# Knowledge spillovers in Europe and its consequences for systems of innovation

# Knowledge Spillovers in Europe and its Consequences for Systems of Innovation

By
Per Botolf Maurseth
(NUPI)
and
Bart Verspagen
(Eindhoven University of Technology & MERIT)

We thank Marjolein Caniëls for help in constructing the distance matrix used in this paper. We also thank Jan Fagerberg, Bart Los, Eddy Szirmai, Erik Biorn , Karl Ove Moene, Arne Melchior and participants at the TSER workshop in Gothenburg, 4-6 June 1998, and at a seminar at the University of Linz (economics Department), June 1998, for useful comments.

ECIS Working Paper 98-001, and paper prepared for the TSER project 'Technology, Economic Integration and Social Cohesion', workshop in Gothenburg, 4-6 June 1998.

Third draft, October 1998

**ECIS - Eindhoven Center for Innovation Studies**
**Eindhoven University of Technology - Faculty of Technology Management**
**PO Box 513**
**5600 MB Eindhoven**
**The Netherlands**
**email:** bart.verspagen@merit.unimaas.nl

## 1. Introduction

European integration has traditionally been aimed at the reduction of barriers to intra-European trade and factor mobility. This has been achieved by the abolition of tariffs and import duties, by liberalisation of capital movements and reduced barriers to foreign direct investments, by legislation facilitating mobility of people across the European Union, and by the abolition of various so-called non-tariff barriers to trade under the 1992 programme.

Has a similar degree of integration been reached in the field of technology and innovation? This is obviously an important question. The extent to which a nation or region can assure access to world-wide technological knowledge, and the extent to which it can contribute to this, is decisive for relative economic growth performance (see Fagerberg, 1994, for a survey of economic theory and empirical results on this issue).

An important characteristic of technological knowledge is that it can be used without being exhausted. Technology is also cumulative in nature, because it is based on previously gained insights. For processes of technological change, this cumulative aspect is crucial. Furthermore, technological knowledge is seldom (completely) limited to the person or firm that developed it, and, consequently, has the property rights to it. In other words, technological spillovers take place. In the recent formal growth models in the neo-classical tradition, increasing returns through spillovers make endogenous growth possible. Without such spillovers, economic growth either ceases in the long run (see Grossman and Helpman, 1991, chapter 3), or is 'explained' as a completely exogenous process (as in the old neo-classical model of the 1950s).

Increasing returns to scale, and with it the main beneficial effects of technological change, thus result from the process in which technological knowledge flows between different agents and institutions in the economy. The literature on so-called national systems of innovation (e.g., Lundvall, 1992) focuses on the ways in which this process of knowledge flow takes place. It is suggested in this literature that many factors have an impact on knowledge flows. In an analogy to percolation theory, David and Foray (1994) and Antonelli (1996) make a distinction between innovation and the way in which it can be appropriated, and factors which have an impact on the capacity to learn from other firms. Obviously, the two factors are related (see Cohen and Levinthal, 1989).

Knowledge flows and the factors which have an impact on them are not easy to quantify. For example, in the national systems of innovation approach, various factors related to institutions (such as the quality and quantity of education, cultural attitudes towards innovation, etc.) are being brought to the fore. However, although knowledge flows are to some extent related to trade flows (e.g., Coe and Helpman, 1995), the general tendency to liberalising trade flows in the European Union does not necessarily imply a proportionate increase of knowledge flows.

The question we wish to investigate here is which are the factors that have an impact on the flow of knowledge (spillovers) in the European union. Much of the recent literature argues that technology spillovers are to an important extent local (Morgan, 1997 and Jaffe, Henderson and Trajtenberg, 1993). The reason for this is that, despite

modern communication techniques, due to the tacitness of knowledge, frequent face-to-face contact, or mobility of knowledge workers are still important channels of knowledge spillovers. Thus, the role of geography will be an important factor in our analysis.

The rest of this paper is organised as follows. Section 2 discusses some implications of spillovers in general and localised spillovers in particular for economic development at the country and regional levels. Section 3 describes innovative capability in European regions with use of data on patenting. Section 4 provides a descriptive analysis of regional technological interaction as evidenced by patent citations. In section 5 econometric evidence on the determinants of the pattern of technological spillovers between European regions are presented. A concluding Section summarises the empirical findings and point out some directions for future research. Data-construction and –sources are discussed in the appendix.

## 2. Economic growth, regional development and technological spillovers

As technological spillovers are understood as an important determinant of economic growth, their specificity or generality throughout the economy and over time and geography have important implications for economic growth. When spillovers are industry-specific, specialisation in certain industries may result in higher growth than specialisation in other industries, and the specialization pattern of a country or region is then likely to have an impact on economic growth. If spillovers are geographically concentrated, knowledge stocks may accumulate in proportion to local industrial activity. Thus, increasing returns resulting from spillovers may be bounded within geographical limits. Localised spillovers thereby facilitate clustering of economic activity.[1] To reap the benefits of local spillovers, production is established nearby pre-existing production. External effects from establishment increase profitability of further establishments.

Alfred Marshall observed early on that knowledge spillovers may play a crucial role for clustering of economic activity.[2] In addition to obvious explanations such as endowments of natural resources, Marshall referred to technological spillovers as one of three possible explanations for clustering of economic activity (Marshall, 1948; 271):[3]

> *When an industry has thus chosen a locality for itself, it is likely to stay there long: so great are the advantages which people following the same skilled trade get from near neighbourhood to one another ...(I)f one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further ideas.*

[1] Grossman and Helpman (1991, 1995).
[2] Marshall (1948, Chapter X)
[3] The other two were local markets for specialised skill (labour market pooling) and for specialised intermediates.

The importance of geography for diffusion of knowledge was also recognised by Raymond Vernon as a basis for his product cycle theory.[4] Vernon showed how localised knowledge and technological opportunities might envisage introduction and production of new products in advanced markets.

Kaldor (1978-72; 143), reflecting on uneven regional development, analysed the role of localised dynamic increasing returns as a result of, among other factors, "the opportunities for easy communication of ideas and know how". Kaldor, inspired by Allyn Young's theorising on technological spillovers as a source of aggregate increasing returns (Young, 1928), hypothesised that regional development was subject to a principle of "circular and cumulative causation" in which regional economic progress (or stagnation) is the seed of further progress (or stagnation). Thus, uneven regional development may be an inherent outcome of decentralised economic processes in absence of counteracting economic policy. Kaldor pointed out that such processes of cumulative causation made a case for regional policies.

Previous empirical research has established that geography may indeed be important for technological spillovers. Analysing patent citations, as one aspect of technology spillovers, Jaffe, Trajtenberg and Henderson (1993) found intra-national citations (national patents citing national patents) and intra-state citations (citations to patents originating in the same state) to occur more often than expected from the distribution of patenting activity, using US patent statistics. Similar results were obtained in Jaffe and Trajtenberg (1996) where it also was found that the geographical concentration of spillovers decreased over time. Sjöholm (1996 and 1997) found citations to patents from neighbourhood countries to occur more often in Swedish patent applications than to patents originating from distant countries, when controlled for patent-activity in the cited country, international trade and production similarities between Sweden and the cited country.

There are also factors that can be identified as stimulating the flow of knowledge through the European economy as a whole. The so-called technology gap theory on economic growth and international trade deals with the (international) diffusion of technological knowledge (Fagerberg, 1994). This theory focuses on how countries ranking low on the productivity ladder may catch up with leading countries. Diffusion of technology facilitates the potential for catch up, but technological progress on the frontier increases the ladder to climb.[5] The ability to adapt new technologies depends on institutional infrastructure, education, geography and resources devoted to R&D. These technology gap theories have increased the understanding of critical factors of catching-up with the technological leading countries (e.g., finance, the educational system and politics, see, *inter alia*, Abramovitz, 1985, Fagerberg, 1988 and Verspagen, 1991). Fagerberg (1994) concludes a survey on the literature on the catch-up debate with the following: "Indeed, what the whole literature, from Gerschenkron

[4] Vernon (1966; 192) states that: "There is good reason to believe, however, that the entrepreneur's consciousness of and responsiveness to opportunity are a function of ease of communication; and further, that ease of communication is a function of geographical proximity."

