specialization in the geographical space.

Among the main results, it is shown that specialization patterns follow a geographical pattern which links contiguous regions. Such a link is however loosing its strength. At the same time there appears a significant link between specialization in innovative activity and in production activity which is increasing along time. In other words, the results suggest that the propensity for innovation to cluster in some specific sectors in a region is attributable not only to the geographic concentration of production in those sectors but also on the role played by knowledge spillovers. So, innovation tends to cluster more in sectors in which the neighbouring regions are also technologically specialized.

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Tab 1. **Innovative activity in European countries (patents per 100.000 inhabitants, annual average)**

		Period							
		1981-83		1988-90		1994-96		1999-01	
Nation	**Num. of regions**	**Pat pc**	**ranking**	**Pat pc**	**ranking**	**Pat pc**	**ranking**	**Pat pc**	**ranking**
Switzerland	7	14.5	1	20.9	1	19.7	1	27.8	1
Germany	40	8.3	2	14.7	2	12.2	2	19.9	2
Sweden	8	6.5	4	8.3	4	11.7	3	18.7	3
Finland	6	1.4	11	4.7	10	9.6	4	18.3	4
Netherlands	4	4.1	5	8.3	3	8.3	5	14.5	5
Denmark	1	2.5	9	4.8	9	7.6	6	12.9	6
Luxembourg	1	7.2	3	5.0	8	6.4	10	12.7	7
Austria	9	3.3	8	6.8	6	6.8	8	10.5	8
Belgium	3	2.2	10	4.5	11	6.6	9	10.1	9
France	22	3.9	6	6.8	5	7.1	7	9.8	10
United Kingdom	12	3.4	7	5.4	7	5.1	11	7.3	11
Norway	7	0.9	13	2.1	13	3.0	13	5.1	12
Italy	20	1.1	12	3.0	12	3.4	12	5.0	13
Ireland	2	0.5	14	1.3	14	1.9	14	4.2	14
Spain	15	0.1	15	0.5	15	0.8	15	1.5	15
Greece	13	0.1	16	0.1	16	0.2	16	0.4	16
Portugal	5	0.0	17	0.1	17	0.1	17	0.3	17
EU	**175**	**3.6**		**6.5**		**6.7**		**10.4**	
CV across nations		**1.05**		**0.91**		**0.75**		**0.71**	
CV across regions		**1.42**		**1.17**		**1.05**		**1.05**	

Tab 2. Innovative activity in the top 20 regions (patents per 100.000 inhabitants, annual average)

CH	Nation	Period 1981-83 Pat pc	ranking	1988-90 Pat pc	ranking	1994-96 Pat pc	ranking	1999-01 Pat pc	ranking
Nordwestschweiz	CH	34.13	1	38.9	1	32.8	1	42.4	3
Zurich	CH	18.40	2	27.4	3	24.7	5	36.6	5
Oberbayern	DE	18.08	3	29.1	2	26.9	2	50.4	1
Rheinhessen-Pfalz	DE	18.01	4	24.9	5	26.0	4	32.5	7
Darmstadt	DE	17.90	5	26.8	4	26.0	3	32.2	8
Koln	DE	14.97	6	19.9	10	17.4	13	24.8	16
Region Lemanique	CH	12.61	7	14.3	19	14.8	20	21.8	25
Karlsruhe	DE	12.09	8	21.0	8	19.9	8	29.6	11
Ile de France	FR	10.74	9	15.9	16	16.1	16	22.1	23
Dusseldorf	DE	10.37	10	20.1	9	15.9	17	22.7	21
Stockholm	SE	10.28	11	13.0	21	20.3	7	30.8	10
Mittelfranken	DE	9.95	12	22.3	6	17.8	12	31.0	9
Stuttgart	DE	9.50	13	21.8	7	23.9	6	43.3	2
Ostschweiz	CH	9.44	14	19.0	11	17.2	14	25.5	15
Espace Mittelland	CH	9.18	15	14.7	17	15.1	19	21.9	24
Sydsverige	SE	9.13	16	9.2	32	12.4	25	23.1	20
Freiburg	DE	8.50	17	16.3	15	18.7	11	29.3	12
Zuid-Nederland	NL	8.15	18	18.4	12	15.5	18	36.8	4
Zentralschweiz	CH	7.39	19	17.4	13	19.9	9	24.5	17
Luxembourg	LU	7.16	20	5.0	66	6.4	59	12.7	44

