Innovation and Technology Spillovers through Space and between Sectors: Evidence from European Regions*

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Abstract

The Importance of innovation for the economic performance of industrialized countries has been largely stressed recently by the theoretical and empirical literature. Very few studies have carefully considered the determinants of European innovation, the productivity of its R&D and the existence of knowledge spillovers across regional boundaries. Here we develop a model which, emphasizing "the demand pull" as a key exogenous determinant of long-run innovation across regions, allows us to estimate the returns to regional R&D as a generator of innovation. We find that most of the cross-regional differences in innovation rates can be explained by own R&D, even after correcting for the endogeneity bias. Moreover, significant spillovers are found among geographically close regions, especially if they are technologically similar.

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1. Introduction

As the nations of the world economy have become increasingly open and interdependent more attention has been devoted to the study of the channels of technology diffusion. Openness fosters new ideas; knowledge spillovers 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[1]. To understand this phenomenon it is crucial to take a closer look at the local as well as the external factors that foster innovation in a region.

The aim of this work is to analyze the importance of research and development and of knowledge diffusion, via sector and space spillovers, in shaping the distribution of innovative activity. 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, might be rising with distance.

To test for the importance of spatial proximity and geography for the innovative activity we use data on European regions. The regional dimension is particularly relevant at the European level, since heterogeneity among countries (difference in their legal systems, in product standards, subsidies to R&D, taxation) would limit the possibility of isolating the space and the sector dimension clearly.

What determines the concentration of innovative activity in a region? Local externalities and local knowledge spillovers are the first candidates. It has been widely documented[2] 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. Also robust evidence has been produced showing that intranational spillovers are stronger than international spillovers. If that is the case local expenses in R&D should show up as the most important determinants of regional innovative output while spillover effects should decrease with distance.

Our empirical results confirm that intuition. However an issue of endogeneity arises. If an increase in resources devoted to R&D foster innovation it is also true that an increase in innovative output increase the

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[1] Quah (1996) among others makes this point.

[2] Jaffe (1986), Feldman (1994) and Audretsch and Feldman (1996) have modified the model of knowledge production function to include an explicit specification for the space dimension. Keller (1996,1999) and Branstetter(1996) measure intra-national versus international knowledge spillovers.

productivity and the profitability of innovation and induce an higher expenditure in research. To cope with the issue of endogeneity our approach distinguish between variables that affect the productivity and the one that influence the profitability of R&D. We use the first as control variables that explain how local characteristics of a region together with expenditure in R&D determines the production of innovation. We use the second as instruments to solve the endogeneity problem.

But what are the variables that affect R&D expenditure without affecting its productivity ? We believe that an important role is played by local demand. Whether for final or for intermediate input local demand is important since it increases the profitability of research. While generally true this is even more evident in Europe where the degree of segmentation of the markets induce firms to rely even more heavily on the local market. The emphasis laid on the importance of market integration for innovative goods by the European Community is a clear evidence of the relevance of this phenomenon. Previous studies on innovation activity in Europe find that the absence of an ample market outlets for innovative products is the factor that is considered crucial to understand the stagnant research activity in Europe . In fact as Eaton et al.(1996,1998) find European countries do not differ in terms of research productivity witj respect to Japan an USA…. In a recent survey on innovation in Europe developed by the EC, firms clearly declare that the aim of their innovative activity is to increase or maintain their market share while it is considered unimportant for the creation of new markets[3].

Also, the countries'ability to absorb innovation influence technology diffusion, as Eaton and Kortum (1996) estimate.

Our idea is compatible with the studies on the localization of high-tech industries over their life cycle. It is no news that firms that are highly innovative develop their strategy first at a local level and change their geo-location or expands their markets only when their products become more mature.

The second question we want to answer in this work is related to the relevance of within versus between sectors spillovers. This entails considering whether the buildup of knowledge receives a stronger influence from spillovers originating from regions whose specialization is in the same industry (Marshall-Arrow-Romer (MAR) externalities) or from spillovers that comes from regions specialized in different sectors (so called "Jacobs" externalities). There is no clearcut and definite answer to this question in the

[3] An indirect piece of evidence of the importance of the domestic market for the development of an innovative firms in Europe comes from the recent creation of the New Stock Markets. Financial prospectuses that contains all informations concerning the the firms that decide to go public are in the country native language. This clearly show that these firms rely on their domestic country in their sources of financing. Moreover, German firms decide to be listed on their Stock Market and not in London or USA. Also they define as their competitors only German or Swiss firms and thee is no mention of USA or Japanese firms.

existing literature. On one side Glaeser et al. (1992), by looking at employment and wage data, suggests that externalities originate from having a local diversity of industries are the most relevant. On the other hand, there is a strand of literature 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).

To measure the importance of specialization versus diversity we follow Jaffe (1986) who quantifies the "direct" (technological opportunity) effects on the productivity of firms' R&D of an exogenous variations in the state of technology. 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. We find similar results.[4]

The structure of the paper is the following.

In section 2 we review some empirical facts. Section 3 presents our theoretical framework 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 workers but low mobility of unskilled workers (and of overall population) across regions. It provides us with a clear relation between R&D, knowledge spillovers and innovation activity, that we estimate in section 4. Section 5 is devoted to the empirical results. Section 7 concludes.

2. Some Empirical Facts

[4] Other related studies are Verspagen (?) and Verspagen and Los (?).

Data analysis confirm the clustering of the innovative activity[5] as its intensity is very different across space in the European regions [6]: the top five patenting regions (Northrein-Westfalia, Bayern, Waden-Wurtenberg, Ile de France and East Anglia) are responsible for 50% of total patents[7] as well as almost 50% of total R&D expenditure, while the bottom 11 regions have almost no patenting at all in the 1977-1995 period.

Figure 1 and figure 2 show the geographic concentration of R&D expenditure and patents in Europe. It is easy to see that the central European regions, and in particular Germany and France, show the highest concentration as regards both dimensions.

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, were R&D equally distributed among European regions, would be 0,011. The same computations for patenting gives us an H-index of 0,145. Production (GDP), although at a lesser degree (H-index has a value of 0,039), is concentrated in the same area.