[5] Krugman (1979) constructs a model of technology gaps in which laggard countries continuously takes over old fashioned products developed in the most advanced countries, which give rise to a product cycle theory in the Vernon-fashion. Krugman (1986) extends this technology gap theory and demonstrates that catch up may harm the most advanced countries, while technological progress on the frontier increases income in both advanced and developing countries.

onwards, suggests is that catching up is very difficult, and that only countries with appropriate economic and institutional characteristics will succeed."

It thus appears that the absorptive capability of a country or region is crucial for the issue of clustering. The cumulative nature of technology and the localness of spillovers bring with them a tendency for clustering, and the extent to which this tendency will be counteracted by wider technology diffusion depends on absorptive capacity. If there are large differences in terms of absorptive capacity, a considerable degree of clustering may arise (depending on whether the peripheral regions have high or low absorptive capacity), whereas if all regions have high absorption capability, spillovers flow easily, and the spread of economic activity will be more even.

An important question, in an increasingly integrated is the extent to which national systems of innovation are still relevant. Increased integration indicates less importance for national borders. In Europe, economic integration (abolishment of trade barriers, common economic policy in several aspects and monetary union) is combined with supranational institution building to support regional development (structural funds), exchange of students, co-operation between universities and R&D-laboratories and infrastructure projects. This process raises the question whether a European system of innovation will come to supplement the national systems.

On the other hand, studies of national systems of innovation highlight important path dependent aspects of such systems. One example is technological spillovers that are somewhat specific in scope (sectorally, geographically etc.). Such factors envisage "path dependence" which provide internal dynamism to historical systems within countries. Reduced importance of national borders and of national policies however, can indicate that national systems of innovation become less national but still geographically concentrated. Thus, analyses of the innovative capacity in Europe should incorporate both distinct European aspects (e.g. in terms of a European system of innovation) and variety at national and regional levels (national and regional systems).

The system of innovation, and whether it can be characterized as European, national or regional, thus provides a crucial link between localised spillovers (which lead to clustering) and diffusion of technological knowledge (leading to convergence). Our analysis in the next Sections will be aimed at answering the question of how knowledge flows in the European innovation system. Can we still observe, despite increased integration since the 1950s, factors that hinder the flow of knowledge through the system? Do we see one truly European system of innovation, in which knowledge spillovers flow between all relevant units (e.g., regions), or do we have instead many isolated innovation systems that only interact marginally with each other?

## 3. Technological Competencies in European Regions

As is well known from evidence at the country level, there are large differences between European countries in terms of technological competencies. In terms of R&D intensity (R&D expenditures as a percentage of GDP), large differences between European countries exist. From the analysis of differences in GDP per capita in the

European Union, we know that regional differences in GDP per capita are much larger than across countries. Because there is a close correlation between technological competencies and GDP per capita (see Fagerberg, Verspagen and Caniëls, 1997), one might expect that regional differences in terms of technology in the European Union are large.

It is the aim of this section to investigate the extent of these differences. Patent statistics will be used to this end. Patents statistics are often used as an indicator of technological strength of a country or region besides R&D.[6] The fact that patent statistics are output indicators rather than input indicators has some advantages as well as disadvantages. The main advantage is that one is able to circumvent the issue of R&D productivity ('the number of innovations per unit of R&D'), and that patent statistics are available for a wider set of regions and longer time period than R&D statistics. The main disadvantages lie in the problem that simple patent counts do not take into account differences in the quality of innovations, that many patents do not lead to innovations, and that the propensities to patent may differ between sectors. Despite these differences, patent statistics are widely used to analyse regional differences in innovation in the European Union (e.g., Caniëls, 1996, Paci and Usai, 1997, Verspagen, 1997).

The expectation of a correlation between GDP per capita and patenting between European regions is indeed confirmed by the data. The rank correlation between GDP per capita in 1994 and the share in patent applications at the European Patent Office (EPO) over the period 1979 – 1996 is 0.67. This paper will not deal further with the correlation between innovation and economic performance. Instead, a closer look at innovation activity will be given.

Map 1 gives an overview of patenting activity in European regions. The map gives four groups (quartiles) of regions, based on the number of patent applications at EPO over 1979 – 1996. All applications are assigned to the region of the home address of the inventor, so we rule out any bias resulting from the fact that patents are often applied for from a different location than where the invention was made.[7] The darker the shade of the region, the higher it ranks on the list of the number of patent applications.

Germany comes out with the highest activity. All regions in the former West Germany rank in the highest group. Even the Eastern part, however, has high values, with all regions except one ranking in either the first or second group. This may partly have to do with the fact that the main office of EPO is located in Munich, but it is unlikely that this has a strong impact. Patents can be filed in any language, and all countries have patent lawyers fully qualified to handle EPO applications. We thus

[6] It is beyond the scope of this paper to examine the (dis)advantages of patents or R&D indicators in detail (see the survey by Griliches, 1990).

[7] In fact, it might be the case that the inventor lives in one region, but works in a different region. (This may be particularly so when inventors are well-paid employees who can afford to live in nice locations at a relatively far distance from their workplace.) However, given that the regional grouping we use consists of rather large geographical areas (often NUTS-1 level), this problem is unlikely to be severe. To assess its impact, we also calculated the numbers of patents based on applicants rather than inventors, and the correlation between the two measures was high.

interpret the German result as confirming the technological leadership of this country in the European context.

The other members of the high patenting activity group are spread out over six countries: United Kingdom, France, Italy, Austria and Sweden. It is noteworthy that there is a clear amount of clustering in two areas: North Italy combined with Southeast France, and England. Also in the Netherlands, patenting activity clusters in two adjacent regions. In Belgium, France, Austria and Sweden, the regions with capital cities rank high.

Note that in general, patenting activity in the South is lower than in the North, as could be expected on the basis of GDP per capita data. Portugal, Spain and Greece are the only countries without a region ranking in the highest activity quartile, and in Italy the high activity regions are located in the North. In fact, in the set of regions consisting of Portugal, Spain, Greece and South Italy, there are only two regions which rank in the 'intermediate high' quartile (regions around Rome and Barcelona). All other regions rank lower. In Portugal, all regions rank in the lowest quartile.

Map 2 adjusts the raw patent applications data for the size of the region, by dividing the number of patents used in Map 1 by the population of the region in 1990. This mainly has the effect to reduce the dominance of the larger countries, such as Italy, the UK and Germany, in favour of smaller countries such as Austria and the Netherlands. Austria now ranks almost fully in the highest quartile, with only two regions ranking in the second group. In the Netherlands, four regions rank in the top group, and two in Sweden. The large clusters of high activity in North Italy and England are reduced in size, although most of the regions in these clusters still rank in the 'intermediate high' group.

The division between North and South still remains clearly visible. Portugal still ranks completely in the lowest group, as does Greece (completely) and the largest part of Spain (3 regions in this country rank in 'intermediate low', the rest in 'low'). South Italy also ranks very low. In fact, no region north of the Pyrenees ranks in the 'low' group.[8]

The conclusion on the geographical spread of inventive or innovative activity over Europe is thus that there is a fair amount of concentration. This concentration occurs in various dimensions. It is perhaps most visible in the North-South context, where we find the familiar pattern of high innovation activity in the North, and low activity in the South. However, also in the within-country dimension, concentration occurs. Each of the countries in our maps clearly shows some geographical concentration of patenting.

The degree to which patenting is geographically concentrated differs, however, between industries. In order to investigate this dimension, we assigned each of the patent applications to one or more of 22 manufacturing industries, according to the MERIT concordance table between IPC and ISIC (Verspagen et al, 1994). We thus

[8] Note that Greece appears more North on the map than it actually is. This is done for typographical reasons.

have, for each region, not only the total number of patent applications, but also the spread of these over 22 sectors.

It turns out that for each sector, particularly the so-called high-tech ones[9], the (rank) correlation between the total amount of patents in the regions, and the sector-wise number of patents by region, is quite high. It would thus be redundant to repeat the maps shown for total patenting at the sectoral level. Instead, we present, in Table 1, a more synthetic measure of concentration, in the form of the Herfindahl index. This index is defined as the sum (over regions) of squares of regional shares of patenting.[10] A high number indicates high concentration.