CH	Nation	Period 1981-83 Pat pc	ranking	1988-90 Pat pc	ranking	1994-96 Pat pc	ranking	1999-01 Pat pc	ranking
Oberbayern	DE	18.08	3	29.1	2	26.9	2	50.4	1
Stuttgart	DE	9.50	13	21.8	7	23.9	6	43.3	2
Nordwestschweiz	CH	34.13	1	38.9	1	32.8	1	42.4	3
Zuid-Nederland	NL	8.15	18	18.4	12	15.5	18	36.8	4
Zurich	CH	18.40	2	27.4	3	24.7	5	36.6	5
Uusimaa	FI	3.48	49	9.4	30	19.5	10	35.5	6
Rheinhessen-Pfalz	DE	18.01	4	24.9	5	26.0	4	32.5	7
Darmstadt	DE	17.90	5	26.8	4	26.0	3	32.2	8
Mittelfranken	DE	9.95	12	22.3	6	17.8	12	31.0	9
Stockholm	SE	10.28	11	13.0	21	20.3	7	30.8	10
Karlsruhe	DE	12.09	8	21.0	8	19.9	8	29.6	11
Freiburg	DE	8.50	17	16.3	15	18.7	11	29.3	12
Tubingen	DE	6.39	25	14.4	18	16.7	15	28.6	13
Vorarlberg	AT	2.52	64	11.3	25	13.3	22	25.8	14
Ostschweiz	CH	9.44	14	19.0	11	17.2	14	25.5	15
Koln	DE	14.97	6	19.9	10	17.4	13	24.8	16
Zentralschweiz	CH	7.39	19	17.4	13	19.9	9	24.5	17
Unterfranken	DE	5.42	29	10.7	26	14.7	21	23.2	18
Braunschweig	DE	3.12	55	8.0	39	6.6	57	23.2	19
Sydsverige	SE	9.13	16	9.2	32	12.4	25	23.1	20

Tab 3. Spatial autocorrelation in the innovative activity
(Moran's I test, normal approximation)

	Period	**1981-83**		**1988-90**		**1994-96**		**1999-01**	
Sector	contiguity	Z-value	Prob	Z-value	Prob	Z-value	Prob	Z-value	Prob
Total manufacturing	1	3.435	0.00	4.111	0.00	4.327	0.00	4.493	0.00
	2	2.850	0.00	3.581	0.00	4.170	0.00	4.256	0.00
	3	3.357	0.00	3.424	0.00	3.672	0.00	3.527	0.00
Mining and energy	1	6.789	0.00	5.135	0.00	5.604	0.00	0.835	0.40
	2	4.825	0.00	3.036	0.00	3.680	0.00	0.822	0.41
	3	1.283	0.20	0.402	0.69	0.888	0.37	-0.004	1.00
Food	1	8.878	0.00	10.313	0.00	10.407	0.00	11.317	0.00
	2	8.176	0.00	9.430	0.00	9.263	0.00	5.349	0.00
	3	5.777	0.00	8.346	0.00	7.224	0.00	-1.002	0.32
Textile and clothing	1	7.482	0.00	7.923	0.00	5.670	0.00	2.783	0.01
	2	5.450	0.00	5.836	0.00	3.801	0.00	5.582	0.00
	3	3.814	0.00	4.621	0.00	3.399	0.00	3.569	0.00
Chemicals and plastic	1	3.567	0.00	3.809	0.00	3.304	0.00	3.375	0.00
	2	2.162	0.03	2.383	0.02	2.394	0.02	2.619	0.01
	3	2.492	0.01	3.300	0.00	3.501	0.00	3.255	0.00
Electronics	1	3.335	0.00	2.409	0.02	3.013	0.00	2.785	0.01
	2	2.793	0.01	1.835	0.07	2.418	0.02	2.251	0.02
	3	2.305	0.02	1.606	0.11	1.725	0.08	1.803	0.07
Transport equipment	1	10.404	0.00	10.308	0.00	9.365	0.00	3.496	0.00
	2	8.532	0.00	8.290	0.00	7.162	0.00	3.245	0.00
	3	5.484	0.00	6.079	0.00	5.221	0.00	1.457	0.15
Other manufacturing	1	4.453	0.00	5.649	0.00	7.924	0.00	4.911	0.00
	2	3.959	0.00	4.682	0.00	6.683	0.00	4.466	0.00
	3	3.750	0.00	3.858	0.00	4.260	0.00	2.493	0.01

