Innovation, Demand and Knowledge Spillovers: Theory and Evidence from European Regions*

Laura Bottazzi
(Universita' Bocconi, IGIER and CEPR)

Giovanni Peri
(Universita' Bocconi and IGIER)

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Abstract

The Importance of innovation for the economic performance of industrialized countries has been largely stresses recently by the theoretical and empirical literature. The performance of European regions has been disappointing in this respect but very few studies have carefully considered the determinants of European innovation and the productivity of its R&D. Here we develop a model which, emphasizing "the demand pull" as a key exogenous determinant of long-run innovation, allows us to empirically determine the importance of within region relative to external R&D as a generator of innovation. We find that, most of the cross-regional differences in innovation rates, can be explained by within region, market driven, R&D but important spillovers happen among geographically close regions, especially if technologically similar.

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1. Introduction

Some economists believe that technological innovation has been the most important factor in explaining labor productivity growth in this century[1]. In the last decades innovation has become an even more important contributor to economic well-being and to the comparative advantages of industrialized countries, as the nations of the world economy are becoming increasingly open and interdependent. The process of opening of the economies facilitates communication and the exchanges of ideas and, thanks to their diffusion, the process of innovation itself. Spillover benefits, it is argued, are not restricted to the national level[2], nor to the most narrowly defined industries. They may spread through sectors, space and time, affecting productivity and growth worldwide. Nevertheless even a cursory look at countries and regions in the world reveals large disparities in productivity and innovation rates. It becomes therefore crucial to take a closer look at the diffusion of technology and in particular at the internal and external effect of research and development in generating innovation to understand this phenomenon.

Knowledge diffusion occurs through i) "temporal spillovers": the research and development process takes time to reveal its innovative output. Hence it becomes relevant to analyze the stock of existing ideas and the time structure of research and innovating activity; ii) "sectoral spillovers": the level of knowledge in any sector depends on its own research and development investment as well as on that in other, technologically similar, sectors or industries and iii) " spatial spillovers" : possible effects of research and development might depend on the physical proximity of industries and laboratories.

The aim of this work is to analyze the importance of research and development and of knowledge diffusion, via sectoral and spatial spillovers, in shaping the distribution of innovative activity among European regions. Why innovation is so highly localized among European regions (as in the world)? Does the pattern of clustering of innovation follow the one of production?

This is the question we want to address in this paper. while the marginal cost of transferring information across geographic space has been made invariant by the tele-communications revolution, the marginal cost of transferring knowledge, especially tacit knowledge, rises with distance[3]. If this is the case, spatial proximity and geography should matter for the innovative activity: the local dimension is still important and the regional dimension is most relevant, especially at the European level, where border effects are still important. The interaction

[1]Most quoted and popular reference: Solow (1957)
[2] see among others Coe and Heplman (1995), Eaton and Kortum (1996) and Eaton, Gutierrez and Kortum (1998)
[3] See D.B.Audretsch (1998)

of an “initial”(exogenous) high market potential in dense and central European regions, which makes them large and profitable markets for innovation, together with increasing returns to innovation and localization of the knowledge spillovers, seem to explain this pattern of high concentration.

To be able to understand the process of generation of innovation at the regional level, as well as to identify spatial and sectoral knowledge spillovers across regions, we need to adapt the theory of the innovation process in a way that captures some of the characteristics of a regional economy: specialization in a range of products, responsiveness to the local conditions of the market, relatively high mobility of skilled worker but low mobility of unskilled workers (and of overall population) across them. Also we want to empirically assess the importance of our theoretical framework. The vast theoretical literature that combines a Schumpeterian approach in a general equilibrium set-up (see Aghion and Howitt (1998) for review of the literature and references) has not been accompanied by the development of an empirical literature of the same dimension. More recently Caballero and Jaffe (1993) and Eaton and Kortum (1996) moving from the theoretical approach of the new growth theory have tried to assess the importance of R&D on innovation estimating a general equilibrium model for innovation in the US or across countries in the world. Jaffe (1986), Feldman(1994) and Audretsch and Feldman (1996) have modified the model of knowledge production function to

Two things are worth mentioning up front. Although the decision to invest in R&D and therefore to innovate, is endogenous to the economic process, and actually driven by the size of the market for an innovation, we do not impose any strong assumption on returns to accumulation of knowledge. The model may generate endogenous growth, whose rate will depend on an average of the R&D investment across regions, or just converge to an exogenous growth rate, which depends on the growth rate of human capital. What certainly happen is that, in balanced growth, the relative rate of innovation across regions and the relative rate of innovation depend on the intensity of R&D in those regions. This very general result allows us to estimate, using relative patenting rates, the productivity of R&D in generating innovation and the intensity of spillovers.

The “local market potential”, which we capture simply with the regional population and its age-structure, is an exogenous variable and actually can explain 35% of the cross regional variation in research intensity.

The structure of the paper is the following: in section 2 we review some empirical facts to show the relevance of the chosen topic and frame it, section 3 is devoted to some review of the related literature, in section 4 we present our model and in section 5 the econometric specification of the fundamental estimated equation. Section 6 presents the data and the empirical results. Section 7 concludes the paper.

2. Some thoughts and Empirical Facts

Technology is a form of knowledge that bears some peculiar properties. First it is a non-rival input in the generation of new knowledge. The use of an idea to produce goods and services by an agent does not preclude any other person to built on it in order to generate a new one (Romer 1990). Secrecy is certainly a way to prevent knowledge diffusion and it is often used by firms to exclude other people from the use of new ideas[4]. However that happens even in the case of a patent, which is public. In fact the research that leads to it and the background ideas are not made public and they may be kept known only to a restricted number of people, at least for a while.

This partial non-excludability of knowledge suggests that R&D, may generate "technological spillovers" and that these spillovers may nevertheless be restricted in space. As Glaeser et al. (1992) put it " intellectual breakthroughs must cross hallways and streets more easily than continent and oceans". The mobility of workers through sectors, firms and space may be a way of spreading innovation, the local formal and informal communication may be another way. All these means are likely to spread ideas, first in the proximity of the place where they have been generated and only later in the rest of the world. In particular, when we consider applied and non-codified knowledge versus theoretical and perfectly codified one, the advantage of geographical proximity consists in the need of a face-to-face interaction to effectively learn from other people's ideas[5]. Hence, while general information is more easily diffused, specific knowledge justifies the concentration of innovation in space, to take advantage of these "externalities"[6].

But is this the whole story? Are knowledge spillovers a factor of first order importance in generating agglomeration of innovative activity? Our strong suspect is that there is another local determinant of knowledge creation, which has a more important effect on innovation, and this is local demand. Innovation clusters where most of the European population is and has been for the last 100 years (see Figures 1,2 and 3). If determinants of research and innovation are "endogenous" to the economic system, they must be the profits that innovation generates: what better engine to generate innovation than a large local market for the new products or processes which innovation will bring to life? If this is a mechanism that generates concentration of innovative activity, then

[4] secrecy is considered the best method for maintaining and increasing competitiveness of their innovation. See the Community Innovation Survey made by the European Commission .
[5] For an in depth analysis of the importance of face-to-face interaction in developing ideas see Gaspar and Glaeser 1998.
[6] The classic references of the importance of "ideas in the air" is, of course, Marshall (1890).

spillovers and increasing returns to knowledge may further contribute to lock in the process and explain the higher concentration of innovation over demand.

Data analysis confirm the clustering of the innovative activity. The intensity of innovative activity is very different across space in the European regions [7]: the top five patenting regions (Northrein-Westfalia, Bayern, Waden-Wurtenberg, Ile de France and East Anglia) are responsible for 50% of total patents as well as almost 50% of total R&D expenditure, and the bottom 11 regions have almost no patenting at all in the 1977-1995 period.