Table 1 presents the results of these calculations for the 22 sectors. The two sectors with highest geographical concentration are both high tech sectors, i.e., pharmaceuticals and computers. Other high tech sectors also show high concentration (e.g. aerospace, electronics). Total patenting scores a relatively low value. Thus, high tech patenting is relatively concentrated (compare also high tech aggregate vs. total). The other sectors for which patenting is relatively concentrated are all scale intensive sectors: ferrous basic metals, chemicals, electrical machinery, refined oil, ships and boats. The high geographical concentration of patenting in these sectors may thus well be the result of a high concentration of economic activity over space, rather than the result of some inherent tendency for technological activity to be clustered.

## 4. Technology spillovers between European regions

From the point of view of a European innovation *system*, what matters is not only the distribution of activities over regions, but also the way in which regions 'interact' with respect to technology. As pointed out in Section 2, technology spillovers may have important effects on economic development in and across regions and countries.

Griliches (1979) distinguishes between two types of spillovers, i.e. rent spillovers and pure knowledge spillovers. Rent spillovers are *pecuniary* spillovers, which result when the innovating firms are unable to raise prices proportionally to the quality improvements of their products. For the firms that use these products as inputs, this results in a better quality – price ratio, which is interpreted as a spillover. Studies estimating the impact of so-called indirect R&D embodied in traded inputs on productivity (e.g., Coe and Helpman, 1995, for a survey see Mohnen, 1992) are generally within this interpretation of spillovers.

The concept of pure knowledge spillovers, on the other hand, is related to "the impact of the discovered ideas or compounds on the productivity of the research endeavours of others" (Griliches, 1992). This corresponds to the impact of 'general knowledge' on the productivity of R&D in Romer's (1990) model. In this context, one may think of 'imitative' spillovers (i.e. one firm copying an innovation by another firm), or

[9] High-tech sectors are usually defined on the basis of R&D intensity (see OECD/EUROSTAT, 1995). The sectors pharmaceuticals (3522), computers and office machines (3825), electronics (3832), aerospace equipment (3845) and instruments (385) are usually considered as high tech (ISIC rev 2 numbers between brackets). We adopt this definition in Table 1 below.

[10] Formally, the Herfindahl index is defined as $\Sigma_i x_i^2$, where $i$ indicates regions, and $x_i$ is defined as $X_i/\Sigma_i X_i$ ($X$ denotes the number of patents).

'idea-creating' spillovers (when an innovation leads to an idea for another innovation).

Because the impact of rent spillovers is largely related to traded inputs, one could expect that the importance of such spillovers increase when trade barriers in Europe are reduced. This does not necessarily hold for pure knowledge spillovers. Unfortunately, pure knowledge spillovers are a difficult concept to operationalize, given the available indicators. Because no data are available on the R&D-financing links between regions or countries, we cannot follow the more traditional methodology to use these data as an indicator of interaction.[11]

Instead, we use data on patent citations as an indicator of interaction. This follows earlier contributions (using data at the national level) in Verspagen (1997a, b), building on a method proposed by Jaffe (1989) and Henderson, Jaffe and Trajtenberg (1993).

Each patent application must refer to previous patent applications. The purpose of patent references is to preclude double patenting of innovations and eventually to limit patent protection. Also, patent references indicate relevant established knowledge for new innovations. One may thus straightforwardly interpret such patent references as indicators of spillovers of knowledge from the cited patent to the citing patent. For the purpose of this paper, citations in European patents are used as our measure of knowledge spillovers. However, it has to be kept in mind that the large majority of the patent citations is added by the EPO patent examiners, which implies that the inventors may not have been aware of the cited patent. Still, the citation link may be seen as an indicator of technological relevance. This certainly indicates potential spillovers, although this potential may not have been realised in all cases. However, patents are public knowledge, so professional R&D laboratories can to a certain extent be assumed to be able to extract useful knowledge from existing patents.

Our choice for patent citations as indicators for knowledge spillovers obviously implies that we take a limited perspective on the issue. Knowledge spillovers are much broader than what is captured by our indicator. In terms of the distinction by Griliches introduced above, we look at a specific form of pure knowledge spillovers, and leave the issue of rent spillovers out of the analysis completely. Even within the category of pure knowledge spillovers, however, patent citations are only a part of the complete story. They refer to spillovers which are very closely linked to the invention process itself, and hence, less directly to the economic impact of invention and innovation. In order for patent citations to take place, both the receiving and generating region must be actively engaged in R&D, leading to patent applications.

Thus, our analysis and its conclusions will only refer to a rather specific, and in some sense, 'advanced' form of knowledge spillovers. This may seem as a rather narrow perspective on the issue at large, but it has the advantage that we can make use of a

[11] Data for R&D-financing links are available at the level of institutional sectors within countries. Thus, for example, one has information on which part of business R&D is financed by government in a particular country. At the regional level, however these data are not available. Moreover, even the data on the institutional shares in regional R&D are so incomplete as to prevent us from using them in a sample as wide as the one we have in Maps 1 and 2.

very detailed and precise database, in contrast to the rather general indicators of spillovers that have been used in other parts of the literature.

The citation data was used to set up a list of pairs of cited and citing patent applications. This list was used to create a region by region matrix. For each pair of cited/citing patent, the region of origin of both patents was established, and then the citation link was assigned to the cell with row of the cited region, and column of the citing region. Thus, the rows in this matrix indicate regions which generate ('transmit') the spillover, the column regions receive the spillover. In principle, this matrix can be set up in four dimensions, i.e. region by region by sector by sector.[12] Obviously, this matrix is quite large (more than 7 million cells!), so only selective use will be made of the sector dimensions, and most of the work will concentrate on the regional dimension.

The regional citation matrix consists of 112 European regions, plus seven country aggregates. Four of these countries are European countries for which no regional breakdown of the data is available. One of the seven country aggregates consists of 'other countries' (other than the US, Japan or European Union countries). The regions for which data are available are those in the maps, plus one 'region' per country which consists of the regionally unspecified patents, plus separate data on Guernsey and the Isle of Man in the UK.

The region by region matrix has a relatively high concentration on the diagonal, i.e., intra-regional citations. Approximately 35% of all citation links in the matrix are concentrated on the diagonal (note that only 0.8% of all cells in a 123x123 matrix is on the diagonal). The data do not enable us to make a distinction between citations within a firm or establishment, and citations between two different firms located in the same region. Obviously, this distinction is of great relevance to a discussion on regional innovation systems. The distinction between Silicon Valley and Route 128 is illustrative in this respect (see Saxenian, 1994). In Route 128, one finds large, vertically integrated firms, which can be expected to have a large number of intra-firm citations. In Silicon Valley one finds much more small firms, operating in an open and interactive system, with, expectedly, more inter-firm (but intra-regional) citations. Saxenian (1994) argues that the two innovation 'systems' can be expected to show quite different levels of performance (the Silicon Valley system is argued to be more efficient).

With the data we have, however, we are unable to separate the Route 128s from the Silicon Valleys. This is the reason why we will generally leave out the intra-regional citations from the analysis. This does not imply that intra-regional and intra-firm citations are not an interesting phenomenon. It merely indicates the limitations of the data collection procedure.

The off-diagonal elements of the region by region matrix (i.e., inter-regional citations) show a highly skewed distribution. This is shown in Figure 1. Slightly more than half of all regional pairs never cites each other's patents. The frequency of citations gradually declines for more intensive citation links. There are only 71 pairs of regions for which the number of citations is 200 or more. Note that the total number of off-

[12] Verspagen (1997a, b) analyzes a purely sector by sector matrix.

diagonal citations in the region by region matrix is approximately 110,000. The number of 200 or more citations thus does not strike one as a very large number.

From this we conclude that strong technological spillovers between European regions, as far as they are related to patent citations, are only found between a relatively small number of regions. These are also the regions which are relatively active in terms of patenting (see Maps 1 and 2).

## 5. Spillovers between European regions - econometric specification and results

The aim of this Section is to systematically investigate the pattern of patent citations in Europe based on the data described in the last section. Of particular interest is the extent to which geography affects the technological interaction between European regions. The previous Sections however, have indicated several other factors of potential importance for knowledge flows. Thus, the effects of technological specialisation, productivity gaps (between spillover-receiving and spillover-producing regions), innovative activity and the effect of national systems of innovation are also taken into account. To this end, the matrix of region by region patent citations is combined with data on technological specialisation, economic development and distances between the regions. The analysis is confined to the European regions only (minus Guernsey and Isle of Man), as comparable data on all variables are not available on overseas regions. The new region by region matrix consists of 112*112 cells (including the four European countries for which regional breakdowns are not available).