Table 4: Econometric results
Dependent variable: local technological specialisation

Variables	OLS estimation								
	1989-91			1994-96			1999-01		
ISP_{t-1}	0.108	0.097	0.095	0.175	0.172	0.174	0.197	0.178	0.177
	0.007	*0.015*	*0.019*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
$W1\_IST_{t-1}$	0.182	0.174	0.175	0.281	0.259	0.259	0.187	0.152	0.151
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.002*	*0.002*
$W2\_IST_{t-1}$		0.022	0.021		0.016	0.018		0.034	0.033
		0.003	*0.005*		*0.063*	*0.039*		*0.000*	*0.000*
$W3\_IST_{t-1}$			0.003			-0.009			0.002
			0.602			*0.233*			*0.846*
Adjusted R-squared	0.09	0.10	0.09	0.13	0.13	0.13	0.11	0.12	0.12
Moran's I	3.350	3.178	3.205	0.909	0.994	1.034	1.478	1.530	1.544
	0.001	*0.001*	*0.001*	*0.364*	*0.320*	*0.301*	*0.140*	*0.126*	*0.123*
LM-ERR	6.650	5.721	5.770	0.032	0.061	0.073	0.543	0.598	0.596
	0.010	*0.017*	*0.016*	*0.859*	*0.805*	*0.787*	*0.461*	*0.439*	*0.440*
LM-LAG	*17.572*	8.752	8.669	*1.383*	1.080	1.168	*2.819*	2.062	2.034
	0.000	*0.003*	*0.003*	*0.240*	*0.299*	*0.280*	*0.093*	*0.151*	*0.154*

Obs: 1225, national and sectoral dummies included

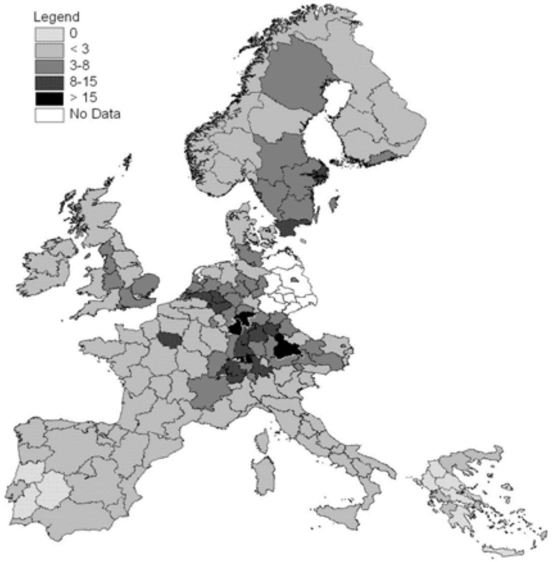
Tab 5: Econometric results
Dependent variable: local technological specialisation