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 73% of the cross regional variation in long run patenting intensity, and that the elasticity of patenting to R&D spending is significantly larger than one[8]. Figure 4 documents these facts.

We can therefore infer that :

a. Within region spillovers might be responsible for the very high returns to regional R&D. Certainly differences in R&D expenditures explain the large part of heterogeneity in regional and country's innovation.

b. Inter-regional spillovers might have a role in explaining the remaining variation in innovative activity. By looking at two regions with the same average total spending in R&D, like Madrid and Hamburg (roughly sixty-four 1985-U.S. Dollars per worker), it is possible to realize that the peripheral region of Madrid produced about one tenth of the patenting per worker than the central region of Hamburg, in

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[5] A patent is here considered as an output while R&D as an input of the process of innovation.

[6] 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

[7] in the paper expenditure in R&D is considered as an input in innovation activity whose output (innovation) is measured by patents. We are aware of all limitations and drawbacks of this measure of output. Neverthless we conform to the existing literature since we have no better measure to adopt.

[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.

the period 1985-1995. Similarly, the peripheral region of Lazio (Italy) produced about one thirtieth of the patenting per worker 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).

Can we say that there exist a systematic effect of the neighbor regions on other region's innovative activity? Knowledge is an input in production 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 build 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[10]: even in the case of a patent, which is made public, the research that leads to it and the background ideas 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 "technology 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 continents 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. Plausibly, ideas spread 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, the advantage of geographical proximity consists in the need of a face-to-face interaction to effectively learn from other people's ideas[11]. Hence, while general information is more easily diffused, specific knowledge justifies the concentration of innovation in space, to take advantage of these "externalities"[12].

But is this the whole story? Of course, not. If the determinants of research and innovation were to be "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 ?

As previously explained demand is for us an instrumental variable that allows to eliminate the possible endogeneity between R&D and innovation that can arise. We measure market potential and

[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] Secrecy is considered the best method for maintaining and increasing competitiveness of their innovation. See the Community Innovation Survey made by the European Commission .

[11] For an in depth analysis of the importance of face-to-face interaction in developing ideas see Gaspar and Glaeser (1996).

[12] The classic references of the importance of "ideas in the air" is, of course, Marshall (1890).

demand with different proxies. The concentration of demand, using as a proxy the population, is high . The H index reached a value of 0,026. A high level of demand in a region is incentive and increase rewards to R&D expenditure.

If this is a mechanism that generates concentration of innovative activity, then spillovers and increasing returns to knowledge may further contribute to lock in the process and explain the higher concentration of innovation over demand. Understanding and measuring the importance of own and local research in generating innovation is an extremely important task as it may shed some light on the cross-regional differences in productivity.

4.The Model

Our economy has N many regions, and a structure of production and innovation where a new good coincides with a new idea and increases the productivity of the manufacturing sector of the region[13]. We assume perfect mobility across regions of skilled workers (H_i), who take part into manufacturing production or into the activity of innovation. We also allow for unskilled workers (L) participating in the production of the manufacturing good. Each region innovates and patents new goods which increase the productivity of its manufacturing sector. In each region there is also a perfectly competitive sector, producing services with Cobb-Douglas technology, using labor and the composite manufacturing goods inputs. We standardize the price of services to one and assume that workers in this sector are specific to it, and their distribution across region exogenous. All agents in a region are similar in terms of their utility function and in the aggregate they generate the demand for the goods and services produced in the region[14]. Our analysis focuses on the manufacturing sector, which is the one where innovation and productivity growth takes place. The service sector could have different sizes in the regions, and could affect the demand for the manufactured good, both as a consumption and as an intermediate good, determining therefore its price. Being exogenous to the process of innovation, though, it provides an excellent instrument for our empirical analysis.

As already mentioned, 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

[13] The framework of our manufacturing sector is very similar to Romer (1990) and Jones (1996).

[14] This assumption does not necessarily imply that the economies are closed but that transportation costs and market segmentation lead regions to consume more of the locally produced goods and services. See also Hanson (?).

Aghion and Howitt (1992) model. Instead, if we think that the patented goods compete for the local market, then a new patent will certainly squeeze the profitability of the existing one. We know from a series of studies (e.g. Eaton and Kortum 1996) and from survey evidence (The Community Innovation Survey by Eurostat and DGXIII) that most of the patenting is done to increase or maintain market share of a firm while it is considered unimportant for the creation of new markets.

We allow for the possibility of knowledge spillovers across regions. In particular there may be a catch-up process, which prevents regions' productivity to grow increasingly apart, or a diffusion of knowledge across regions which binds them together. Two stylized facts make us more comfortable in describing the situation of the European regions in the period 1978-1995 as captured by a balanced growth path (BGP) distribution of productivity-levels growing at a common rate. First GDP per capita in the European regions has grown at an average annual rate of 0.038 in the period 1978-1992, with an average standard deviation across regions of 0.012, very stable over time. Second, in a regression of convergence of per capita growth levels, the "β" coefficient of growth rates on initial levels turns out to be equal to -0.12[15].

In our approach we are in the spirit of the "endogenous growth" literature since we consider, as determinants of growth, the incentives to innovate, which endogenously arise from the markets. The existence of some regions where the profits for innovation are 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 the size of the regional markets affects the profits from innovating in that region, while it does not affect the productivity of R&D in the region, is an important insight which allows us to correct for the endogeneity problem and estimate the parameters of the "innovation" function.

4.1 Production and Innovation

Each region produces one composite manufactured good using intermediate capital goods and raw labor. One unit of each capital good requires one unit of skilled labor to be produced. The total production of the composite manufactured good in region i is as follows:

[15] 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.

(1) $$y_{it} = L_t^{1-a} \int_{s=0}^{A_t} x_{it}^{a}(s)ds \quad \text{where } \alpha<1$$

A_{it} is the number of intermediate patented goods in the region, each of which is produced in amount $x_{i,t}$ by a monopolistic firm. L_t is the amount of unskilled labor used in production. The production function of the service sector is a Cobb-Douglas combination of Service-specific labor (S_I), which is not mobile across regions, and the output of the manufacturing sector.