One problem in research on economic agglomeration effects and localisation of spillovers is to separate spillovers as such from correlation in spillover-patterns that may be due to pre-existing pattern of localisation of technology-producing activity. For example, if patent seekers from Ludwigshaven in Germany (the headquarter of the chemistry-giant BASF) cite other German patents, this may be due to several distinct effects which all do not necessarily reflect spillovers.

Firstly, as pointed out in Section three above, German regions are highly innovative as compared to the European average. Thus, German patents are more likely to cite each other just because of the above-average German patent-activity. This effect should not be taken as evidence of clustering-effects of spillovers. Technologically active regions are a priori supposed to cite each other more often than technologically inactive regions. In fact, the data reveal a high correlation between citations and the numbers of patents in the related regions.[13] This is largely due to the fact that patenting in both the cited and the citing region is a necessary condition for any reference between them at all. For this reason, we construct a dependent variable where the numbers of citations between two regions are expressed as a fraction of the sum of patents in the citing and the cited regions. In other words, what we are trying to explain is not the absolute amount of spillovers as indicated by patent citations, but rather the intensity of this flow compared to total patenting activity in the regions.

[13] The correlations between the (log of ) the number of citations between two regions and the (log of) these region's individual number of patents are very close to 0.50.

Secondly, patent-applicants affiliated to, say, BASF are a priori more likely to cite patents related to chemistry than patents related to other sectors. If Germany is specialised in chemistry, patent-applicants from Ludwigshaven are more likely to cite other German patents because of the pre-existing pattern of economic specialisation. This type of spillovers may be taken as evidence of industry-specific spillovers. As discussed in Section two, industry specific spillovers may have important implications for the effects of economic specialisation.

To take industrial specialisation into account, we construct a variable called the 'compatibility index', which makes use of the observed pattern of citations between sectors and the regions' sectoral specialisation in patenting. If two regions are specialised in sectors that are often observed to cite each other, this combination of regions receives a high score on the compatibility index. The technicalities concerning this index are discussed in the appendix. The compatibility index, denoted by $s_{ij}$, ranges between minus one and one, and the impact of the index on the spillovers between two regions is expected to be positive.[14]

To measure distance between regions, we relied on a simple method. Distance data was constructed by counting the number of regional borders one has to cross to reach one region from another. This yields a region by region matrix of distances for all European regions. The distance variable is denoted by $d_{ij}$. Technicalities regarding the distance matrix are discussed in the appendix.

The literature on national systems of innovation seeks to explore how differences in national history, institutions, policy and traditions may affect countries' innovative capability and competencies. This paper does not aim to explore all aspects of such national systems. To take into account possible effects of national systems of innovation however, we include a dummy-variable for intra-country citations, as well as dummy-variables for each cited and citing country in the sample.

Technology gap models point to a potential for poor countries to catch up with economic and technological leaders. However, as noted in Section two, spillovers not only depend on technology gaps, but also on absorption capability in the lagging country or region, and technological congruence. Taking into account these two variables, Verspagen (1991) argued that while a large gap indicates a large potential for spillovers, it may also imply a low capacity to assimilate spillovers. Thus, (very) low-income regions may become stuck in a kind of underdevelopment trap, unable to make use of spillovers from advanced countries. Medium-income countries may be better placed to take advantage of knowledge created in other countries. In other words, the amount of realized spillovers may well be a non-monotonic function of the size of the gap.

It is hard to judge on *a priori* grounds what constitutes a large gap (i.e., one that hinders spillovers more than it creates potential for it) or small gap (i.e., one that stimulates spillovers). Fagerberg and Verspagen (1995) and Paci (1997) indicate that

[14] We have also experimented with two simpler alternatives for the compatibility index. These alternative indicators do not take into account the inter-sectoral citation linkages. The first alternative is defined as the sum of squared differences between sectoral shares in patenting, the second alternative as the sum of absolute values of these differences. The results with these indicators do not change the results very much. Exact results are available from the authors.

the productivity gaps between some European regions are substantial, and that the disparity is substantially larger at the regional level than at the national level. Thus, one would want to allow for a positive as well as a negative impact of the productivity gap on technology spillovers. We therefore allow for a non-linear relationship between spillovers and the productivity gap, by including a GAP-variable, as well as its squared value. The productivity gap variable GAP is defined as the log of the ratio of GDP per capita in the spillover-receiving and the spillover-generating region.

Finally, we take into account the possibility that the distribution of patents between the receiving and generating region has an impact on the intensity of patent citations. In order to quantify this, we include (the log of) the two region's share of their total patenting, $P_i/(P_i+P_j)$ and $P_j/(P_i+P_j)$ as explanatory variables. If these two variables receive an equal coefficient in the regressions, this indicates that an equal distribution of total patenting (the spillover-receiving region patents as much as the spillover-generating region) is most conducive for growth. Should any of the two variables receive a higher coefficient than the other, this indicates that a distribution in favour of that particular region is most conducive to spillovers. For example, should the log of the share of the spillover-generating region receive a higher share, this indicates that spillovers are maximized when the spillover-generating region patents more than the spillover-receiving region.

Expressing all variables in natural logarithms, we arrive at the following regression model:

$$\begin{aligned} SP_{ij} = \ln\left(\frac{C_{ij}}{P_i+P_j}\right) &= \alpha_0 + \alpha_1 \ln\left(\frac{P_i}{P_i+P_j}\right) + \alpha_2 \ln\left(\frac{P_j}{P_i+P_j}\right) + \alpha_3 \ln d_{ij} \\ &+ \alpha_4 COUNT + \alpha_5 \ln GAP_{ij} + \alpha_6 \left(\ln GAP_{ij}\right)^2 + \alpha_7 s_{ij} \\ &+ \sum_{n=1}^{14} \alpha_n CitedCOUNTRY + \sum_{m=1}^{14} \alpha_m CitingCOUNTRY + \varepsilon \end{aligned}$$

COUNT is a dummy variable for intra-country spillovers. CitingCOUNTRY and CitedCOUNTRY are dummies for the citing and cited individual countries (14 of each). A significant CitingCOUNTRY-result indicates that the country's capacity to absorb spillovers differs significantly from the average. A significant CitedCOUNTRY variable indicates country-specific effects in terms of producing spillovers. ε is the error term in the regression. The model is estimated by heteroscedasticity consistent least squares. The results are reported in table 2.[15]

Only significant results (at the 10 percent level) for the country-specific are reported in Table 2. P-values are given in parentheses. The general impression is that the model fits the data well. The relatively high $R^2$ indicates an overall good fit, and most of the coefficients are significant at better than 1 per cent probability level. This

[15] All reported estimations exclude intra-regional spillovers. These are excluded because we have no way to distinguish between intra-regional, extra-firm spillovers, and intra-regional, intra-firm spillovers, which makes the interpretation of such regressions difficult. We have experimented, however, with regressions including intra-regional spillovers, and this did not change the results markedly. These results are available from the authors on request.

applies to all the structural variables, although some of the country-specific dummies show higher p-values (and some are not significant at all).

The results indicate that there are important barriers to technology spillovers in Europe. This is seen by several results. Firstly, spillovers between a pair of regions decrease significantly with the distance between them. Even if the dependent variable is weighted, making the interpretation harder, the magnitude of the coefficient of the distance-variable is large. A one percent increase in distance decreases the expected spillovers (in terms of the constructed weighted dependent variable) between two regions by 0.37 percent. As an example of the impact of distance, consider the spillovers between Paris and it neighbour-region Picardie. Compared to Picardie, a region that is at distance 2 from Paris (e.g., Wallonie in Belgium) receives 22% less spillovers (ceteris paribus). For a region at distance 8 from Paris (such as Sicily), the percentage is 53.[16]

Secondly, the intra-country dummy-variable (COUNT) is positive and significant. The magnitude of this variable indicates that country-borders significantly hinder knowledge spillovers. This finding gives some support for the importance of national systems of innovation, although we have not investigated whether this result is due to language, institutions or other factors.[17]

Thirdly, the impact of the GAP-variable should be noted. The sign of the estimated coefficients indicates a hill-shaped parabola, i.e., knowledge spillovers decrease with the size of the gap (on both size of the vertical axis). The top of the parabola (i.e. the value of the GAP-variable that ceteris paribus maximises the amount of spillovers) occurs for a value of lnGAP slightly less than zero.[18] This indicates that a small productivity gap (i.e., the spillover receiving region lags somewhat behind relative to the spillover-generating region) is most conducive for spillovers. Very poor regions and very rich regions do not receive many spillovers from other regions. For very rich regions, this may indicate that its high technological competency relative to the other region reduces the potential for learning. For very poor regions, the result indicates that poor regions lack absorptive capacity to benefit from technology developed elsewhere. This result thus gives support for the existence of low-growth underdevelopment traps, as found, e.g., in Verspagen (1991) for a large sample of countries at different levels of development. It also indicates that spillovers do not flow so easily between core and periphery, but rather tend to stay within a group of already relatively well-developed regions.