Variables	ML estimation								
	1989-91			1994-96			1999-01		
ISP_{t-1}	0.112	0.104	0.108	0.184	0.167	0.168	0.194	0.174	0.173
	0.004	*0.008*	*0.006*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
W_IST	0.163	0.140	0.140	0.119	0.101	0.102	0.130	0.104	0.103
	0.000	*0.000*	*0.000*	*0.002*	*0.008*	*0.007*	*0.001*	*0.006*	*0.007*
W2_IST		0.030	0.033		0.032	0.032		0.036	0.034
		0.004	*0.000*		*0.001*	*0.000*		*0.000*	*0.000*
W3_IST			-0.013			-0.007			0.003
			0.101			*0.402*			*0.699*
Adjusted R-squared	0.114	0.121	0.123	0.130	0.137	0.137	0.128	0.139	0.139
LR test	18.512	13.136	13.154	10.125	7.096	7.252	11.614	7.129	7.035
	0.000	*0.000*	*0.000*	*0.001*	*0.008*	*0.007*	*0.001*	*0.008*	*0.008*
LM spatial error	0.904	0.189	1.534	0.027	0.125	0.001	0.009	0.016	0.084
	0.342	*0.664*	*0.216*	*0.870*	*0.724*	*0.981*	*0.923*	*0.900*	*0.772*

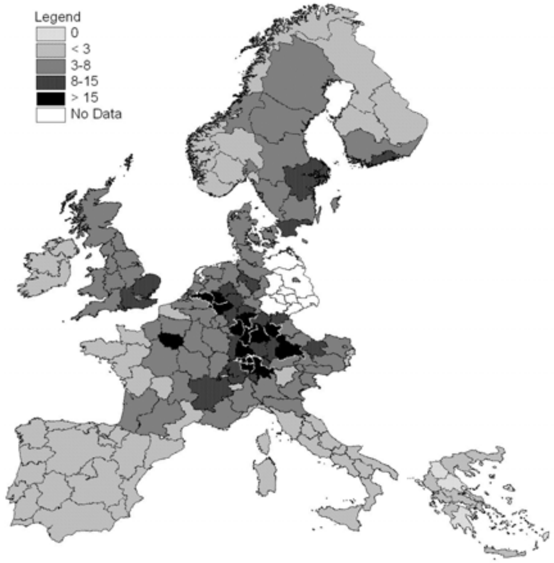
Obs: 1225, national and sectoral dummies included

Map 1. Distribution of innovative activity in the European regions (patents per 100,000 inhabitants, annual average)

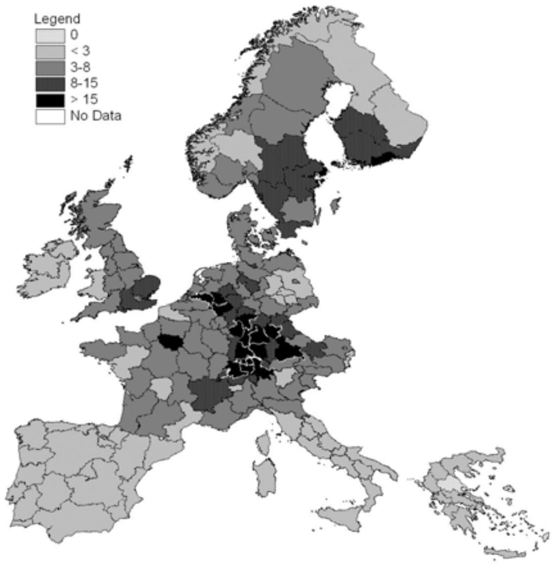
panel a (1981-83)



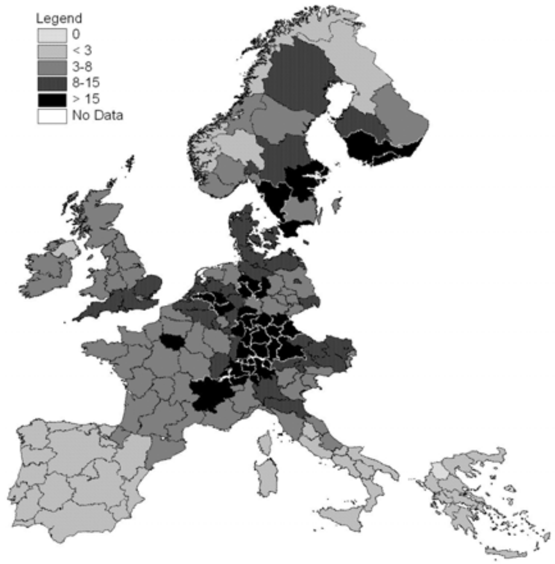
panel b (1989-91



panel c (1994-96)