Figure 1, figure 2 and figure 3 show the geographic concentration of R&D expenditure, patents and demand (population density) in Europe. It is easy to see how the central European regions, and in particular Germany and France, show the highest concentration as regards all three dimensions and how innovation is more concentrated than demand. The eye effect is confirmed by computing an Herfindhal concentration index of R&D for the 86 regions of our sample.

The H-index has a value of 0.17 while the value of the index, where R&D equally distributed among European regions, would be 0,01160. The same computations for patenting gives us an H-index of 0,145. Production (GDP) and population are less concentrated: the H-index has a value of 0,049 and 0,039 respectively.

How much of these disparities in innovative output is due to R&D intensity in the regions? A simple regression shows that average long run R&D expenditure explains almost 85% of the cross regional variation in long run patenting intensity, and the elasticity of patenting to R&D spending is significantly larger than one[8]. This tells us two things:

1) These very high returns to regional R&D could be the sign of increasing returns in own research, and certainly within region spillovers may be responsible for this. Certainly differences in R&D explain the large part of differences in innovation.
2) There may be, nevertheless, a role for inter-regional spillovers, in explaining the rest of the variation in innovative activity. In particular some occasional examples tell us that the location of a region is importantly correlated with its productivity in innovation. Looking at two regions with the same average total spending in R&D for the period 1985-1995 as Madrid and Hamburg (roughly sixty-four 1985-U.S. Dollars per worker) the peripheral region of Madrid produced about one tenth of the patenting per worker that the central region of Hamburg and, similarly, the peripheral region of Lazio (Italy) produced about one thirtieth of the patenting per worker

[7] the same is true for the US. Also,few countries are the generators of most of the patenting that takes place world-wide Inventors from US, Japan, Germany, France and the UK advance 81% of the patent application at the European Patent Office

[8] Elasticity = 1.12, standard error=0.05: This result is just a stylized fact, we will consider the endogeneity problem seriously in the empirical part.

than the central region of south-Netherland[9]. The same is true for the central French region of Champagne-Ardenne that produces the same patenting per worker than the peripheral French region "Midi'-Pirennee" using less than one third of the R&D resources (28 US $ per worker versus 91)? Are these example mere exceptions or there is a systematic effect of the neighbor regions on the innovative activity of one region?

The percentage of workers in R&D is highly and positively correlated with the population of a region (measure of the market size) and about 25% of the cross regional variation in this percentage is explained by the size of the population[10]. Therefore the population of a region and its demand create incentives for investing in innovation, and as the spillovers of ideas remain local, this generates higher polarization of innovation. The marginal mobility of human capital tends to reduce the differences in wage that could arise, so that income per worker is less unequally distributed. Nevertheless, the variation in the intensity of innovation is an important determinant of the variation of the productivity per worker in Europe. It explains about 13% of the cross sectional variation of workers' productivity by itself. Compared, for example, with a measure of education, which is known to have an important impact on productivity, the fraction of college educated people in one region explains only 7% of the cross sectional variation of productivity per worker[11]. We think therefore that we are considering an extremely important problem, per se, that of understanding and measuring the importance of own and local research in generating innovation, and this problem may shed interesting light on the other, more economically relevant, problem of explaining cross-regional differences in productivity.

3. Related literature

The idea developed here is very simple. Resources and knowledge can be combined to produce new knowledge, some of which spills over to the research community and facilitates the subsequent creation of knowledge. We develop a multi-sector, multi-region version of the Jones (1995) model, which allows us to determine the relation at the regional level between R&D, innovation, productivity and local demand.

[9] The definition of "central" or "peripheral" is relative to what is considered the economic center of Europe, roughly the triangle London, Paris, Bonn

[10] . This is consistent with the known fact that, for example in the US, most of the innovation, happens in large urban centers (in SMSA, especially in PMSA, see Jaffe et al. (1993)).

[11] The data on educational attainment per region are only available from national sources for Spain, Italy, Germany, France and the UK.

The literature that relates to our paper is twofold. On one hand people have studied agglomeration of production and innovation in space. On the other hand a few paper have related innovation and patenting to the dimension of the market demand. We consider local demand as a proxy for potential profits from innovation[12].

Audretsch and Feldman (1996) document the clustering of innovative activity, especially at the early stage of the life cycle of products, showing that in the initial stage local spillovers are particularly important. Another paper suggesting the existence of local spillovers, by looking at employment and wage data, is Glaeser et al. (1992), that suggest that positive effects come from having a local diversity of industries, generating the so called "Jacobs" (1969) externalities. There is a strand of research, on the other hand, that stresses more intra-industry spillovers as important contributors to innovation, as researching and working on similar things may benefit each other's productivity (Griliches 1992).

The extent of regional specialization versus regional diversity is explicitly addressed in our paper since we consider both spatial and sectoral spillover, finding that technological similarity enhances technological spillovers, once regions are close. A similar approach is followed by Jaffe (1986) who quantifies the effects on the productivity of firms' R&D of an exogenous variations in the state of technology (technological opportunity) and on the R&D of others firms (spillovers of R&D). He finds evidence of spillovers of R&D from several indicators of technological success on the productivity of R&D. In particular he shows that firms whose research is in areas where there is much research by other firms have, on average, more patents per dollar of R&D. He obtains an estimate of firm's R&D elasticity of 0.875 that reaches the value of 1.1 when the effect of R&D from other firms is taken into account. These estimates are very close to ours, as in one region we are internalizing large part of inter-firm spillovers.

The last work that appears particularly interesting in the light of our analysis is Eaton and Kortum (1996) and their analysis of the European countries experience (Eaton et al.(1998)). They estimate a general equilibrium model on cross-country data, which defines simultaneously the dynamics of innovation and productivity growth. Their specification of a patenting equation allows them to find a measure of the productivity of resources used in R&D in generating innovation. They find that technology diffusion between countries falls as the distance between them grows. Also, human capital raises the ability of a country to absorb technology and the elasticity of ideas production with respect to research employment is estimated to be close to unity. Therefore technology diffusion is significant and proportional to the countries' ability to absorb innovation.

[12] The existence literature studies the relation between innovative activity and profitability, by concentrating the attention on the degree of competitiveness versus monopoly of a market. We will not address any discussion on the market structure of the market for innovation

These results confirm the existence of a spillover phenomenon and leave room for the study of the variation of spillovers in different geographical areas.

As regards the role played by demand factors in explaining R&D activity it is worth citing the work by Geroski, Walter and Van Reenen (1996)(GWV) and Gordon (?).

GWV studies the determinants of innovative activity. They find the production of innovation is more sensitive to demand pull preasuures and less sensitive to supply preassure, like industry R&D spending, than patent.

Hanson examines the spatial distribution of economic activity in the US to see to what extent demand linkages, strongly stressed by the new economic geography literature as determinant of agglomeration in production, are relevant empirically. In order to study this issue he express potential demand for goods produced in a location as the sum of purchasing power in all other locations, weighted by transportation costs that take care of distance. His results suggests that the combined effects of scale economies and expenditure share make geographic concentration a stable feature of the spatial distribution of economic activity. His results resemble our empirical findings: demand and knowledge spillovers through space and technology are the important determinant of innovation clustering.

4.The Model

We consider an N regions economy, which is a multi-region[13] extension of a growth model a' la Romer (1990) and Jones (1996). As a first approximation we assume perfect mobility of skilled workers both between production and research and across regions. We consider in the end the effect of introducing some immobility of human capital. We assume that each regional unit experiences continuous innovation and patenting which happens on the frontier of the region's technological level. We could think of N also as the number of aggregate goods (sectors) produced in our economy which would imply that each region specializes in only one sector.