(2) $$X_{it} = S_i^{g} y_{it}^{1-g}$$

The demand generated by this sector on the manufacturing sector as intermediates is $(1-g)S_{it}^{g} y_{it}^{1-g}$. Each agent has a utility function which is Cobb-Douglas, and for simplicity we assume, w.l.o.g., of the same form of (2). She, therefore,divides her income into a fraction γ spent to purchase the manufacturing composite (y_{it}) and a fraction (1-.γ) spent in purchasing services (X_{it}).

Equating the local demand and supply for the manufacturing sector we find the expression of the corrispondent prices[16]:

(3) $$P_{it} = \frac{(1-g)(1+g)}{g} S_i^{g} y_{it}^{(1-g)}$$

Each monopolistic producer of an intermediate capital good earns profits, which, in equilibrium, are equal to the rent from innovating and therefore to the reward to the innovator. These profits depend positively on the local demand of the innovative goods produced, which in our economy depends on the size of the service sector, and negatively on the number of firms in the region, as more firms squeeze the single margin for profits. Solving for the profit level as a function of the average wage for skilled workers, the local service employment and the local number of innovative firms we get[17]:

(4) $$p_{it} = C_p\, w(t)^{\frac{a(1-g)}{1-a}} A_i(t)^{(1-ga)(1-g)-1} S_i^{g(1-ga)}$$

[16] Detail in appendix A1.
[17] Details in the appendix A1

Profits will be increasing in local demand (and therefore S_t), while they will be decreasing in the total number of cumulated innovations (A_I) which squeeze the market for the marginal innovation.

Innovation, in a region, is generated by the amount of resources employed in R&D as well as by the intensity of spillovers from existing knowledge. We represent this features in the following function which describes how new knowledge is generated:

$$\text{(5)} \qquad \dot{A}_{it} = l(n_{it}) f_1(A_{it}) f_2(A^s_{it}), \quad l'>0, \quad f_1'>0 \quad f_2'>0$$

l is an increasing function of n_{it}, the amount of labor employed in R&D, capturing the productivity of R&D in generating innovation. We will define its elasticity as ε_λ. f_1 is the contribution of the local existing knowledge to the creation of new knowledge and f_2 is a function which captures the effect of spillovers from other regions' knowledge. A_{it} is the stock of knowledge of region i at time t, while A^S_{it} is the average stock of knowledge in those regions which have a spillover effect on region i. More precisely, A^S_{it} is a geometric average of other regions' stock of knowledge, where the exponent weighting knowledge of region j, is a measure of the intensity of the knowledge spillovers from region j to region i, (see appendix for a formal definition). It can be shown that under the condition of decreasing return on total knowledge spillover ($1-\varepsilon_{f1}-\varepsilon_{f2}>0$, where ε_{f1} and ε_{f2} are the elasticities of the function f_1 and f_2), the system of N differential equations in (5) admits a balanced growth path, which is locally stable[18]. The common rate of growth of the regions will be $\frac{e_l g_H}{1-e_{f1}-e_{f2}}$, where g_H is the growth rate of the skilled labor force[19], and the relative innovating rate, namely the growth rate of the relative stock of knowledge $a_{it}=\frac{A_{it}}{\bar{A}_t}$, could be expressed, in BGP, in compact vector notation, as:

$$\text{(6)} \qquad \log(\dot{\underline{A}}) = \underline{c} + \frac{e_l}{(1-e_{f1})}\left(I - \frac{e_{f2}}{1-e_{f1}} e_{f2} M \right)^{-1} \log(\underline{n})$$

[18] Deatails of this derivation in appendix A2
[19] We report in appendix A4 the growth rates of all variables in BGP

Equation (6) is the key equation for the empirical implementation of the model. Each underlined variable is an Nx1 vector of regional variables: $\underline{c}$ is a vector of constant capturing all the common terms affecting innovation, $\underline{n}$ is the vector of employees in R&D. I is the identity matrix while M is an NxN matrix of spillovers coefficients. The equation states that in BGP the flow of new knowledge (which we will capture with the patenting rate of a region), depends on the level of resources spent in R&D in the region and in all the other regions, via the "spillover matrix" M. The M_{ij} element of such matrix, captures the spillover of knowledge from region j into region i, as described in the definition of A_{it}^{S}. A linearized version of equation (4) is estimated in the empirical section.

4.2 The issue of endogeneity

Equation (6), derived from the innovation-generating equation, in BGP is one of the two key equilibrium relations. It states that, the more resources are spent in R&D, the more innovation is generated, directly or via spillovers. Nevertheless the model provides us also with another important equilibrium relation. In fact, the amount of the resources allocated by the regional economy to innovation is not exogenous, but it is determined by the perspective profits accruing to the innovation, and by the productivity of regional innovation function. Therefore the number of employed in R&D, in BGP, depends positively on the total size of the local market (S_i) but it could also depend on the level of local knowledge, which affects productivity in the innovation activity. This channel could induce endogeneity. The exact equilibrium relation, derived in greater detail in the appendix, shows that $\underline{n}$, the vector of regional employment in R&D depends, in BGP, log-linearly both on the local market size and on the relative level of cumulated knowledge (A_I).

(7) $$\log(\underline{n}) = \underline{c_1} + (1-ga)(1-g)\log(\underline{a}) + g(1-ag)(1-\log(\underline{S}))$$

This relation expresses the endogeneity of $\underline{n}$ in BGP, as that variable depends, in turn, on $\underline{a}$. The espression is derived from the model and its intuition is very simple. In BGP exists a positive relationship between the level of knowledge (which affects the productivity of research) and the amount of resources which are devoted to research. Regions which are more productive as they have cumulated more knowledge will devote more risources to innovation. Therefore OLS estimates of equation (6) will suffer from an endogeneity bias. Nevertheless equation (6) also provides the potential instruments to fix this endogeneity problem. The size of the service sector (S_I), and in general of the local demand generated from the local economy, affects the amount of resources devoted to R&D while, not entering in equation (6) does not affect productivity of R&D. Variable proxying demand and the size of the service sector have an uneven spatial distribution across european regions and will be used as instrumental variable in the estimates of the productivity od R&D and of its spillovers.