The importance of technological compatibility for spillovers is also supported. Regions specialised in sectors that are observed to cite each other often, do in fact cite each other more often than average regions do.

---

[16] Suppressing the other variables, spillovers depend on distance according to the following expression: $Spillovers=Ad_{ij}^{-0.37}$.

[17] This result indicates that country borders significantly affected the *intercept* of the regression line. We tested whether this applied also to the *slope*-coefficients of the other variables, but it was not possible to demonstrate any clear effects. Detailed results are available from the authors on request.

[18] We tested whether the value of the lnGAP variable for which the top of the parabola occurs is significantly different from zero by using a non-linear Wald Test. The null hypothesis (i.e., that the maximum value occurs at lnGAP=0) is rejected at the 10 per cent level, but not at the 5 per cent level (P=0.1, F=2.71).

Finally, patenting activity in both the cited and the citing region impacts positively, (almost) symmetrically and very significantly on spillovers between each pair of regions. This indicates that regions that patent in approximately equal amounts share most spillovers.

Table 2 also reports the coefficients of the significant country-specific dummy-variables.[19] The coefficient for the *citing* country was negative and significant for 9 countries. These countries receive significantly less knowledge in terms of patent citations than other countries. Also, 9 countries are cited relatively less than other countries. This indicates that these countries *produce* less spillovers than other countries. Germany, Denmark and Portugal are the only three countries that produce relatively more spillovers than others do. The results on the country-specific dummy variables indicate effects of the individual countries' national system of innovation (defined as everything affecting individual countries). Thus, these results indicate to what extent the particular countries have systems of innovation that effectively absorb or produce spillovers.

Because of the logarithmic relation used, all observations in which either the numbers of patents or the number of citations are zero were not included in the regressions. About half of all pairs of regions do not cite each other. Thus, excluding these leaves a biased and not representative sample. The easiest way to include the zero-observations is to add a small value to the (raw) citations variable. This makes it possible to take log of these numbers, although they receive small weights due to the fact that logarithmic functions approach minus infinity for numbers approaching zero. The results reported in table 3 below are obtained by adding 0.0001 to the observations of inter-regional patent citations.

The signs of the coefficients are the same as in Table 2. However, the magnitudes of the coefficients (except for the compatibility index) are larger than in the case when the zero observations were excluded. Also, the linear GAP variable loses significance. These changes relative to Table 2 may reflect the fact that the logarithmic expression gives a large and negative effect on the observations that are very small (smaller than zero). The fit is somewhat reduced when these observations are included.

Since least-square regressions are based on assumptions of normally distributed residuals, and because our addition of 0.0001 is rather arbitrary, the results in Table 3 may be based on a mis-specified model. In order to test for a different specification, we experimented with a probit regression model. This model estimates the (marginal) effects on the *probability* (not the propensity) that two regions cite each other by a (marginal) increase in the explanatory variables in the model. We thus estimate the probability that (any) spillovers occur, rather than the magnitude of the spillovers. Thus, this model has a quite different interpretation than the previous one. Given this different interpretation, we use the number of citations rather as the dependent variable, rather than the relative citation variable used so far. As a consequence, we also substitute $\ln P_i$ and $\ln P_j$ for $\ln(P_i/[P_i+P_j])$ and $\ln(P_j/[P_i+P_j])$ as explanatory variables. The results are given in Table 4.

[19] Note that the coefficients and significance of the country-specific variables turned out fairly sensitive to model specification. This does not apply to same extent for the other variables. Detailed results are available from the authors.

The signs of the estimated coefficients in Table 4 are similar to the ones in Tables 2 and 3, and mostly significant. The only two variables that are not significant are the GAP variables. Thus, while the amount of spillovers appears to be a non-linear function of the GAP, this does not seem to hold for the probability that any spillovers occur. The obtained pseudo $R^2$ is quite high, indicating an overall good fit.

## 6. Conclusions

This paper investigates whether knowledge spillover flows in Europe take place within one large European system of innovation, or within several localised systems of innovation, with little flow between those systems. The descriptive analysis of innovation activities as measured by patenting statistics revealed that there is indeed a large degree of concentration in terms of patenting. Thus, there are clearly some regions or clusters of regions that can be characterised as 'high-tech', and others as 'low-tech'.

We used patent spillovers as an indicator of knowledge spillovers. This means that we focus on a particular part of spillovers only, namely that part which is most directly related to the innovation process itself (so-called pure knowledge spillovers). In other words, our conclusions relate to the impact of spillovers on the efficiency of the invention process, rather than to the broad economic impact of technology spillovers. (Naturally, invention and innovation have such an impact, but we do not measure this aspect). Our regression analysis on the flows of spillovers between regions (as measured by patent citations) reveals that there are four main factors that limit technology flows across Europe.

Firstly, spillovers are more extensive between regions with similar or complementary specialization patterns. Partly, this is due to the fact that knowledge flows more easily within sectors than between them. Inter-sectoral spillovers occur mostly between sectors that are technologically linked (e.g., electronics and computers).

Secondly, distance matters a lot for inter-regional citations. There is a clear negative and strong impact of distance on spillovers from one region to another. There are several aspects that need more investigation, however. The data used for this paper have no time dimension. Jaffe and Trajtenberg (1996) found evidence that the impact of distance decreases over time.[20] It is important to discriminate between two possible implications of this. Decreased effects of distance over time may imply that knowledge diffuses slowly. However, reduced impact of distance as time passes by may also imply that technological change enhances knowledge diffusion. If the second interpretation is right, as a consequence of e.g. improved communication-technology, the age of localised knowledge may eventually come to an end. This study does not allow any conclusions on this question.

Thirdly, the data reveal that knowledge flows more freely within than across national borders. Intra-country spillovers are more extensive than inter-country spillovers. Thus, the concept of national systems of innovation seems to be relevant for technological competencies among European regions. However, the impact of

[20] See also Verspagen and De Loo (1997) for a discussion of the time dimension in European patent citation statistics.

national systems of innovation may be similarly (or even more) reduced by developments in communication technology and by European integration. Thus, future research should investigate whether the impact of country-borders has decreased over time.

Fourthly, productivity gaps play an important role in the spillover process through their impact on absorptive capacity. Spillovers are most effective when the receiving region lags somewhat (but not too much) behind the spillover generating region. Also, we find that regions that patent in approximately equal amounts (i.e., regions that are on approximately equal technology levels) share most spillovers. This result is to be taken as a confirmation of the result from technology gap theories that technology diffusion is in no sense automatic, but demands a certain level of economic development, in addition to innovative efforts and favourable institutional settings. In particular, this shows that in the European context, spillovers are mostly taking place between a limited set of already fairly highly developed regions.

This leads us to the conclusion that the European system of innovation, as far as the role of knowledge spillovers is concerned, is to be characterized as one with polarisation between several centres, rather than a single system without major barriers for knowledge flows. Within these individual centres of polarisation, knowledge flows relatively freely, helped by relatively small productivity gaps, small geographical distances, absence of national borders and similar or complementary specialization patterns. Spillover flows from the individual centres to more peripheral regions is hindered by unfavourable conditions for flows as indicated by these variables.

**Appendix on data-construction and -sources**

*Patents*

Data on patents are from the European Patent Office (EPO, 1996). The patent data contain the address of the innovator(s) and the patent-applicant(s) of each patent. For the purpose of this paper, it is the address of the innovator(s) that are used to assign regions (NUTS level 2) to patents. In the data provided by EPO each patent is assigned to one main technology class. Based on the concordance table in Verspagen et al (1994) these technology classes are assigned to 22 economic sectors. Thus, the EPO patent data are used to construct data on patenting in 112 European regions, including Ireland, Norway, Denmark and Finland for which regional breakdowns are not available. In the data used in this paper one mid-Swedish region is lacking. EPO also provide data on patent citations. To preclude or limit patent protection, the patent offices search previous patent applications in the same and related technology classes, and refer to relevant existing patents. These references constitute links between related patents and are thus used as indicators of technological spillovers.