Each region innovates by adding further intermediate goods that increase the productivity of the region itself. In our model the arrival of an innovation and patent does not destroy the profitability of the existing patents in the region, as the extreme effect of creative destruction does in the Aghion and Howitt (1992) model. Instead, if we think that the patented good compete for the local market, then a new patent will certainly squeeze the profitability of the existing patents. We know from a series of studies (e.g. Eaton and Kortum 1996) that most of the patenting is done to protect inventions on the local market and to keep or increase the market share of one firm.

[13] we assume horizontal rather than vertical innovation in the model

Also, we allow for the possibility of spillovers in the level of knowledge across regions. In particular there is a catch-up process, which prevents regions' productivity to grow increasingly apart. Two stylized facts make us more comfortable in describing the situation in European regions in the period 1978-1995 as more correctly captured by a BGP distribution of productivity-levels growing at a common rate rather than diverging over time. First GDP per worker in the European regions has grown at an average annual rate of 0.02 in the period 1978-1992, with a standard deviation across regions of 0.009. Second, in a regression of convergence of productivity growth, the "β" coefficient turns out to be of - 0.55 and significant[14].

In our approach we are close to the spirit of the "endogenous growth" literature since we consider, as determinants of growth, the incentives, endogenously arising from the markets. The existence of some regions where the profits in production is larger than in others, due to demand or technological reasons, is one of the important determinant of R&D allocation. In particular the idea that some characteristics of the regional markets affects the profits from innovating in that region, while they do not affect the productivity of R&D in the region, is the crucial assumption which allows us to identify and estimate the parameters of the "innovation" function.

4.1 Production

Let N be the different regions in the economy. Each region produces a composite good using intermediate non tradable goods, unskilled labor and, possibly, some other local factor. All these characteristics, which differ across regions and affect the total demand for production in the region, are captured by a shifter term in front of the production function of the regional composite good[15]. This shifter will be 1 on average. The aggregate production function in region i is:

(1) $$Y_{it} = D_i \int_{s=0}^{A_i} x_{it}^{a}(s)ds \quad \text{where } \alpha<1$$

where x_{it} is the amount of intermediate good i, produced in monopolistic competition and which is used in the production of the final composite good Y_{it}, A_{it} is the number of intermediate patented goods in the region while D_i is the demand shifter, due to different demand in different

[14] Similarly we do not adopt the specification proposed by Segerstrom (1998), where different R&D soending is compatible with different GDP growth as it would have the implausible implication (in the cross section) of equal rate of patenting in different regions.

[15] This shifter may also capture different prices for the regionally produced composite goods.

regions: it can be seen as a region fixed effect. Each unit of any intermediate good is produced with the use of one unit of skilled labor (as the intermediate goods are complex capital goods) which could also be used in R&D. The total production will simply be a sum of the production in each region. The demand curve for the intermediates will be $p_{it}(s) = D_{it} a x_{it}^{a-1}(s)$ where p_{it}(s) is the price of the s-th intermediate good in region i at time t. The demand for skilled labor by one producer of intermediate good s is:

$$(2) \qquad x_{it} = \left(\frac{w_t}{a^2 D_{it}} \right)^{\frac{1}{a-1}}$$

where we have assumed perfect mobility of labor across regions and therefore a unique wage. The profit of each monopolist in the i region is:

$$(3) \qquad p_{it} = \frac{1-a}{a} w_t x_{it} = \frac{1-a}{a} w_t \left(\frac{a^2 D_{it}}{w_t} \right)^{\frac{1}{1-a}}$$

Let's define with $\overline{A} = \prod_1^N A_i^{1/N}$, the geometric average of the patented goods in different regions. It will be useful to use the following variable:

$$a_{it} = \frac{A_{it}}{\overline{A_t}}$$

which represent the relative patenting of one region with respect to the average.

4.2 The structure of Spillovers

Innovation, in a region, follows a Poisson process whose rate of arrival increases in the amount of resources employed in R&D as well as in the intensity of regional spillovers. We represent this features in the following function:

$$(4) \qquad \frac{\dot{A}_{it}}{A_{it}} = l n_{it} f\left(\frac{A^{S}{}_{i,t}}{A_{i,t}}\right)$$

l is an exogenous parameter which captures the productivity of R&D, in terms of probability of the occurrence of an innovation, n_{it} is the amount of labor employed in R&D rather than in production, and f is a function which captures the effect of catch-up/spillovers.

A_{it} is the technological level of region i at time t, while A^{S}_{it} is the average value of technology in the regions which have a spillover effect on region i. In particular A^{S}_{it} can be different across regions as, due to location in the geographical and technological space, each region could be more affected by some regions rather than others. Let's express A^{S}_{it}, as follows:

$$(4') \qquad A^{S}_{it} = \prod_{j=1}^{N} A_{jt}^{t_{ij}} \quad \text{where} \quad \sum_{j=1}^{N} t_{ij} = 1$$

Our identifying assumption to estimate the parameters τ 's is to consider them depending only on the geographic or the technological distance among regions.

If we call g_x the rate of change of the variable x, and ε_f the elasticity of the function f with respect to its argument, then we can take the rate of change on each side of expression (4), assuming no human capital growth[16], and we have:

$$(5) \qquad \dot{g}_{A_i} = g_{A_i}\left[e_f g_{\bar{A}} - e_f g_{A_i}\right] \qquad \text{for i= 1,2…N}$$

It is easy to see that it exists a BGP, where all sectors' technology grows at a constant and equal rate. The common rate of growth can be written as:

$$(6) \qquad \overline{g_A} = l\,\overline{n}\,\overline{a}^{(\bar{t} - 1/N)}$$

where $\bar{n} = \prod_1^N n^{1/N}$ and $\bar{a}^{(\bar{t}-1/N)} = \prod_1^N a_i^{\bar{t}_i - 1/N}$ and $\bar{t}_i = \sum_{j=1}^N t_{j.i}$. Expression (6) says that the average rate of growth will depend on the average resources employed in R&D in the different regions and also on the distribution of spillovers. Note that if the spillovers are perfectly symmetric $\bar{t}_i = 1/N$ or all the regions are the same then the common growth rate will simply become $l\bar{n}$. If we log-linearize the expression (5) around the BGP we have that the system can be written in vector form as:

$$\dot{\underline{g}}_A = e_f (M - I)(\underline{g}_A - \overline{\underline{g}_A}) \qquad (7)$$

where the underlined variables are vectors, M is an NXN matrix with $\tau_{i,j}$ as entries in each position and I is the identity matrix. As M is a Markov matrix it admits all characteristic roots smaller than or equal to one in absolute value, while the identity matrix admits N characteristic roots equal to 1. The characteristic roots of the matrix (M-I), which are the differences of the characteristic roots of the two matrices, are therefore negative and the differential system of equations (7) is stable[17]. In the rest of the model we analyze the behavior of the system in the locally stable BGP.

In BGP the following equation holds:

$$\log(g_A) = \log(l) + \log(n_i) + e_f \log(a_i) - e_f \sum_{j=1}^N t_{i,j} \log(a_i) \qquad (8)$$

which, in matrix notation and solved for log(a) gives:

$$\log(\underline{a}) = \underline{c} + \tfrac{1}{e_f}\left(I - M\right)^{-1} \log(\underline{n}) \qquad (9)$$

where I have collected all the constants in the vector c. Equation (9) is one of the key equations for the empirical implementation of the model. It states that in BGP the level of knowledge in each region and therefore also the flow of new knowledge (which in BGP is just proportional to the stock), depends on the level of resources spent in R&D. A linearized expression of this equation is estimated in the empirical section. Also, the relative level of innovation in region i depends not only on her resources spent in R&D but also on the resources spent in the other regions, whose spillovers affect innovation in region i .