5. Empirical specification and the structure of the spillovers

We empirically implement the relationship expressed by equation (3). This expression is non linear in the parameter ε_{f2} and all the spillovers parameters M_{ij} enter via the inverse matrix in square brackets. Although in principle we could estimate the parameters directly from this specification using a non linear method, we would have to do an inversion of a matrix and obtain extremely non linear function of the parameter, with extremely hard estimation problems. What we could do is to re-write the matrix in braces, linearizing it around the point where the parameter ε_{f2}=0. We apply the Taylor formula for a vector equation and terminate it after the first term. The linear expression we find is:

$$(5)\quad \log(\dot{\underline{A}}) \approx \underline{c} + \frac{e_l}{(1-e_{f1})}\left(I + \frac{e_{f2}}{1-e_{f1}} e_{f2} M \right) \log(\underline{n})$$

Equation (5) is a general relation between regional innovation rate and regional resources used in R&D that can be estimated using IV , once we find the right instrument for R&D employment[20]. The interpretation of (5) is rather intuitive. It says that the determinants of innovation in a region are two factors:

a. The R&D done in the region itself,

[20] The drawback of linearizing this expression rests in the treatment of the 11 regions with 0 patents' application. In fact, in any given year, a number of firms perform R&D but generate no patents. The linear model is not designed to handle such data. We follow Eaton, Gutierrez and Kortum (1998) and we attribute a rate of patenting equal to 0.02 per year to the regions with 0 patent applications. This results in zero patents in 18 years, on average.

b. The R&D done in all the other regions, filtered by a coefficient capturing the overall spillovers (ε_{f2}) and a matrix which identifies the intensity of spillovers across space (as M_{ij} will depend on the distance between region i and region j).

The coefficient on the term log($\underline{n}$) captures the total returns to own R&D in generating new knowledge. It is a combination of two factors: the productivity of R&D in the innovation equation (ε_{λ}) and the intensity of spillovers from own knowledge stock (ε_{f1}). The coefficient of the term M*log($\underline{n}$), on the other hand, is a measure of the intensity of the effect of other regions' R&D on one region's innovation and will be considered as a measure of the intensity of the spillovers.

As first approach we do not want to impose any parametric structure on the intensity of the spillovers (M_{ij}) allowing only that they vary with distance (in the geographic or in the technological space). Therefore we decompose the matrix M as follows:

$$(6) \qquad M = b_1^{'} M_1 + b'_2 M_2 + ... + b'_K M_K$$

To construct M_i we have grouped the regions in K classes of distance, including in each class the couple of regions whose distance d_{ij} is in the interval [h_{k-1}, h_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 a β'_k coefficient that captures the intensity of the spillovers from the regions in that class of distance which we can estimate. It is then possible to assess the effect of the inter-regional spillovers of R&D on innovation, and to identify the rate of decay of spillovers with geographical or technological distance. The system that we can estimate is, in matrix notation, as follows:

$$(7) \qquad \log \dot{\underline{a}} = \underline{C} + b_0 \log \underline{n} + b_1 M_1 \log \underline{n} + b_2 M_2 \log \underline{n} + ... + b_K M_K \log \underline{n}$$

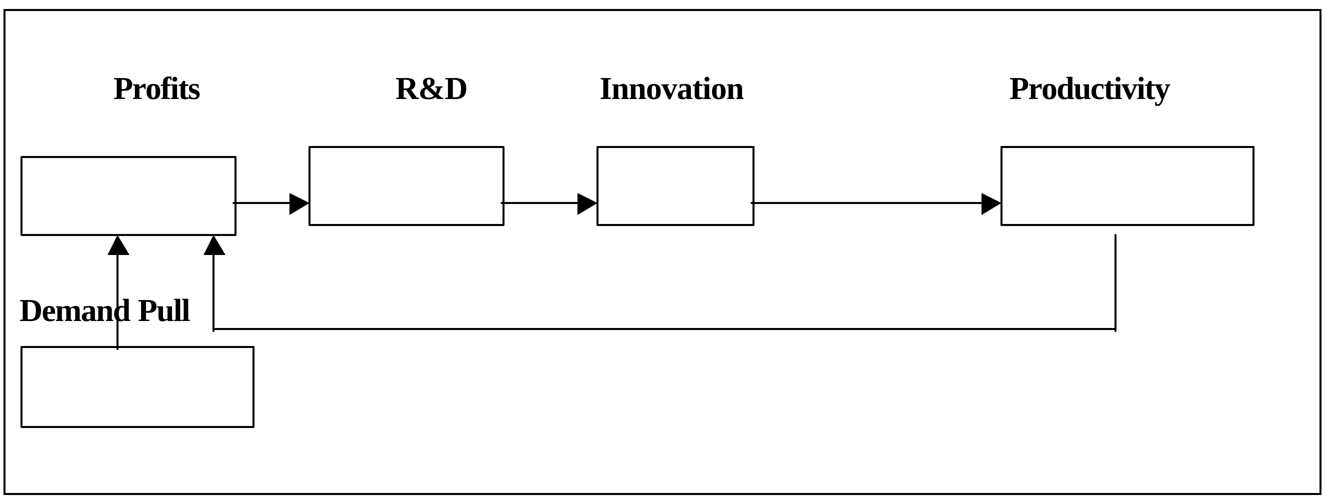
b_0 gives a measure of the BGP elasticity of innovation to own research while (β_{κ}/β_0) is a measure of the relative importance of the knowledge spillovers coming from regions at distance k from region i.

The theoretical analysis developed in the previous section tells us that the expression (7) 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 need 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. Local demand, i.e. market potential, that fosters profits without affecting the productivity of research, the term S_i in equation (7),is therefore a 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. There is a circular causation, shown in Figure 1, in which R&D generates innovation, and productivity growth (equation (5)), which in turn generates profits and incentive to invest in R&D (equation (4)). 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 (much as the classic growth literature assume as exogenous the countries' savings rates, Mankiw, Romer and Weil (1992)). This is in contrast, we think, with the whole theory of endogenous growth.

Figure I

Scheme of causation



We measure "market potential" of one region, by means of different variables: population, population less employment in manufacturing, employment in services and sector VA weighted on the basis of an I-O national matrix.