*Geography*

There is no coherent data on distance between European regions available. For the purpose of this paper, such data was constructed on basis of maps of European regions from Eurostat (NUTS level 2) (Eurostat, 1995). The distance between two regions was set as the smallest number of regions one has to cross to reach one region from another one. Thus, intra-regional distances were set equal to zero, the distance between two adjacent regions was set equal to one and so on. In case of sea between two regions a "dummy-region" was constructed. Thus, the distance from e.g. French regions next to the English Channel and the corresponding English regions was set equal to two. The procedure yielded a matrix of distances between 113 European regions.

*Economic development*

The data on economic development are regional (NUTS level 2) GDP in PPP per habitant in ECU from 1992 and are taken from EUROSTAT (1997). GDP data from Norway are from Statistics Norway (1997).

*Regional compatibility*

The index for regional sectoral compatibility between two regions (region i and j), $s_{ij}$, was calculated in the following way. The starting point is a matrix $Z$ which describes the sectoral citation relations. In this matrix, the element $Z_{pq}$ denotes the number of patents originating from sector $p$ cited by sector $q$. We construct a new matrix $z$ by dividing the elements of $Z$ by the column sums, i.e., $z_{pq} = Z_{pq} / \Sigma_p Z_{pq}$. The matrix $z$ describes the distribution of a sector's received spillovers over spillover generating sectors. For each region $i$, we now calculate the share of sector $p$ in total patenting as $\sigma_{ip} = P_{ip} / \Sigma_p P_{ip}$, where $P$ is the number of patents. The next step is to calculate, for each region, 22 (i.e., the number of sectors) correlation coefficients $\rho_{ip}$ between $z_{pq}$ and $\sigma_{ip}$. Now calculate the share of a region in patenting of sector $p$ as $\chi_{ip} = P_{ip} / \Sigma_i P_{ip}$. The regional sectoral compatibility between regions $i$ and $j$ is now calculated as

the correlation coefficient between the 22 observations on $\rho_{ip}$ and $\chi_{jp}$. This correlation coefficient measures to what extent the sectoral patenting structure of region *j* is likely to be cited by region *i*, given the sectoral structure of *i* and the sectoral citation linkages. The range of the compatibility index is between minus one and one, where minus one denotes that there is no probability of region i citing region j, and one means that the sectoral distribution in patenting in the two regions perfectly envisage citation. Note that this measure of regional sectoral compatibility is not symmetric so that generally, $s_{ij} \neq s_{ji}$.

**References**


Abramovitz, M. (1985) *Catching Up and Falling Behind*, Economic Research Report No. 1, Trade Union Institute for Economic Research, Stockholm.

Antonelli, C. (1996). "Localized knowledge percolation processes and information networks." *Journal of Evolutionary Economics* **6**: 281-295.

Caniels, M. (1996) *Regional Differences in Technology. Theory and Empirics.* MERIT Research Memorandum, 2/96-009, Maastricht.

Coe, D. T. and Helpman, E. (1995): "International R&D spillovers", *European Economic Review*, 39, pp. 859-887.

Cohen, W, M. and D. A. Levinthal (1989) "Innovation and Learning: The two Faces of R&D", *The Economic Journal*, 99, pp. 569-596.

David, P. A. and D. Foray (1994). The economics of EDI standards diffusion. *Global telecommunications strategies and technological changes*. G. Pogorel. Amsterdam, North Holland.

European Patent Office (1996) *European Patent Bulletin Information on CD-ROM,* Wien.

Eurostat (1997) *Regional Statistics*, Electronic Version, New Cronos Systems, Luxembourg.

Eurostat (1995) *Regions – Nomenclature of territorial unit for statistics*, Luxembourg.

Fagerberg, J. (1994): "Technology and International Differences in Growth Rates", *Journal of Economic Literature,* Vol. XXXII, pp. 1147-1175.

Fagerberg, J. and B. Verspagen (1996) "Heading for divergence? Regional growth in Europe reconsidered", *Journal of common market studies*, 34, pp. 431-448.

Fagerberg, J., B. Verspagen and M. Caniëls, 1997, "Technology, Growth and Unemployment across European Regions", *Regional Studies*, 31, 5, pp. 457-466.

Griliches, Z. (1979) "Issues in assessing the contribution of research and development to productivity growth" *Bell Journal of Economics* 10, 1, pp. 92-116.

Griliches, Z. (1990) "Patent statistics as economic indicators: A survey" *Journal of Economic Literature*, 2, 4, pp. 1661-1797.

Griliches, Z. (1992) "The Search for R&D Spillovers", *Scandinavian Journal of Economics,* 94, pp. 29-48.

Grossman, G. M. and E. Helpman (1991) *Innovation and growth in the global economy,* MIT Press, Cambridge, Massachusetts.

Grossman, G. M. and E. Helpman (1995) "Technology and Trade" in Grossman, G. M. and Rogoff, K. (1995) *Handbook of International Economics – vol. 3,* North Holland, Amsterdam, pp. 1279-1337.

Haavelmo, T. (1956) *A Study in the Theory of Economic Evolution*, North Holland Publishing Company, Amsterdam.

Jaffe, A. B. and M. Trajtenberg (1996) *Flows of Knowledge from Universities and Federal Labs: Modelling the Flow of Patent Citations over Time and across Institutional and Geographical Boundaries,* NBER Working Paper 5712, Cambridge Massachusetts.

Henderson, R, A. B. Jaffe and M. Trajtenberg, and (1993) "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations", *Quarterly Journal of Economics,* 108, pp 577-598.

Kaldor, N. (1978 – 70) "The Case for Regional Policies" in *Further Essays on Economic Theory*, Holmes & Meier Publishers, New York, pp. 139-155.

Krugman, P. (1979) "A Model of Innovation, Technology Transfer, and the World Distribution of Income" *Journal of Political Economy,* 87, 2, pp. 253-266.

Krugman, P. (1986) "A "Technology Gap" Model of International Trade" in Jungenfelt, K. and D. Hauge (ed.) *Structural Adjustment in Advanced Economies,* Macmillan.

Lundvall, B.-Å. (1992) *National Systems of Innovation – Towards a Theory of Innovation and Interactive Learning,* Pinter, London and New York.

Marshall, A. (1948) *Principles of Economics,* 8th ed, 6th print, The Macmillan Company, New York.

Mohnen, P. (1992). *The Relationship Between R&D and Productivity Growth in Canada and Other Major Industrialized Countries*. Ottawa, Economic Council of Canada.

Morgan, K. (1997). "The Learning Region: Institutions, Innovation and Regional renewal." *Regional Studies* **31**: 491-504.

Nelson, R. R. (ed) (1993) *National Innovation Systems – A Comparative Analysis,* Oxford University Press, Oxford.

OECD/EUROSTAT (1995). *Classification of high-technology products and industries*. Paris, OECD.

Paci, R. (1997) "More Similar and Less Equal: Economic Growth in the European Regions" *Weltwirtschaftliches Archiv,* 133, 4, pp.

Paci, R. and S. Usai (1997). Technological enclaves and industrial districts. An analysis of the regional distributions of innovative activity in Europe. *CRENOS Working paper*. Cagliari, University of Cagliari.

Rebelo, S. (1991) "Long-Run Policy Analysis and Long-Run Growth" Jorunal of Political Economy, 99, 3, pp. 500-521.

Romer, P. (1990) "Endogenous Technological Change" *Journal of Political Economy,* 98, pp. 71-102.

Saxenian, A. (1994). *Regional Advantage. Culture and Competition in Silicon Valley and Route 128*. Cambridge MA and London, Harvard University Press.

Statistics Norway (1996) *Statistisk Årbok,* Official Statistics of Norway, Oslo-Kongsvinger.

Sjøholm, F. (1996) "International Transfer of Knowledge: The Role of International Trade and Geographic Proximity" *Weltwirthschaftliches Archiv,* 132, pp. 97-115.

Sjøholm, F. (1997) "Knowledge inflow to Sweden. does geography and international trade matter?" in Fagerberg et. al (eds) (1997) *Technology and International Trade* Edward Elgar, Cheltenham, pp. 127-139.