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[16] In the generalization of this equation, in section 3, we will allow for positive growth of the human capital, but we will impose decreasing return to existing ideas in innovation.

[17] hence the BGP exists for such a system and is locally stable.

4.3 Value of a Patent

In order to determine the value of a patent we consider the system along its BGP. In this situation the average productivity and the single sector's productivity all grow at the same rate g_A , defined by (6). The value of a patent is the present discounted stream of profits, which are generated by the invention. Using (3) as the expression of profits for a typical producer in region i at time t, we obtain the following expression as value of the patent in region i:

(10)

$$V_{it} = \int_{s=0}^{\infty} e^{-rs} p_i(t)\,ds = \int_{s=0}^{\infty} e^{-rs}\left(\frac{1-a}{a}\right) w(s)^{\frac{a}{a-1}} \left(D_i a^2\right)^{\frac{1}{1-a}} ds = \frac{1}{r+\frac{a}{1-a} g_A}\left(\frac{1-a}{a}\right) w(t)^{\frac{a}{a-1}} \left(D_i a^2\right)^{\frac{1}{1-a}}$$

The flow of profits from innovation (patent) of a firm in the i-th region is discounted at the market rate r. Also a faster pace of innovation in the sector squeezes the profits as is clear from the term g_A which appears in the denominator. The assumption of perfect mobility of skilled workers across regions and between production and R&D, implies that the wage is equal in all sector, in equilibrium. Hence, the marginal productivity of a skilled worker in R&D, is the same as the productivity of a worker in production. The wage earned by a worker in R&D is the value of the innovation times the productivity of innovations per worker in the unit of time $(\dot{A}/n_i)$. Using (10) and the BGP condition, the equilibrium condition on the labor market is:

$$w(t) = \left(\frac{g_A a_i \bar{A}}{n_i}\right)\frac{1-a}{a} w(t)^{\frac{a}{a-1}}\left(\frac{1}{\left(r+\frac{a}{1-a}\right)}\right)\left(D_i a^2\right)^{\frac{1}{1-a}} \qquad (11)$$

Solving (11) for n_i and taking logs, we can re-write this equilibrium condition in matrix form obtaining the following relation, which describes the incentives of workers to undertake research in region i, as a function of the productivity of research in that region (captured by a_i) and as a function of the profitability of production in region i, given by the local demand and local productivity characteristics D_i .

$$(12) \qquad \log(\underline{n}) = \underline{c_1} + \log(\underline{a}) + \tfrac{1}{1-a}\log(\underline{D})$$

Equation (12) deserves some comments. It clearly shows that the stock of innovation (patenting) in one region affects the amount of employment in R&D so that to estimate the productivity of R&D in innovation we cannot simply apply OLS to equation (9). However, this same relation supplies the instrument we need to correctly estimate the productivity of R&D in innovation. All the variables which affect the profitability of an innovation, via the demand for the new product, but that do not affect the productivity of R&D, are determinants of $\underline{n}$ and not (directly) of $\underline{a}$ and could, therefore, be used as instruments. That can be the case of all the variables that capture the size and tastes of the local market without affecting directly the productivity of research. We take care of defining them explicitly in the empirical section.

4.4 Equilibrium and growth rates in BGP

We can easily characterize the BGP of the model. We already know the growth rate of A_i, the number of patented intermediate goods in each region. We use the two following equilibrium conditions, in order to find the growth rate of output and wages, given zero growth in human capital (skilled employment).

$$(13) \qquad \sum_{i=1}^{N} n_i + \left(\frac{a^2}{w(t)}\right)^{\frac{1}{1-a}} \sum_{i=1}^{N} A_i(t) D_i = H$$

$$(14) \qquad A_i(t)p_i(t) + A_i(t)x_i(t)w(t) = Y_i(t) \qquad \text{for} \qquad i = 1,2,\ldots N$$

The first condition, which must hold for the aggregate of the economy, says that the total number of employed skilled workers in the R&D sectors plus the total number of employed skilled workers in production, must equate the total number of skilled workers (H). The second relation, which holds for each single region, says that the total income of that region is the sum of the wage paid plus the profit made. From (13), as n and H are constant it must be:

$$(15) \qquad g_w = (1-a)g_A$$

Substituting $p_i(t)$ and $x_i(t)$ from (2) and (3) in (14), we obtain the following relation among growth rates:

$$(16) \qquad g_A + \tfrac{a}{a-1} g_w = g_Y$$

which implies $g_w = g_Y$. The growth rates of regional income and of wages are equal and they are proportional to the growth rate of varieties of goods.

Equation (13) defines the equilibrium wage rate, w(t), which depends on the average n_i and the average A_i. The fact that condition (13) is linear while the other two equilibrium conditions (9) and (12) are log linear makes it difficult to find the closed form solution

4.5 Immobility of Skilled Workers across regions

The mobility of European workers across regions and countries is rather low [18]. Let's assume the absence of mobility of the skilled workers across regions. In this case the relevant labor market is the regional market and conditions (11) and (13) are modified as follows:

$$(11') \qquad w_i(t) = \left(\frac{g_A a_i \overline{A}}{n_i}\right)\frac{1-a}{a} w_i(t)^{\frac{a}{a-1}}\left(\frac{1}{\left(r+\frac{a}{1-a}\right)}\right)\left(D_i a^2\right)^{\frac{1}{1-a}}$$

$$(13') \qquad n_i + \left(\frac{a^2}{w_i(t)}\right)^{\frac{1}{1-a}} A_i(t) D_i = H_i \quad \text{for } i = 1,2 \ldots N$$

The wage becomes region-specific, and the condition which determines it, namely the clearing of the labor market, differs for each region. If we solve for $w_i(t)$ in (13') and substitute into (11') we get:

$$(17) \qquad w_i(t) = \left(\frac{H_i - n_i}{\left(A_i(t) D_i \big/ a^2 \right)} \right)^{a-1}$$

$$(18) \qquad \frac{n_i}{H_i - n_i} = \left(\frac{g_A a_i \overline{A}}{n_i} \right) \frac{1-a}{a} \left(\frac{1}{\left(r + \frac{a}{1-a} \right)} \right) \left(D_i a^2 \right)^{\frac{1}{1-a}}$$

Condition (17) shows that the wage in region i depends positively on the number of skilled workers in R&D and on the technological level of the region: higher technological level and lower employment in production increase the productivity of skilled labor. Condition (18) introduces this further channel of equalization in the equilibrium condition for returns in R&D and production. Better conditions in supply (technology) and demand (profitability) across regions determine higher employment in R&D, but this effect is less pronounced than before. Smaller differences in employment in R&D offset the differences in regional profitability in BGP.

4.6 Qualitative implications in BGP

The model developed above draw some clear predictions for the relative productivity of each region and for the impact of R&D on innovation and productivity across regions.

In BGP, the regions grow at the same rate, but the differences in relative productivity and in the intensity of innovation are driven by the different amount of resources (skilled workers) employed in R&D. Also, as condition (9) shows, the number of patented goods in one region depends on the level of resources in R&D used in that region and in all the other regions, via the matrix of spillovers.

If there is perfect mobility across regions, the wage paid is the same. This implies that the most profitable sectors will attract a larger number of workers in production and R&D (see equation (12)), until the marginal productivity of its workers is equated to the rest of the world. The profitability conditions, therefore, attract both production and R&D workers, in the better regions.

Introducing some degree of immobility of labor across regions (but keeping the mobility between R&D and production, within one region) generates difference in wages, rather than in employment level. The situation of the European economy is probably in between the two extreme cases of full mobility and no mobility at all. The model, allowing for a-symmetric catch-up

[18] See Eichengreen 1993, Decressin and Fatas 1995 among others

spillovers is very well suited to capture the spatial dimension of spillovers, allowing for different intensity of spillovers in the geographical and technological space.