As we describe in the empirical part, these two sets of instruments do relatively well in capturing the cross-sectional variation of the intensity of R&D (R&D employed as percentage of the labor force), in fact they jointly explain around 37% of such variation.

6. Empirical Results

The first empirical issue to be addressed is how to measure the "stock of knowledge". If a new patented good can be considered as a new intermediate and a new idea, as in Romer (1990) and Jones (1995), the patent count can be used as a measure of increase in the stock of 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 ones, 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. Moreover as the region, rather than the sector, is the unit of our analysis it seems plausible to consider a new patent produced within the region as a complement rather than a substitute of the existing ones. Therefore we take patent count as a proxy for the increase in economically profitable knowledge. One patent is one new good and all of them give the same contribution to productivity. We attribute a patent to the region of residence of its first inventor, as we want to capture the spillovers from ideas to generate new ideas, and therefore the location of the inventor is the location where the idea has been developed.

With these assumption, and considering that the economy will be on average on the balanced growth path, in the 18 years period we consider[21], we are able to estimate equation (20). In particular, equation (7) has a direct translation in terms of patents, which is:

$$(8)\quad \log(\underline{Pat}) = \underline{C_0} + b_0 \log \underline{n} + b_1 M_1 \log \underline{n} + b_2 M_2 \log \underline{n} + ... + b_K M_K \log \underline{n}$$

Equation (8) is the basic specification of our empirical estimates. The average yearly amount of patents' application , in each region (in the period 1977-1995) is considered as the measure of BGP

[21] 18 years could be a short period of time if we believe in the low estimate of convergence by Barro and Sala (1991). Nevertheless stylized facts and new estimates of the speed of convergence from panel data (Canova and Marcet 1995, De la Fuente 1996, DeLa Fuente 1998) lead us to believe that western Europe is close to its BGP since the 70's.

intensity of patenting[22]. This in turn, is assumed to depend, on the number of workers employed in R&D (average in the 1977-1995)[23] 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 depends on the distance between regions. Hence, the cross sectional variation of the employment in R&D in the other regions, assuming that these spillovers vary with distance, allow us to identify the relative intensity of the spillovers. b_0, on the other hand, captures the elasticity of innovation to own R&D employment. Intuitively, if the different intensities of R&D get translated into a more polarized distribution of innovation, as the data suggest, then the parameter b_0 should be (as in most of the estimates) larger than one.

Comparing the OLS and the IV estimates, we realize that the second procedure gives always lower point estimates of the elasticity of innovation to R&D.

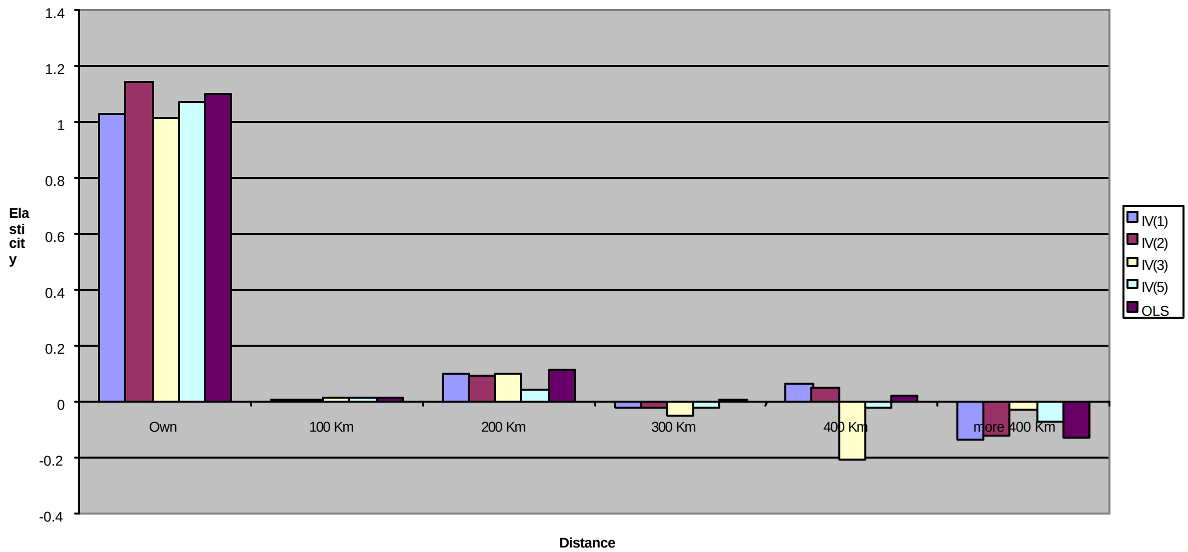
6.1 The basic model with geographical spillovers

In the empirical implementation of equation (8) we have two important issues to address, namely the frequency and the length of the "space" intervals for each explanatory variable in order to have a reasonable trade-off between explained variance and precision of the estimates. The first problem is made much more severe by the possibility of collineariety between variables. The inclusion of variables that capture average R&D employment in regions far away might give rise to a collinearity problem since the relative "change" in environment every 100 Kilometers decreases with distance. The standard 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 0.9-0.95 among the last 5-6 variables out of 10. This will make the estimates totally unreliable, and the standard 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] 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.

[23] 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.