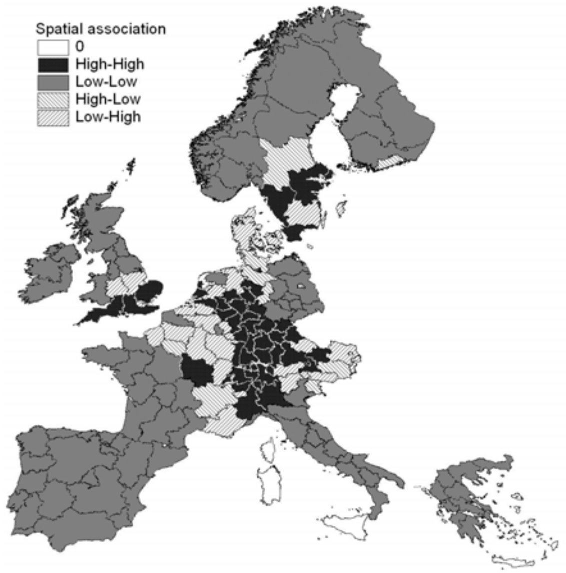


panel d (1999-01)

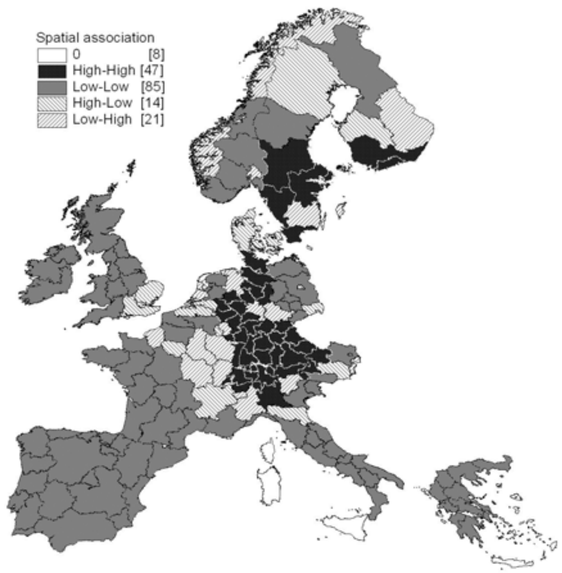


Map 2. Scatter for innovative activity in the European regions (patents per 100,000 inhabitants, annual average; number of regions in parenthesis)

Panel a (1989-91)

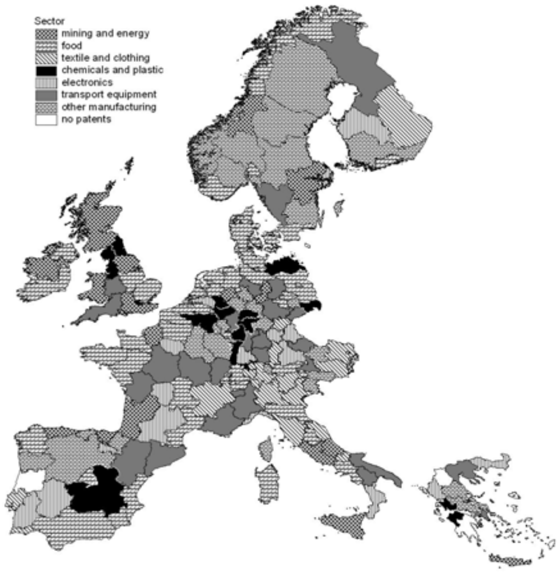


Panel b (1999-01)



Map 3. Index of technological specialisation (top sector) in the European regions (annual average)

Panel a (1989-91)



Panel b (1999-01)