5. Empirical specification and the structure of the spillovers

Let's consider equation (9). We can relax the assumption that the growth rate of the stock of knowledge (patents) in a region is proportional to the amount of R&D employment . Instead we represent the increase in the technological stock as:

$$(4') \qquad \dot{A}_{it} = l n_{it} f_1\left(A^S{}_{i,t}\right) f_2 (A_{\ i,t})$$

where f_2 is a function of the level of knowledge and exhibits decreasing return to scale[19], and f_1 captures the effect of spillovers as discussed before. This specification will still exhibit convergence to a BGP, but the growth rate of technology in BGP is, now, the growth rate of H, the total skilled labor force. Qualitatively, equation (9) remains unchanged, the only change being the constant $\underline{c}$ in which the exogenous growth rate of H substitutes the endogenous common growth rate g_A .The coefficient ε_{f1} and (ε_{f2} -1), substitute ε_f as coefficient of I-M and M respectively:

$$(9') \qquad \log(\underline{a}) = \underline{c} + \tfrac{1}{(1-e_{f2})}\left(I - e_{f1} M\right)^{-1} \log(\underline{n})$$

This relation is non linear in the parameter ε_{f1} but if we think that this parameter is small, compared to $\tfrac{1}{(1-e_{f2})}$, so that the second order terms are negligible, we can safely linearize (9') and get:

$$(19) \qquad \log(\underline{a}) \approx \underline{c} \quad \tfrac{1}{(1-e_{f2})}\left(I + \tfrac{e_{f1}}{(1-e_{f2})} M\right)\log(\underline{n})$$

R&D that can be estimated using IV , once we find the right instrument for R&D employment.

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[19] The accumulation of knowledge can lead to congestion and therefore to decreasing returns.

As we do not want to impose any parametric structure on the intensity of the spillovers (τ's) but we want to find empirically how they depend on the distance (in the geographic or in the technological space), we decompose the matrix M as follows:

$$(18) \qquad M = \tau_1 M_1 + \tau_2 M_2 + \ldots + \tau_K M_K$$

To construct M_i we have, first of all, grouped the region in K classes of distance, including in each class the couple of regions whose distance d_{ij} is in the interval $[x_{k-1}, x_k]$ units. Each entry ij of the M_k matrix has a value of 0 when the distance between region i an j does not fall in the k-th class. The entry is equal to $(1/n_i)$, where n_i is the size of the k-th class for region i, if the distance between i and j falls in that class. Hence we obtain K, Markov M_k matrices, multiplied by τ_k a coefficient that captures the intensity of the spillovers from the region in that class of distance and that we are going to estimate. It is then possible to assess the effect of the inter-regional spillovers of R&D on innovation, and to identify the speed at which the intensity of spillovers varies with geographical or technological distance. The system that we can estimate is, in matrix notation, as follows:

$$(21) \qquad \log \underline{a} = \underline{C} + \beta_0 \log \underline{n} + \beta_1 M_1 \log \underline{n} + \beta_2 M_2 \log \underline{n} + \ldots + \beta_K M_K \log \underline{n}$$

β_0 gives a measure of the intensity of the "own knowledge spillover" $\frac{1}{(1-\varepsilon_{f2})}$ while $\frac{\sum_1^K \beta_k}{\beta_0}$ is a measure of the relative importance of the knowledge spillovers coming from other regions. β_0 captures the returns to R&D in the innovative activity of the regions, while $\sum_1^K M_k$ captures the total effect on innovation of inter-regional spillovers of ideas. The theoretical analysis developed in the previous section tells us that the expression (18) is a linear approximation of the exact BGP relation between knowledge stock and its determinants. In particular this relation is only a part of the BGP conditions and we have to keep in mind equation (12) to account for endogeneity of $\log(\underline{n})$.

The amount of resources employed in R&D, in fact, depends importantly on the profits that innovation generates, once implemented. Regional characteristics, influencing the demand for new products, but not the productivity of research, appear in the term D_i of equation (12) and not in (18) and are therefore good instruments to estimate the β's. We think that the issue of valid instruments to estimate the effect of R&D and of the spillovers on innovation is a crucial one, not addressed by the recent empirical literature. If innovation is endogenous to the system, it arises for the profits that the innovative good generate. There is a circular causation, in which R&D generates innovation, and technological growth (equation (9)), which in turn generates profits and incentive to invest in R&D (equation (12)). Most of the empirical literature, which considers the cross-country implication of R&D on growth (Eaton and Kortum 1996, Bayoumi, Coe and Helpman 1999), assumes the exogeneity of the R&D expenditure, with respect to the productivity level. This is in contrast, we think, with the spirit and a sensible generalization of a model of endogenous growth. At the regional level, we have some variables which are not correlated, cross sectionally, with the productivity growth, but are certainly correlated with the size of the local market and therefore with the demand for the products. These are the population and the age structure of the population in a region.

6. Empirical Results

The first empirical issue to be addressed is how to measure the "stock of knowledge". If the increased stock of knowledge increases the amount of intermediate patented goods, as in Romer (1990) and Jones (1995), the patent count can be used as a measure of increased knowledge. In Aghion and Howitt (1992), Eaton and Kortum (1996) and in all the models based on a "quality ladder" and vertical innovation, the "count of patents" cannot measure the relevant stock of knowledge: both the frequency and the "size" of innovations matter. Also, since the new patents substitute and do not complement the existing onesr, all that really matters in those models is to establish the "degree of knowledge" set by the last generation of patents in each sector.

The shortcoming of this approach is that we have only extremely coarse and noisy measures of the "size" of one patented innovation and an even worse understanding of which sector is relevant for patenting purposes. Therefore we take patent count as a proxy for the increase in economically profitable knowledge, as patents are a measure of the variety and of the number of intermediate new goods used in production. One patent is one new good and all of them give the same contribution to productivity. With this assumption, and considering that the economy will be on average on the balanced growth path, we are able to estimate equation (20). In particular, as the change in the stock of knowledge in each region is proportional to the stock itself, equation (20) has a direct translation in terms of patents, which is:

$$(22)\qquad \log(\underline{Pat}) = \underline{C_0} + b_0 \log \underline{n} + b_1 M_1 \log \underline{n} + b_2 M_2 \log \underline{n} + ... + b_K M_K \log \underline{n}$$

Equation (21) is the core specification of our empirical estimates. The average yearly amount of patents' application , in each region[20] (in the period 1977-1995) is considered as the measure of BGP intensity of patenting[21]. This in turn, is assumed to depend, on the number of workers employed in R&D (average in the 1977-1995)[22] in the region itself and in the other regions, if there are any cross-regional spillovers of knowledge. The coefficients $b_1, b_2, ...b_K$ are a measure of the intensity of cross-regional spillovers that depend on the distance between regions, assuming that all regions at such distance have the same spillovers effect. The cross sectional variation of the employment in R&D in the other regions, allows to identify the intensity of the spillovers. b_0, on the other hand, captures the intensity of the own effect of R&D employment on innovation: The larger it is, the more existing knowledge, generated in the region, has an effect on creation of new knowledge. Intuitively, if the different intensities of R&D get translated into a more polarized distribution of innovation (as the data suggest) then parameter b_{01} should be (as in most of the estimates) larger than one.