Figure 6. Elasticities of Innovation to R&Destimated with 100 Kms cells

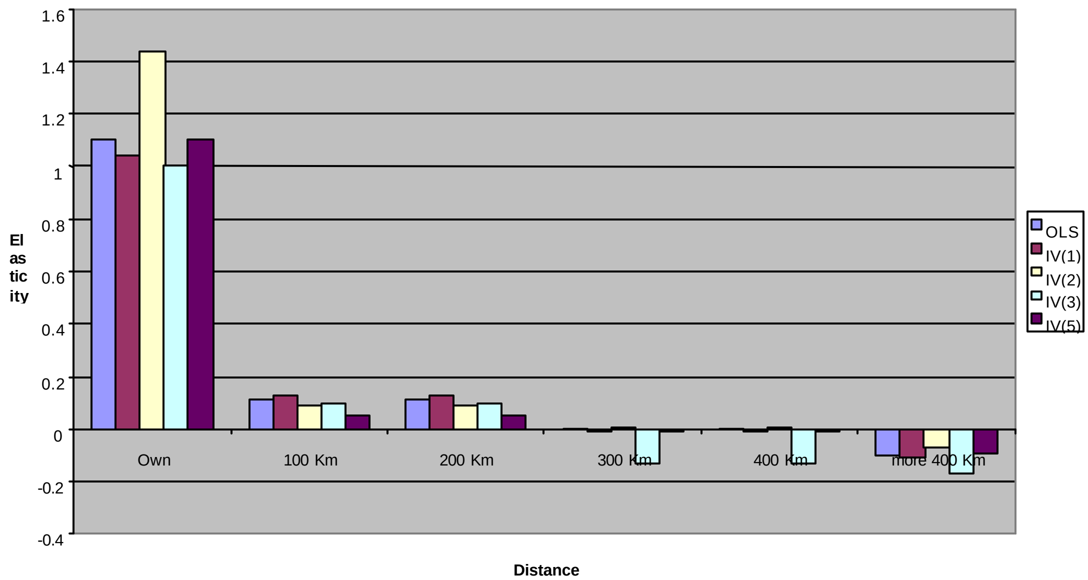


In this way we are able to include four intervals (from 0 to 400 Km by 100) in the case of 100 Km cells and 2 intervals (from 0 to 400 Km by 200) in the case of 200 Kms Cells. The R&D employment for longer distances is included as an average variable, (whose coefficient in the tables is denoted as β^{4+} or β^{2+} depending on the cell's length), aimed at capturing the effect of average R&D employment more than 400 Kilometers away and at controlling for the "average R&D in the rest of Europe. We perform weighted OLS and IV estimates of the coefficients of the basic regression (8) with the chosen length of space intervals[24]. The weighting is made because, due to different size of regions the size of the measurement errors could be different across them. The full results are reported in Table 2a and 2b, in the first case using R&D[25] employment and in the second real R&D spending as explanatory variable . Table 3a and 3b, contain the same regression results, but with 200-Km's distance cells to capture the spillover of R&D. This results are also shown in figure 6 and 7 so that we may eyeball the decreasing effects of R&D via spillovers.

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

[25] These results are obtained using total R&D. We have also run the regressions distinguishing between private and public R&D. The results do not change significantly: the elasticity of patenting to private or to total R&D remains almost unchanged. The results could be severely affected by the quality of the data on private R&D available at regional level.

Figure 7. Elasticities of Innovation to R&D, estimated with 200



Let's concentrate on the basic specification estimated with local population as IV (regression IV(1) in all tables), as all the other specifications include some other variables to check the robustness of the results. 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 close to one (see figure 6). Most of the cross-regional variation in patenting is due to differences in R&D.

2) Spillovers through space exist and are statistically significant for the R&D done within 200 Km's from the region (see figure 7). In particular when we sub-divide the interval in 100 Km's cells the most significant and consistently positive elasticity is that on R&D in the 100-200 Kms range. This is probably due to the fact that, in the closest 100 Km's from a regional capital, there are very few other capitals (in the case of large regions none at all). This dilutes the effect of the first variable. The magnitude of these spillovers effects, if not negligible is not very large either: 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 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 important but second order of importance.

We perform a number of different checks 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) and IV(4) 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[26], 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 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.

Border Effect and Parametric Specifications

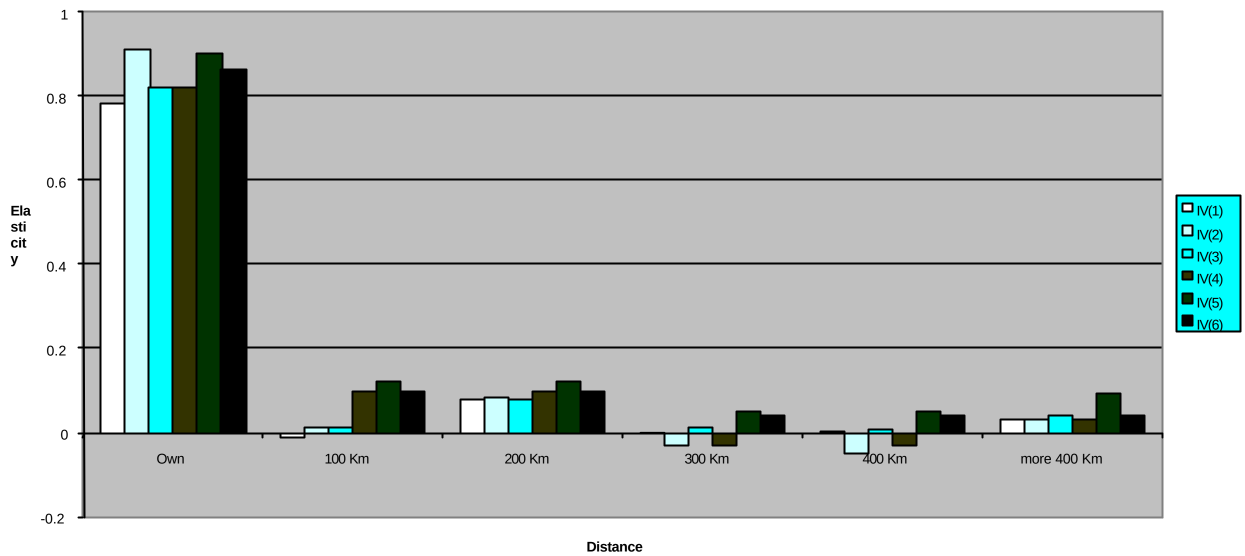
The benefits of ideas could spread more easily within countries than across, even in absence of any barrier, due to the common language and similar educational background of the skilled workers. Therefore the effect of decreasing spillovers across distance may be simply capturing the fact that we have positive and perfect spillovers within a country while zero spillovers across countries. Hence we take care of a "border effect", after consideringorder effect, we add the average level of R&D spending or employment to our regressors, in each of the eleven countries. If one region receives benefits just from being in a high R&D country his "border" variable will be significant and R&D of regions in the neighborhood will not matter any longer. The results of including this variable, together with the usual controls and using both 100 and 200 KMs cells, are reported in table 4. The national R&D variable has a very strong and positive effect, but the elasticity to R&D of regions in the vicinity remains almost unchanged and mostly significant. We tend to believe that this is the best specification of our model. It reveals strong evidence that within country spillovers matter so that there is a strong border effect. Moreover it generates the usual feature of

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

decaying spillovers over space, without the undesirable feature of negative values[27] for the spillovers from farther regions (see figure in the following page that summarizes these results). Again, the visual impression, confirmed by the data, indicates that only the two closest groups have significant effects, but of one order of magnitude smaller than the effect of own R&D.