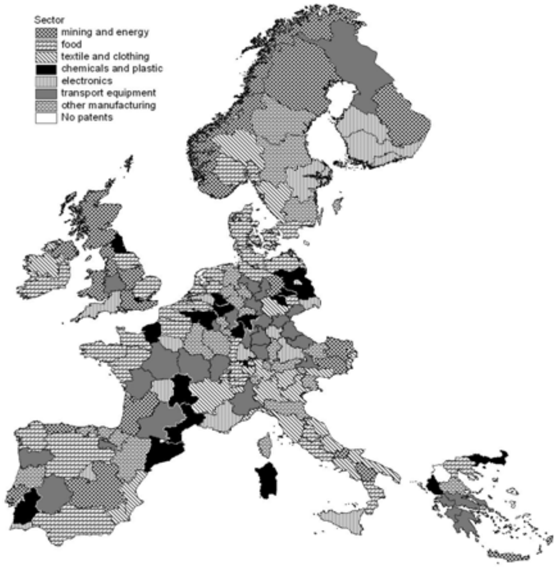


Figure 1. Coefficient of variation for innovation activity across European regions (1981-2001)

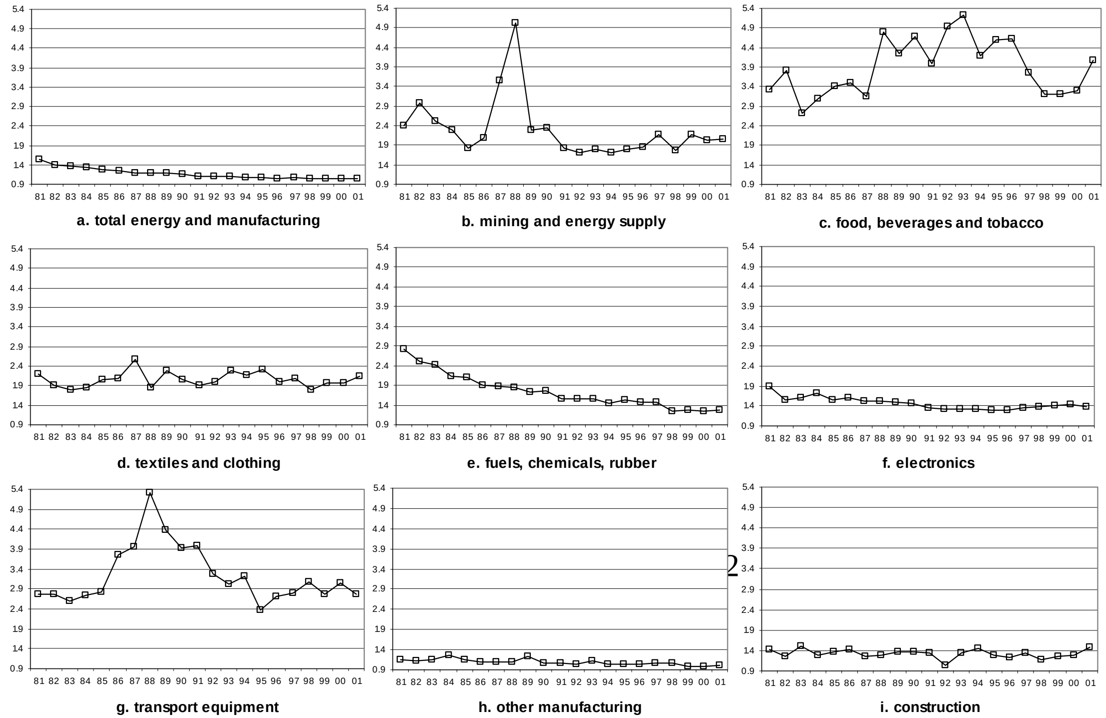
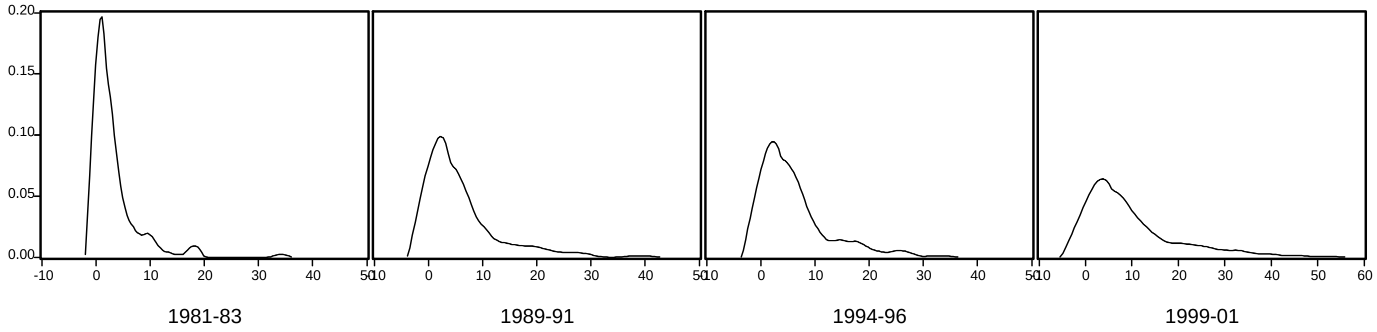