The problem of estimating equation (21) is the endogeneity of the employment in R&D. As already anticipated, if innovation (patenting) improves technology and decreases the cost of production, the consequent increase in firms' profit, and the reward to patenting, attracts more workers in R&D. Regions with high patenting will be places where it is more profitable to innovate and where R&D is higher. This circular causation will distort the estimates of the β's and will not allow us to capture the true returns to R&D and the spillovers. However our model, developed in section 3, gives us an important insight to guide the search for instrumental variables. If we are able to find some factors that affects the profits from innovation, independently from the productivity of innovation in one region, by affecting the demand that an innovative good may have in that region, than we have found the needed instrument. That variable, in fact, could be considered exogenous to the process. The virtuous circle becomes: innovation -productivity growth -higher profits-more innovation.

The first and most natural variable, to be considered as a determinant of the demand is the "size of the local market" or the "market potential". If the local demand is high because many consumers (and producers) are located in the region then any innovation has a large market, higher demand and higher expected profits. In that case incentives to innovate are higher and the return to research larger with the result of observing larger R&D intensity and more innovation in these

[20] The region to which the patent is attributed is the region of the first inventor.
[21] For the 11 regions with 0 patents' application, we attribute a rate of patenting equal to 0.04 per year, which would not have given even one patent in 18 years, on average.

regions. We use as a proxy of the dimension of the market the level of population. Regional population in Europe can be considered a sufficiently exogenous variable as, in relative terms, it has changed little in the last 100 years. Moreover we are considering population and not employment, to emphasize the demand side and not the density of economic activity. What we claim is that the main channel through which population affects innovation, is in generating a market for the products of innovation.

If we simply consider the 86 European regions, in the 12 EU countries for which we have data, we see, interestingly, that 25% of the cross-sectional variation of R&D per worker is explained by regional population alone, and the percentage becomes 37% if we include the age structure of local population (shares of 5 age cohorts[23]). The strong positive correlation between the population and the intensity of research per worker, is, to us, a sign that the market incentives are really making investment in innovation endogenous.

6.1 The basic model with geographical spillovers

In the empirical implementation of equation (12) we have an important issue to address, namely how many space intervals for each variable to introduce in order to have a reasonable trade-off between explained variance and precision of the estimates. We also have to decide the size of a space interval within which to consider different observations at the same distance. The first problem is made much more severe by colleariety of the variables. Including variables which capture average R&D employment in regions farther away, results in including variables that can be highly collinear. The collinearity arises because the relative "change" in environment every 100 Kms decreases with the size of the group included (which increases with distance). The std. deviation of the average R&D employment remains stable, at one third of its mean, when distance increases. The result is that, if we include 10 variables for the intervals from 0 to 1000 Km's, by 100, and one for all the distances larger than 1000 km, we have a coefficient of correlation in the order of 0.95-0.9 among the last 5-6 variables in 9. This will make the estimates totally unreliable, and the std. errors very large. We use, therefore the following procedure: we start with the smallest distance and we keep adding space intervals in R&D employment as long as the correlation coefficient between the last two added variables is smaller than 0.80 (see Table 1a and Table 1b for the correlation between R&D real expenditures in different space intervals).

[22] All the variables included in the regression are in their average value in the conisdered period (1977-1995). In some cases not each annual value is available in the series, and in this case the average has been computed using only the available years in the period.

Table 1a

Correlation Coefficient between Space Intervals of R&D: 100 Km. cells

R&D Employment	Correlation
[own]-[0-100]	-0.17
[0-100]-[100-200]	0.60
[100-200]-[200-300]	0.73
[200-300]-[300-400]	0.75
[300-400]-[400-500]	0.81
[400-500]-[500-600]	0.84
[500-600]-[600-700]	0.89
[600-700]-[700-800]	0.83
[700-800]-[800-900]	0.87
[800-900]-[900-1000]	0.96

Table 1b

Correlation Coefficient between Spatially Lagged R&D: 100 Km. cells

R&D Employment	Correlation
[own]-[0-200]	-0.12
[0-200]-[200-400]	0.75
[200-400]-[400-600]	0.87
[400-600]-[600-800]	0.84
[600-800]-[800-1000]	0.96
[800-1000]-[1000+]	0.97

[23] The cohorts are: 14-25, 25-34, 35-44, 45-54, 55-64 and more than 65.

In this way we are able to include four intervals (from 0 to 400 Km by 100) in the case of 100 Km cells and 2 intervals (from 0 to 400 Km by 200) in the case of 200 Kms Cells. The rest of the spatially lagged R&D employment are included as an average variable. This “average variable” capturing the effect of average R&D employment more than 400 Kilometers away, has a correlation coefficient with each of the R&D in each space interval, at a distance larger than 400 Km’s, larger than 0.92. It conveys basically the same information as each of the spatially lagged variables. Table 2a reports the (regional employment-) weighted OLS and IV estimates of the coefficients of the basic regression with the chosen length of spatial lags[24], while Table 2b reports the same results, using real R&D spending rather than employed in R&D as explanatory variable:

[24] All regressions include a constant, which depends on the common growth rate.

Table 2a:

Indep. Variable Log(R&D Employed), cell length: 100 Km (Geographical distance)
Standard errors in parenthesis

Dep. Var: log (Patents)	Weighted OLS	Weighted IV(1)	Weighted IV (2), per capita	Weighted IV(3),with college +	Weighted IV(4), with infrastr.	Weighted IV(5) with country-R&D
β_0	1.10***	1.03***	1.14***	1.01***	1.07***	0.78***
	(0.08)	(0.19)	(0.44)	(0.09)	(0.08)	(0.11)
β_1	0.01	0.003	0.008	0.02	0.01	-0.01
	(0.02)	(0.03)	(0.03)	(0.03)	(0.015)	(0.03)
β_2	0.11***	0.10***	0.09**	0.10***	0.043**	0.08**
	(0.04)	(0.04)	(0.047)	(0.04)	(0.022)	(0.04)
β_3	-0.003	-0.02	-0.02	-0.05	-0.028	-0.001
	(0.07)	(0.07)	(0.07)	(0.09)	(0.03)	(0.07)
β_4	0.02	0.06	0.05	-0.21	-0.02	0.002
	(0.07)	(0.07)	(0.09)	(0.13)	(0.04)	(0.08)
β_{4*}	-0.13	-0.14	-0.12	-0.03	-0.078	0.03
	(0.09)	(0.09)	(0.12)	(0.16)	(0.05)	(0.10)
R^2	0.75	0.68	0.34	0.74	0.79	0.71
Tot. observations	86	86	86	71	86	86

*significant at 1% level
** significant at 5% level
*** significant at 10% level

Table 2b:

Indep. Variable Log (Real R&D spending), cell length: 100 Km (Geographical distance)
Standard errors in parenthesis

Dep. Var: log(Patents)	Weighted OLS	Weighted IV(1)	Weighted IV (2), per capita	Weighted IV(3), with college +	Weighted IV(4), with infrastr.	Weighted IV(5) with country-R&D
β_0	1.11***	1.01***	1.43***	1.05***	1.17***	1.12***
	(0.05)	(0.07)	(0.032)	(0.07)	(0.08)	(0.10)
β_1	0.01	0.016	0.01	0.03***	0.017	0.03
	(0.01)	(0.02)	(0.03)	(0.014)	(0.015)	(0.02)
β_2	0.04**	0.046**	0.075*	0.038**	0.043***	0.05**
	(0.02)	(0.02)	(0.040)	(0.022)	(0.02)	(0.025)
β_3	0.05	0.01	-0.01	0.004	0.02	-0.002
	(0.03)	(0.04)	(0.07)	(0.05)	(0.02)	(0.052)
β_4	-0.008	-0.01	0.02	-0.12	-0.02	0.01
	(0.04)	(0.04)	(0.08)	(0.08)	(0.04)	(0.052)
β_{4*}	-0.11**	-0.08	-0.08	-0.05	-0.07	-0.15**
	(0.05)	(0.05)	(0.11)	(0.10)	(0.05)	(0.07)
R^2	0.86	0.68	0.41	0.80	0.79	0.72
Tot. observations	86	86	86	71	86	86

Table 3a and 3b, on the other hand contain the same regression results, but in this case we have chosen 200-Km's cells to capture the spillover of R&D.