Vernon, R. (1966) "International Investment and International Trade in the Product Cycle", *Quarterly Jorunal of Economics,* LXXX, pp 190-207.

Verspagen, B. (1991) "A New Empirical Approach to Catching Up and Falling Behind", *Structural Change and Economic Dynamics,* 12, pp. 374-397.

Verspagen, B. (1993) *Uneven Growth Between Interdependent Economies – A evolutionary view on technology gaps, trade and growth*, Avebury, Aldershot.

Verspagen, B. (1997a) "Measuring Intersectoral Technology Spillovers: Estimates from the European and US Patent Office Databases" *Economic Systems Research,* Vol. 9, No. 1, , pp. 47-65.

Verspagen, B. (1997b) "Estimating International Technology Spillovers Using Technology Flow Matrices", *Weltwirtschafliches Archiv*, 133, 2. pp. 226-248.

Verpsagen, B. and I. De Loo (1998) *Technology Spillovers between Sectors and over Time,* MERIT Research Memorandum, 2/98-007, Maastricht.

Verspagen B., T van Moergastel and M. Slabbers (1994) *MERIT concordance table: IPC - ISIC (rev.2)*, MERIT Research Memorandum, 94-004, Maastricht.

Young, A. (1928) "Increasing Returns and Economic Progress", *The Economic Journal*, XXXVIII, 152, pp. 527-542.

**Table 1. Concentration of patenting over European regions for 22 manufacturing sectors, total patenting and high-tech patenting**

| | HF-index |
|---|---|
| Pharmaceuticals | 0.075 |
| Computers and office machines | 0.073 |
| Ferrous basic metals | 0.071 |
| Electrical machinery | 0.068 |
| Aerospace | 0.067 |
| Chemicals | 0.064 |
| Refined oil | 0.059 |
| Ships and boats | 0.056 |
| Electronics | 0.055 |
| Motor vehicles | 0.051 |
| **High tech aggregate** | **0.049** |
| Other transport | 0.048 |
| Paper and printing | 0.047 |
| Textiles, apparel, leather | 0.046 |
| Instruments | 0.046 |
| Non-ferrous basic metals | 0.045 |
| **All sectors aggregate** | **0.043** |
| Machinery | 0.042 |
| Metal products | 0.042 |
| Wood and wooden products | 0.041 |
| Food, drinks and tobacco | 0.040 |
| Glass, stone and clay | 0.039 |
| Rubber and plastic products | 0.035 |
| Other manufacturing | 0.034 |

**Source: calculations on EPO data.**

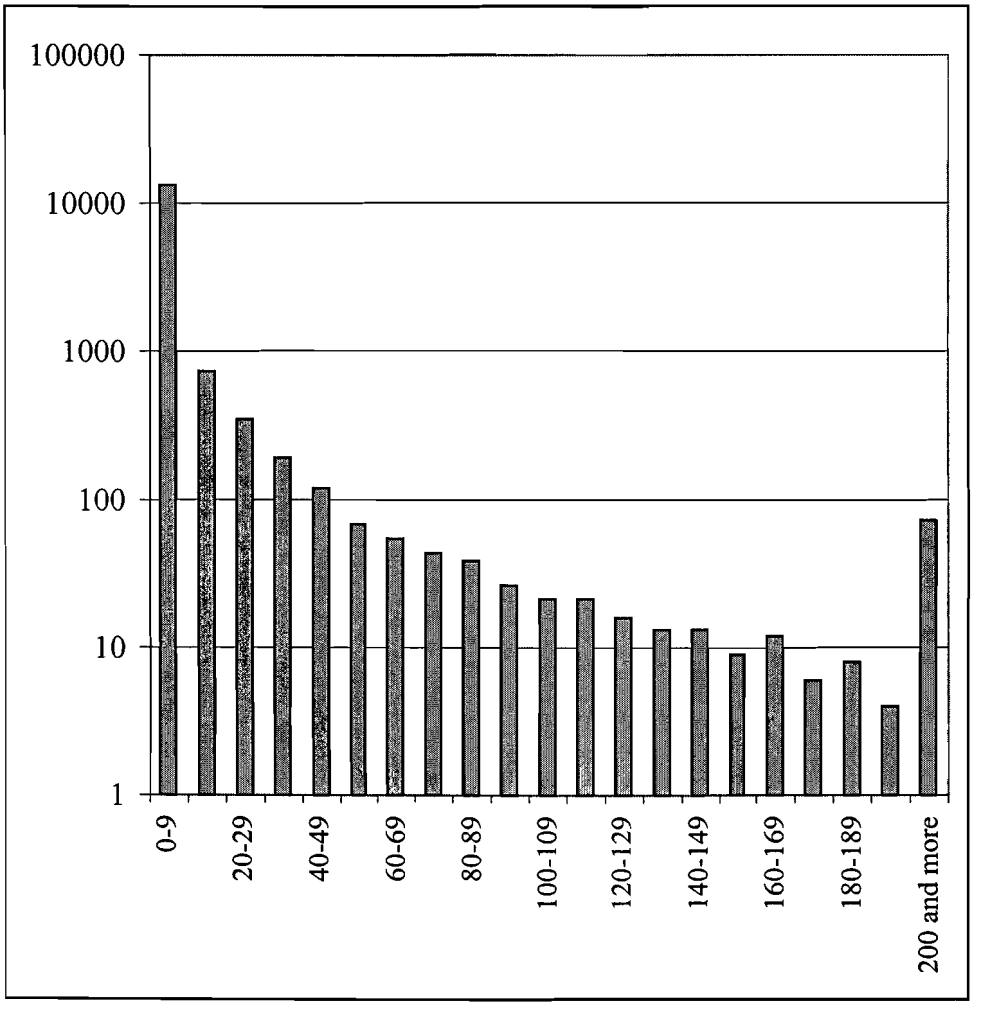



**Figure 1. Frequency of inter-regional citations (vertical axis) vs number of citations (horizontal axis)**

**Table 2. Regression results on spillovers, least squares regression, excluding observations with zero citations. Heteroscedasticity-consistent P-values.**

| Dependent variable: $\ln(C_{ij}/[P_i+P_j])$ | $R^2$=0.47 | Numbers of observations 6341 |
|---|---|---|
| **Variable** | **Coefficient** | **P-value** |
| $\ln(P_i/[P_i+P_j])$ | .5174105 | 0.000 |
| $\ln(P_j/[P_i+P_j])$ | .4984828 | 0.000 |
| $\ln d_{ij}$ | -.3693099 | 0.000 |
| COUNT | .441461 | 0.000 |
| $s_{ij}$ | .758228 | 0.000 |
| $\ln GAP_{ij}$ | .0657392 | 0.084 |
| $(\ln GAP_{ij})^2$ | -.2888199 | 0.000 |
| CitedAustria | -.3804609 | 0.000 |
| CitingAustria | -.3954055 | 0.000 |
| CitedBelgium | -.1009139 | 0.066 |
| CitedGermany | .0744331 | 0.050 |
| CitedDenmark | .147704 | 0.050 |
| CitedSpain | -.3796585 | 0.000 |
| CitingSpain | -.1935664 | 0.032 |
| CitedFinland | -.144358 | 0.086 |
| CitedFrance | -.3584707 | 0.000 |
| CitingFrance | -.389756 | 0.000 |
| CitedIreland | -.1422584 | 0.082 |
| CitingIreland | -.4010963 | 0.000 |
| CitingItaly | -.2087445 | 0.013 |
| CitedItaly | -.3006061 | 0.000 |
| CitingNetherl. | -.3032179 | 0.000 |
| CitedNetherl. | -.1638283 | 0.000 |
| CitedNorway | -.311349 | 0.000 |
| CitingNorway | -.3788722 | 0.000 |
| CitedPortugal | .4058662 | 0.035 |
| CitingSweden | -.4994988 | 0.000 |
| CitedSweden | -.200282 | 0.000 |
| CitingUK | -.2205901 | 0.008 |
| Constant | -5.528802 | 0.000 |

Note: 28 country-specific dummy variables included in regression. Only those significant at ten percent level or better in one or both regressions are reported.