Figure 2. Kernel density function for innovation activity (patent per 100,000 inhabitants, annual average)



Appendix Table A.1 European Regions in CRENoS database
(Id-CRENoS; Id-Nuts; Region; Nuts level)

1	AT11	Burgenland	2
2	AT12	Niederosterreich	2
3	AT13	Wien	2
4	AT21	Karnten	2
5	AT22	Steiermark	2
6	AT31	Oberosterreich	2
7	AT32	Salzburg	2
8	AT33	Tirol	2
9	AT34	Vorarlberg	2
10	BE1	Bruxelles-Brussel	1
11	BE2	Vlaams Gewest	1
12	BE3	Region Walonne	1
13	CH01	Region Lemanique	2
14	CH02	Espace Mittelland	2
15	CH03	Nordwestschweiz	2
16	CH04	Zurich	2
17	CH05	Ostschweiz	2
18	CH06	Zentralschweiz	2
19	CH07	Ticino	2
20	DE11	Stuttgart	2
21	DE12	Karlsruhe	2
22	DE13	Freiburg	2
23	DE14	Tubingen	2
24	DE21	Oberbayern	2
25	DE22	Niederbayern	2
26	DE23	Oberpfalz	2
27	DE24	Oberfranken	2
28	DE25	Mittelfranken	2
29	DE26	Unterfranken	2
30	DE27	Schwaben	2
31	DE3	Berlin	2
32	DE4	Brandenburg	2
33	DE5	Bremen	2
34	DE6	Hamburg	2
35	DE71	Darmstadt	2
36	DE72	Giessen	2
37	DE73	Kassel	2
38	DE8	Mecklenburg-Vorpomm.	2
39	DE91	Braunschweig	2
40	DE92	Hannover	2
41	DE93	Luneburg	2
42	DE94	Weser-Ems	2
43	DEA1	Dusseldorf	2
44	DEA2	Koln	2
45	DEA3	Munster	2
46	DEA4	Detmold	2
47	DEA5	Arnsberg	2
48	DEB1	Koblenz	2
49	DEB2	Trier	2
50	DEB3	Rheinhessen-Pfalz	2
51	DEC	Saarland	2
52	DED1	Chemnitz	2
53	DED2	Dresden	2
54	DED3	Leipzig	2
55	DEE1	Dessau	2
56	DEE2	Halle	2
57	DEE3	Magdeburg	2
58	DEF	Schleswig-Holstein	2
59	DEG	Thuringen	2
60	DK	DENMARK	0
61	ES11	Galicia	2
62	ES12	Asturias	2
63	ES13	Cantabria	2
64	ES21	Pais Vasco	2
65	ES22	Navarra	2
66	ES23	Rioja	2
67	ES24	Aragon	2
68	ES3	Madrid	2
69	ES41	Castilla-Leon	2
70	ES42	Castilla-la Mancha	2
71	ES43	Extremadura	2
72	ES51	Cataluna	2
73	ES52	Com. Valenciana	2
74	ES61	Andalucia	2
75	ES62	Murcia	2
76	FI13	Ita-Suomi	2
77	FI14	Vali-Suomi	2
78	FI15	Pohjois-Suomi	2
79	FI16	Uusimaa	2
80	FI17	Etela-Suomi	2
81	FI2	Aland	2
82	FR1	Ile de France	2
83	FR21	Champagne-Ard.	2
84	FR22	Picardie	2
85	FR23	Haute-Normandie	2
86	FR24	Centre	2
87	FR25	Basse-Normandie	2
88	FR26	Bourgogne	2
89	FR3	Nord-Pas de Calais	2
90	FR41	Lorraine	2
91	FR42	Alsace	2
92	FR43	Franche-Comte	2
93	FR51	Pays de la Loire	2
94	FR52	Bretagne	2
95	FR53	Poitou-Charentes	2
96	FR61	Aquitaine	2
97	FR62	Midi-Pyrenees	2
98	FR63	Limousin	2
99	FR71	Rhone-Alpes	2