*significant at 1% level
** significant at 5% level
*** significant at 10% level

Table 3a:

Indep. Variable Log(R&D employment), cell length: 200 Km (Geographical distance)
Standard errors in parenthesis

Dep. Var: log (Patents)	Weighted OLS	Weighted IV(1)	Weighted IV (2), per capita	Weighted IV(3), with college +	Weighted IV(4), with infrastr.	Weighted IV(5) with country-R&D
β_0	1.10***	1.04***	1.44***	1.00***	1.10	0.82***
	(0.08)	(0.09)	(0.17)	(0.09)	(0.05)	(0.10)
β_1	0.11***	0.13***	0.09	0.10**	0.055*	0.096
	(0.04)	(0.06)	(0.06)	(0.05)	(0.030)	(0.58)
β_2	-0.001	-0.01	0.01	-0.13	0.01	-0.03
	(0.07)	(0.11)	(0.10)	(0.20)	(0.06)	(0.11)
β_{2*}	-0.10	-0.11	-0.07	-0.17	-0.09	0.03
	(0.07)	(0.08)	(0.10)	(0.21)	(0.06)	(0.09)
R^2	0.74	0.67	0.43	0.71	0.75	0.70
Tot. observations	86	86	86	71	86	86

*significant at 1% level
** significant at 5% level
*** significant at 10% level

Table 3b:

Indep. Variable Log(Real R&D spending), cell length: 200 Km (Geographical distance)
Standard errors in parenthesis

Dep. Var: log(Patents)	Weighted OLS	Weighted IV(1)	Weighted IV (2), per capita	Weighted IV(3), with college +	Weighted IV(4), with infrastr.	Weighted IV(5) with country-R&D
β_0	1.08***	0.99***	0.96***	1.00***	1.05***	1.10***
	(0.05)	(0.069)	(0.24)	(0.07)	(0.072)	(0.09)
β_1	0.03	0.05**	0.05	0.06**	0.043	0.055*
	(0.02)	(0.024)	(0.03)	(0.03)	(0.25)	(0.03)
β_2	0.06	0.04	0.04	0.05	0.03	0.03
	(0.04)	(0.05)	(0.05)	(0.13)	(0.05)	(0.06)
β_{2*}	-0.11***	0.10*	0.11	-0.22	-0.08	-0.15
	(0.03)	(0.055)	(0.06)	(0.14)	(0.05)	(0.08)
R^2	0.86	0.77	0.48	0.79	0.77	0.69
Tot. observations	86	86	86	71	86	86

*significant at 1% level
** significant at 5% level
*** significant at 10% level

Let's concentrate on the basic specification estimated with regional population and "spatially lagged" regional population as IV (regression IV(1) in all tables). Two things emerge clearly and consistently:

1) The coefficient on R&D (employment or spending) is always very significant and most of the time equal or larger than one. Most of the cross-regional variation in patenting is due to differences in R&D and there is a little extra effect of existing knowledge on creation of new knowledge (the point estimates of ε_{f2} is in the range 0-0.10 although it is not significantly different from 0).
2) The spatial spillovers exist and are statistically significant for the R&D done within 200 Km's from the region. (actually the spillover in the 100-200 Km's range seem to be the strongest, probably because the first 100 Km are not enough for most region's capital to include most of the neighbor's capitals). Nevertheless their magnitude is not very large: the elasticity of patenting to "close" R&D is between 4 and 11%, while the elasticity to own R&D is in the range of 100-140%. This result, suggests that spatial spillovers may be important but are not first order in determining the BGP differences in innovation rates across regions.

Hence, there is a difference between the effect of own R&D and that of R&D from closer regions of one order of magnitude. We can infer that the spatial concentration of R&D (probably for market reasons) creates incentive for innovation to cluster while spillovers are of second order of importance.

We perform a number of different trials to test the robustness of the results:

1. In regressions IV(2) we have re-scaled the variables to have them in "per worker" terms. This measures patenting per worker (a measure of intensity in innovation) as a function of R&D per worker (a measure of R&D intensity). The results do not change significantly to demonstrate that it is not the size of a region that drives the results.

2. In regression IV (3), IV(4) and IV(5) we have included some controls, to check that the omission of some variables, potentially spatially correlated, is not responsible for the results.

In IV(3) we have included a measure of human capital in the region, i.e. the fraction of workers with education equal or more than college[25]., which could be an important input of innovation process and that can be correlated across regions. Including this variable, which appears always highly significant, does not reduce the estimates of the spillovers effect. In IV(4) we have

[25] See Data appendix for the sources. We only had data for 71 of the 86 regions on the education variable

considered the importance of local infrastructure in increasing productivity of research.. We have used a measure of the density of roads and other way of transportation in the region to capture the quality of communication infrastructures. Again this variable enters with a positive (not significant) coefficient, and does not substantially change the estimates of the spillovers. Finally in IV(5), in order to understand whether most of the effect is a “within country” effect we include a variable capturing the average regional spending in research in a country (or average number of employed in R&D). This variable, again positive and significant, does not eliminate the spillover effect, although often increases the standard error of the estimates, reducing somewhat the significance of the coefficient.

6.2 Spillovers in purely technological space

The natural question to ask is whether “geographical space” is the most natural dimension in which regions innovate and in which spill-overs happen. R&D and spillovers coming from regions which are close in the “technological space” (produce and innovate in similar sectors) rather than in “geographical space” could be more relevant. To shed some light on this point, i.e. on the importance of spillovers coming from region technologically similar we may construct a distance which is a metric in the technological space. In particular two regions will be close if they share many sectors (of production), while they are far if they specialize in different sectors. Once we have defined an index of “distance” we proceed as described in section 3 to define cells into which the value of this index falls and to construct the matrices M_1 , M_2 …M_K and to estimate the β’s.

The index of distance we use is the index of bi-lateral specialization for two regions. After having defined 9 manufacturing sectors[26] we calculate the following value for each couple of regions (k,l): $\sum_i \left| sh_{ik} - sh_{il} \right|$. Sh_{ij} is the share of total value added in manufacturing in region j, produced by sector i. The index will be 0 in case of exactly identical composition of value added, and 2 in case of exact complementarity. In our sample of 86 EU regions we have that the index range from 0.3 (very similar regions) to 1.2 (dissimilar ones). Regions which have a very different productive specialization of the manufacturing sector will be distant in this metric and may receive small spillover from each other, even if they are geographically close. We identify 4 class of distance, each covering an interval equal to 0.3 in the metric of the specialization index and ranging from 0.3 to 0.12. The estimates of specification (21), using this metric on the “external effects” of

[26] Metals, non metallic minerals, chemicals, machinery, means of transportation, food, textiles and leather, paper, Others

R&D are reported in Table 4. Although the point estimates are positive for β_1 and β_2 while negative for β_3 and β_4 (i.e. decreasing with distance) they are not significant in almost any specification. This suggests that considering regions as innovative units, the metric induced by their productive specialization is not appropriate to capture R&D spillovers, or actually that the purely spatial spillovers are more important than the purely technological ones.