In this specification the pattern of the spillovers exhibit a decay of the elasticity towards 0, as the distance increases (see figure 8). Moreover, in this case, an F test of significance of the sum of all coefficients capturing externalities ($\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_{4+} = 0$) rejects the null at the standard levels of significance confirming the hypothesis of existence of externalities. This is a direct test of the assumption that

Figure 8. Elasticities, controlling for avergae national R&D



total R&D spillovers are significant in determining innovation in one region[28].

The results obtained so far only use the first 400 Km's in distance from each region (as we had to eliminate the other variables due to colineariety). At the cost of specifying a functional form for the dependence of spillovers on distance, we may parametrize this decay and use all the data on R&D at any distance to estimate only one parameter that captures this dependence.

We specify three different functional forms for the decay of spillovers with distance:

[27] we are not the only one to obtain negative spillovers effect of R&D on patents. In different set-ups both Jaffe(1986) and Branstetter(1996) argues that if technological rivalry with other firms is intense enough and the scope of intellectual property rights conferred by patents is broad enough, firms may sometimes find themselves competing for a limited pool of available patents--a patent race. For this reason the positive externality is potentially confounded with a negative effect of other firms' research due to competition. Because of this the spillover coefficient might be negative. This might even be more true for distant regions or firms.

[28] Test F(1,80) = 4.88, p-value 0.02.

exponential ($e^{l(dist)}$), power ($l^{(dist)}$) and inverse ($\frac{1}{l(dist)}$). We still divide the regions in 100 Km's cells, but now we use as dependent variables the average R&D weighted for the parametric function. We use the 86 regions to estimate the parameter λ, using non linear instrumental variables.

The results, reported in table 5a reveal that, although there is a significant amount of noise, all three methods estimate parameters which imply spillovers quickly decreasing with distance. The best fit is obtained with the exponential specification, which delivers also the fastest rate of decay. With any method, however, only R&D in the regions within a range of 100 Kms has an impact larger than 1% on innovation (see simulation in table 5b). These effects, obtained imposing parametric forms seems somewhat smaller than those obtained using non-parametric methods, although broadly consistent in terms of tendency and order of magnitude. The parametric specification forces a smooth behavior, which does not seem supported by the data.

Our results that knowledge spillovers have a strong intranational component, receive supports from other studies. Branstetter (1996) measures the importance of domestic versus foreign spillovers between Japanese and US firms that belongs to the same technological field[29]. Though different in his approach and methodology he finds that the elasticity of patenting to domestic R&D is around 1% while the effect of foreign spillovers can be negative both for Japanese and for US firms. Using data on citations in scientific papers, Jaffe and Trajtembergeg (1995) find similar results: patent citations have a strong intranational component while surveys on the appropriability of R&D distributed to manager in the US and Japan and Europe report that domestic spillovers are more important tan the international one. Nadiri and Kim (1996) find that the relative importance of domestic and foreign research seems to vary considerably among countries. Domestic research is more important for the United States, while countries like Italy and Canada are strongly affected by the spillovers of foreign research. We do not find this strong difference among European regions.

Non Linear Estimation and Spatial Auto-correlation

Our estimated specification in logarithm (equation 8), allowed us to use linear regression techniques, at the cost of assigning to those regions with zero average patenting rate a patenting rate equal

[29] Following Griliches (1979) and Jaffe(1986) Branstetter measures the distance of firms from each other in "technological" space, since this can be measured by the similarity of the field in which firms patent. The spillover variable for a particular firm is the research of the other firms, weighted by the distance in technology space.

to 0.02[30]. In order to avoid this small correction we may estimate equation (8) in levels, rather than in logs, using non linear least squares, so that the coefficients estimated are the exponents of the following regression

$$(9)\quad \underline{Pat} = \underline{C_0}\,\underline{n}^{b_0} (\overline{\underline{n_1}})^{b_1} (\overline{\underline{n_2}})^{b_2} ....(\overline{\underline{n_k}})^{b_{k1}} (\overline{\underline{n_{country}}})^{b_{country}}$$

where n_1 , n_2, …n_k are the geometric averages of R&D employment in regions within a distance increasing with the index, $n_{country}$ is the average R&D in the country and the β's are the elasticities as in equation (8). Estimating equation (9) using non-linear least squares, and distance cells of 200 kilometers, we get the following parameter estimates: β_0= 0.79*** (s.e.= 0.09), β_{0-200}= 0.11** (s.e.= 0.04), $\beta_{200-400}$= –0.18 (s.e.= 0.10)

β_{400+}= 0.05 (s.e.= 0.12) $\beta_{country}$= 0.30** (s.e.= 0.15)

Comparing with the estimates obtained from the log-linear transformation, reported in table 4, we notice a strong similarity, except for the coefficient of the "border effect" that in this case is significantly smaller.

Another potential concern in estimating the model assuming uncorrelated errors, is that there may be some spatial auto-correlation of the errors. If in the specification of the relation between R&D and innovation we are omitting some factors, which are spatially correlated, this may result in residuals which are spatially correlated. This problem does not affect the consistency of the point estimates obtained from the IV method, but may distort the estimates of the standard errors. This should not be cause of particular concern, though, as taking into account the spatial correlation of the residuals would probably result, as in Conley and Ligon (1997), in a smaller estimate of the residuals, without changing the point estimates of the parameters. This is the reason why we do not introduce any correction, although the spatial autocorrelation of the residuals of the specification reported in table 4 column 1, is significant for distance within the 400 Kms[31].