100	FR72	Auvergne	2
101	FR81	Languedoc-Rouss.	2
102	FR82	Prov-Alpes-Cote d'Azur	2
103	FR83	Corse	2
104	GR11	Anatoliki Makedonia	2
105	GR12	Kentriki Makedonia	2
106	GR13	Dytiki Makedonia	2
107	GR14	Thessalia	2
108	GR21	Ipeiros	2
109	GR22	Ionia Nisia	2
110	GR23	Dytiki Ellada	2
111	GR24	Sterea Ellada	2
112	GR25	Peloponnisos	2
113	GR3	Attiki	2
114	GR41	Voreio Aigaio	2
115	GR42	Notio Aigaio	2
116	GR43	Kriti	2
117	IE01	Border	2
118	IE02	Southern and Eastern	2
119	IT11	Piemonte	2
120	IT12	Valle d'Aosta	2
121	IT13	Liguria	2
122	IT2	Lombardia	2
123	IT31	Trentino-Alto Adige	2
124	IT32	Veneto	2
125	IT33	Fr.-Venezia Giulia	2
126	IT4	Emilia-Romagna	2
127	IT51	Toscana	2
128	IT52	Umbria	2
129	IT53	Marche	2
130	IT6	Lazio	2
131	IT71	Abruzzo	2
132	IT72	Molise	2
133	IT8	Campania	2
134	IT91	Puglia	2
135	IT92	Basilicata	2
136	IT93	Calabria	2
137	ITA	Sicilia	2
138	ITB	Sardegna	2
139	LU	LUXEMBOURG	0
140	NL1	Noord-Nederland	1
141	NL2	Oost-Nederland	1
142	NL3	West-Nederland	1
143	NL4	Zuid-Nederland	1
144	NO01	Oslo og Akershus	2
145	NO02	Hedmark og Oppland	2
146	NO03	Sor-Ostlandet	2
147	NO04	Agder og Rogaland	2
148	NO05	Vestlandet	2
149	NO06	Trondelag	2
150	NO07	Nord-Norge	2
151	PT11	Norte	2
152	PT12	Centro	2
153	PT13	Lisboa e V.do Tejo	2
154	PT14	Alentejo	2
155	PT15	Algarve	2
156	SE01	Stockholm	2
157	SE02	Ostra Mellansverige	2
158	SE04	Sydsverige	2
159	SE06	Norra Mellansverige	2
160	SE07	Mellersta Norrland	2
161	SE08	Ovre Norrland	2
162	SE09	Smaland med oarna	2
163	SE0A	Vastsverige	2
164	UKC	North East	1
165	UKD	North West	1
166	UKE	Yorkshire and the Humber	1
167	UKF	East Midlands	1
168	UKG	West Midlands	1
169	UKH	Eastern	1
170	UKI	London	1
171	UKJ	South East	1
172	UKK	South West	1
173	UKL	Wales	1
174	UKM	Scotland	1
175	UKN	Northern Ireland	1