Table 4:

Indep. Variable Log(R&D Employment), cell length: 0.3 units (technological distance)
Standard errors in parenthesis

Dep. Var: log(Patents)	Weighted OLS	Weighted IV(1)
β_0	1.14***	1.05***
	(0.07)	(0.09)
β_1	0.04	0.03
	(0.04)	(0.04)
β_2	0.30	0.20
	(0.19)	(0.21)
β_3	-0.34	-0.027
	(0.18)	(0.19)
β_4	-0.001	-0.001
	(0.04)	(0.04)
R^2	0.74	0.63
Tot. observations	86	86

6.3 Spillovers in Technological space for close regions

In the previous section we have considered a purely technological metric for the space in which regional spillovers take place. Nevertheless, we may suspect that technological similarity is not irrelevant, but we need to consider only the regions which are close in space to detect an effect. In particular geographical space could be an important determinant of technological spillovers (as shown before), but, at a given distance may be more important the R&D performed in similarly specialized regions. To inquire into this we estimate again four spillover parameters, considering now, only the regions within the 200 Kms range from one's capital city. If we group these regions into the four cells, in decreasing order of production-sectors proximity, and we construct the four spillover matrices as usual, the effect of outside R&D on regional patenting is estimated in the regressions of Table 5. First let us point out that most of the (geographically) "close" regions are also technologically similar: the vast majority of technological distances for these regions fall in the first or second cell of the "technological distance". Second it clearly emerges, in all specifications, that the technologically closer regions among those in geographical proximity, are by far the most important in generating R&D spillovers on innovative activity. The elasticity of innovation to R&D employment in these regions is around 0.13 and highly significant, while the effect of R&D in more different regions is not significant and often negative. It appears that the importance of R&D in neighboring regions for one's own innovation is enhanced by the similarity in the productive structure of the regions.

Table 5

Only regions in the 0-200 Km range. Indep. Var log (R&D Employment)
cell length: 0.3 units (technological distance)
Standard errors in parenthesis

Dep. Var: log(Patents)	Weighted OLS	Weighted IV(1)	Weighted IV (2), per capita	Weighted IV(3), with college +	Weighted IV(4), with infrastr.
β_0	1.02***	0.92***	0.75**	0.86***	0.95***
	(0.08)	(0.09)	(0.36)	(0.10)	(0.10)
β_1	0.11***	0.13***	0.14***	0.14***	0.13***
	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)
β_2	0.01	0.02	0.03	0.03	0.02
	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)
β_3	-0.02	-0.02	-0.02	-0.06	-0.03
	(0.03)	(0.03)	(0.03)	(0.035)	(0.03)
β_3	-0.06	-0.09	-0.11	-0.13	-0.07
	(0.05)	(0.05)	(0.07)	(0.07)	(0.05)
R^2	0.78	0.72	0.44	0.76	0.72
Tot. observations	86	86	86	71	86

7.Conclusions

While there is an increasing consensus on the importance of technological innovation for the economic performance of the European Union, few studies have considered the geography of innovation in Europe, in relation to its determinants and to the productivity of R&D. Eaton et al. (1998) point the finger to the European disappointing performance in innovation and identify in the small size of the local market for innovation the main cause of this failure. This paper take seriously the geographical relation between the size of the market and the innovative activity and uses it to determine what part of the innovation is due to own (market driven) research and development and what part could be attributed to inter-regional spillovers. The findings indicate that own R&D has an effect on innovation about 10 times larger than other regions' R&D, in balanced growth path, but nevertheless inter-regional spillovers exist, are significant and are stronger for close regions. Moreover if physical proximity is what allows the spillovers, technological proximity enhances them, as among close regions those more similar in the productive structure are also the more effective in influencing the innovation.

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Data Appendix

Patent Data: The data on Patents are taken from the CD ROM of the European Patent office, Ed. 1995 which contains all the patent applications received by the patent office from 1977. Each record contains several pieces of information, including the city and region of residence of the inventor(s) which we use to localize the patent. Also the International Patent Classification codes, relative to the patent have been grouped into 30 sectors, and 5 macro-sectors following the classification elaborated by the French patent office and the Observatoire des Sciences and des Techniques described in Breschi 1998. We list the sectors and the macro grouping at the end of this appendix. The value used in the regression is the average number of patents per year in the considered period, as the BGP patenting rate of the region.

Data on Education: The data on education at the regional level come from national sources. They are the share of the labor force in 4-6 educational groups from which we were able to recover for all the regions the fraction of the population with college or more education. They refer to the period 1985-1990. We gratefully acknowledge Antonio Ciccone for providing us with the data. The sources that he quotes (Ciccone 1998) are the following:

French data- Pissarides and Wassmer 81997)

German data- Volkstzahlung (1987) and Seitz (1995)

Italian Data- Censimento generale della popolazione (1991)

Spanish data -Perez (1996)

United Kingdom- Labor Force Survey (1996).

Data on VA per manufacturing Sector: The regional data on value added per sector have been kindly provided by the Italian Confindustria, from Eurostat sources . All regions are covered, except for Germany where we only have the national data and therefore consider each region as a miniaturized version of the whole country, i.e. having the same industrial specialization

Other Data: Data on R&D spending and employment, GDP, population, population in age cohorts, employment, roads, are from the "Regio" data set, edited by the Eurostat. We used various issues (from 1980 to 1996). As real GDP we used the regional GDP in national currencies, deflated with the national GDP deflators and converted in US. Dollars 1985.

Technological Groupings in the Patent Classification:

I. Electric Engineering

1. Electric Machinery and apparatus
2. Audio-Visual technology
3. Telecommunications
4. Information Technology
5.Semiconductors

II Instruments

6. Optics
7. Measurement Control
8. Medical Technology

III Chemistry, Pharmaceuticals

9. Organic fine chemistry
10. Macromolecular chemistry
11: Pharmaceutical cosmetics
12. Biotechnology
13. Materials metallurgy
14. Food chemistry
15. Chemicals and Petrol industry

IV Process engineering

16. Chemicals Engineering
17. Surface Technology and Coating
19. Thermal processes and apparatus
20. Environmental Technology

V Mechanical Engineering

21. Machine Tools
22. Engine, Pumps, Turbines
23.Mechanical elements
24. Handling, Printing
25. Agricultural and Food Processing
26. Transport
27. Nuclear Engineering
28. Space technology
29. Consumers' Goods and equipments
30. Civil Engineering

List of the EU Regions Considered

Belgium (3):
Bruxelles
Wllaams gewest
Regione Wallonne

Luxemburg (1)

Denmark (1)

Germany (11, only west):
Baden-Wurtenberg
Bayern
Berlin
Bremen
Hamburg
Hessen
Niedersachsen
Northrein-Westfalia
Rheinland-Pfalz
Saarland
Schleswig-Holstein

Greece (4):
Voreia ellada
Kentriki Ellada
Attiki
Nisia Aigaiou, Kriti

Spain (7):
Noroeste
Noreste
Madrid
Centro
Este
Sur
Canarias

France (22):
Ile de France
Champagne-Ardenne
Picardie
Haute Normandie
Centre
Basse Normandie
Bourgogne
Nord-Pas-de-calais
Lorraine
Alsace

France Comte
Pays de la Loire
Bretagne
Poiteau Charentes
Acquitaine
Midi-Pirenees
Limousin
Rhone Alpes
Auvergne
Languedoc
Provence cote d'Azur
Corse

Ireland (1)

Italy (20):
Piemonte
Val d'Aosta
Liguria
Lombardia
Trentino
Veneto
Friuli
Emilia Romagna
Toscana
Umbria
Marche
Lazio
Abruzzi
Molise
Campania
Puglia
Calabria
Basilicata
Sicilia
Sardegna

The Netherlands(4)
Noord netherland
Oost netherland
West Netherlands
Zuid netherlands

Portugal (1)

Great Britain (11):
North
Yorkshire and Humbershire
East midlands
East Anglia

South West
South east
West Midlands
North west
Wales
Scotland
Northern Ireland