**Table 3. Estimation result when observations of no citation were included, least squares regression. Heteroscedasticity-consistent P-values.**

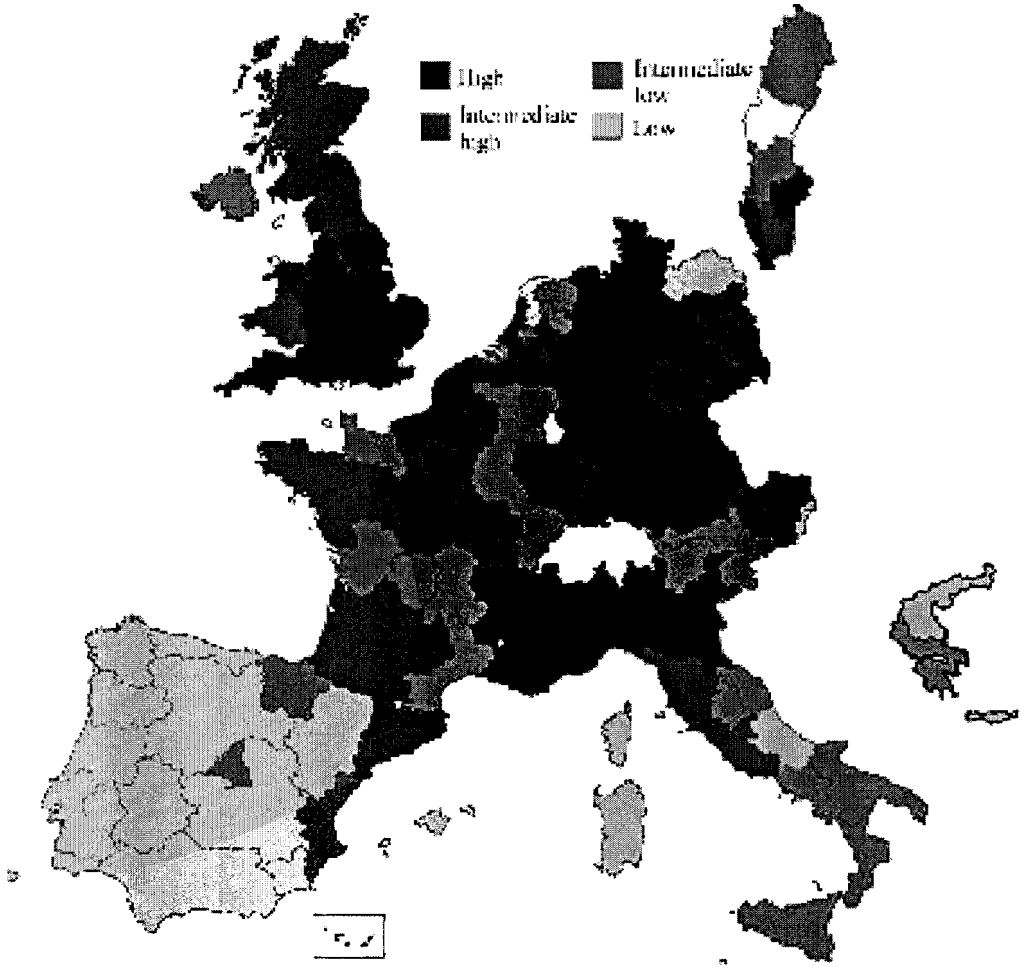
| Dependent variable: $\ln(C_{ij}/[P_i+P_j])$ | $R^2$=0.41 | Numbers of observations: 12432 |
|---|---|---|
| **Variable** | **Coefficient** | **P-value** |
| $\ln(P_i/[P_i+P_j])$ | .8919232 | 0.000 |
| $\ln(P_j/[P_i+P_j])$ | .9304383 | 0.000 |
| $\ln d_{ij}$ | -1.839696 | 0.000 |
| COUNT | .2210878 | 0.084 |
| $s_{ij}$ | 1.022066 | 0.000 |
| $\ln GAP_{ij}$ | .1840636 | 0.143 |
| $(\ln GAP_{ij})^2$ | -.3519486 | 0.033 |

Note: 28 country-dummies included in regression, but not reported.

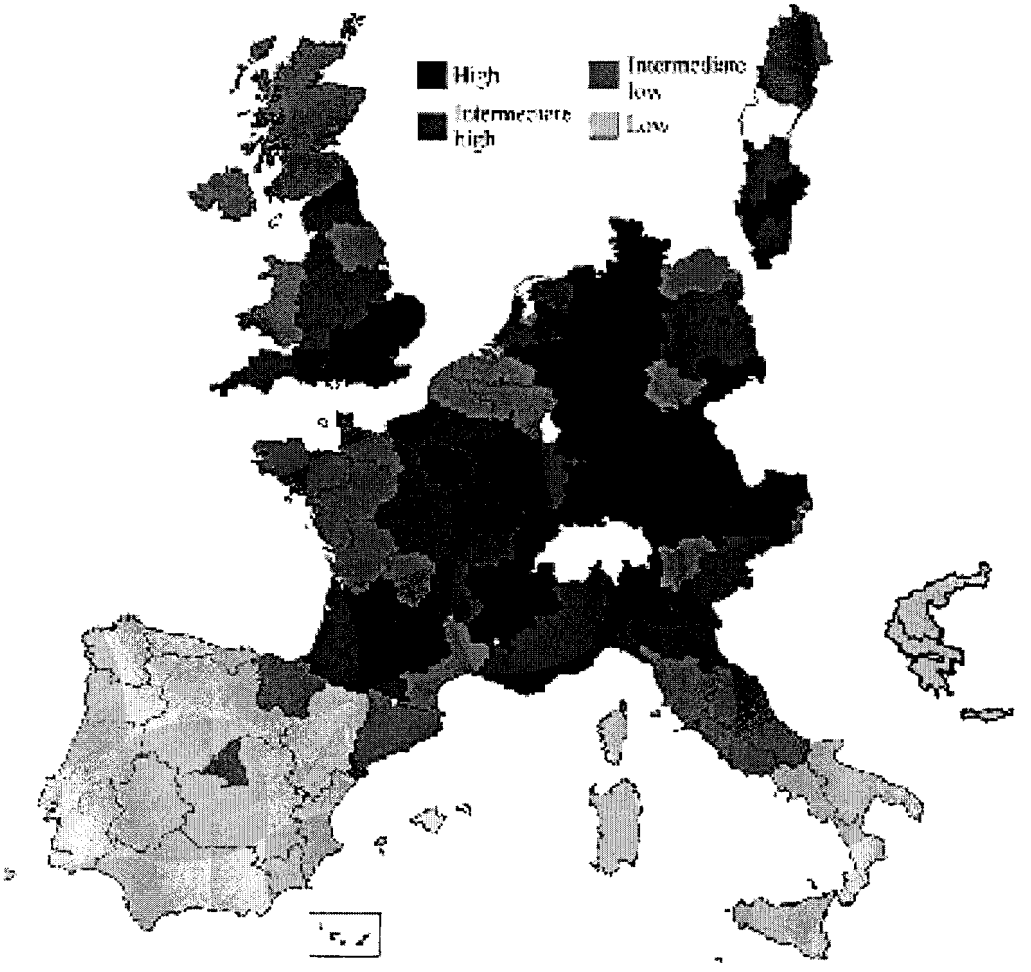
**Table 4. Estimation result when observations of no citation were included, probit estimation. Heteroscedasticity-consistent P-values.**

| Dependent variable: Yij=Cij | Pseudo-$R^2$=0.61 | Numbers of observations: 12432 |
|---|---|---|
| **Variable** | **Coefficient** | **P-value** |
| $\ln P_i$ | .7792036 | 0.000 |
| $\ln P_j$ | .8011874 | 0.000 |
| $\ln d_{ij}$ | -.4117427 | 0.000 |
| COUNT | .5306639 | 0.000 |
| $s_{ij}$ | .6786857 | 0.000 |
| $\ln GAP_{ij}$ | .116141 | 0.129 |
| $(\ln GAP_{ij})^2$ | .0043662 | 0.966 |
| Log-likelihood* | -3340.078 | |

Note: 28 country-dummies included in regression but not reported. Pseudo-$R^2$=1-$L_1/L_0$, where $L_0$ is the value of the log-likelihood function with the constant only $L_1$ is the value with all the variables included. *Log-likelihood after 6 iterations.




**Map 1. Patent applications at EPO 1979 – 1996 (share in total)**




**Map 2. Patent applications at EPO 1979 - 1996 per head of population in 1990**