6.2 Spillovers in purely technological space

[30] see footnote (20)

[31] We estimate the auto-correlation function non parametrically, using the estimator in Conley and Ligon (1997), with a rectangular kernel with bandwidth equal to 50 Kilometers, evaluated at the points k=50,150,250 and 350. The values of the autocorrelation is 0.15, 0.48, 0.47, 0.47 and they are all significant.

The natural question to ask is whether “geographical space” is the most natural dimension in which regions innovate and in which spillovers 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 construct a distance matrix which is a metric in the technological space. 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.

Technology spillovers have been measured following different methodologies in the literature. An extensive review of the existing measurement methods is offered by Los (2000). We therefore leave aside any discussion on the pro and the cons of the different approaches. We follow Jaffe (1986) and we construct a measure of technological distance between regions, on the basis of the distribution of regions' patenting activities over technological fields. We then assume that spillovers can be measure by the stock of R&D developed by other regions, where each region's input into this stock of external knowledge is weighted by its technological distance from the spillover-receiving region. Our technological proximity measure is thus:

$$w_{ij} = \frac{\sum f_{ik} f_{jk}}{\sqrt{(\sum_{k=1}^{F} f_{ik}^2 \sum_{k=1}^{F} f_{jk}^2}}$$

Which is the cosine of two vectors consisting of the shares of the F patent classes in the "patent portfolio" of a region. If the two regions have patented in roughly the same classes the cosine will be close to one, if the patenting activities are greatly different the cosine will be virtually zero.

In our sample of 86 EU regions we have that the index range from 0 to 0.92. We identify 3 classes of distance, the first two covering an interval equal to 0.2 in the metric of the specialization index and the third 0.4 to 0.9. The estimates of specification (21), using this metric on the “external effects” of R&D are reported in Table 6. 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.

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 has an effect only on those regions which are geographically close. 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. We group these regions into the four cells, in decreasing order of production-sectors proximity, and construct the four spillover matrices. The effect of outside R&D on regional patenting is estimated in the regressions of Table 7. 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 0.10 and highly significant, while the effect of R&D in more different regions is not significant and often negative for the most different ones. 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.

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 decrease rather quickly with distance. Moreover if physical proximity is what allows the spillovers, technological proximity enhances them, as among closer regions those more similar in the productive structure are also the more effective in influencing the innovation.

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Tables

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

Table 2a[32]:

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.
β_0	1.10***	1.03***	1.14***	1.01***	1.07***
	(0.08)	(0.19)	(0.44)	(0.09)	(0.08)
β_1	0.01	0.003	0.008	0.02	0.01
	(0.02)	(0.03)	(0.03)	(0.03)	(0.015)
β_2	0.11***	0.10***	0.09**	0.10***	0.043**
	(0.04)	(0.04)	(0.047)	(0.04)	(0.022)
β_3	-0.003	-0.02	-0.02	-0.05	-0.028
	(0.07)	(0.07)	(0.07)	(0.09)	(0.03)
β_4	0.02	0.06	0.05	-0.21	-0.02
	(0.07)	(0.07)	(0.09)	(0.13)	(0.04)
β_{4+}	-0.13	-0.14	-0.12	-0.03	-0.078
	(0.09)	(0.09)	(0.12)	(0.16)	(0.05)
R^2	0.75	0.68	0.34	0.74	0.79
Tot. Observations	86	86	86	71	86

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

[32] *significant at 10% level, ** significant at 5% level, *** significant at 1% level

Tot. Observations	86	86	86	71	86	86

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)	(0.058)
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

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

4.Ols Estimates

(same regression as the basic in table 4a,b,c,d estimated by OLS)

Dep. Var: log (Patents)	I (100 Km cells) Basic	As in I (200 Km cells)
β_0	0.99*** (0.09)	0.99*** (0.09)
β_1	0.00 (0.03)	0.09*** (0.04)
β_2	0.10*** (0.04)	
β_3	0.00 (0.07)	0.00 (0.07)
β_4	0.01 (0.07)	
β_{4+}	-0.05 (0.09)	-0.05 (0.07)
Average Country R&D	0.43*** (0.19)	0.42*** (0.17)
R^2	0.76	0.77
Observations	86	86

Table 4a: Population as instrument:

Preferred specification, weighted IV estimation: Instruments= Total Population

Indep. Variable Log(R&D employment)

Standard errors in parenthesis

Dep. Var: log (Patents)	I (100 Km cells) Basic	II Controlling for Human Capital [1]	III Controlling for infrastructures [2]	As in I (200 Km cells)	As in II (200 Km cells)	As in III (200 Km cells)
β_0	0.78*** (0.11)	0.91*** (0.11)	0.82*** (0.11)	0.82*** (0.10)	0.90** (0.10)	0.86*** (0.10)
β_1	-0.01 (0.03)	0.01 (0.3)	-0.01 (0.03)	0.096* (0.058)	0.12** (0.06)	0.10* (0.06)
β_2	0.08** (0.04)	0.085** (0.04)	0.08** (0.04)			
β_3	-0.001 (0.07)	-0.03 (0.10)	0.01 (0.08)	-0.03 (0.11)	-0.05 (0.25)	0.04 (0.12)
β_4	0.002 (0.08)	-0.05 (0.13)	0.007 (0.08)			
β_{4+}	0.03 (0.10)	0.03 (0.17)	0.04 (0.10)	0.03 (0.09)	0.09 (0.25)	0.04 (0.10)
Average Country R&D	1.05*** (0.17)	0.62*** (0.21)	1.04*** (0.18)	1.01*** (0.17)	0.60*** (0.20)	1.00*** (0.18)
R^2	0.71	0.74	0.71	0.70	0.73	0.70
Observations	86	86	86	86	86	86

[1] Human capital is the share of workers in the region with college degree

[2] Infrastructure is the density in the region of roads and railways

Table 4b: Population net of Manufacturing employment as instrument:

Preferred specification, weighted IV estimation: Instruments= TOT. POpulation – Manuf. Employment
Indep. Variable Log(R&D employment)
Standard errors in parenthesis

Dep. Var: log (Patents)	I (100 Km cells) Basic	II Controlling for Human Capital [1]	III Controlling for infrastructures [2]	As in I (200 Km cells)	As in II (200 Km cells)	As in III (200 Km cells)
β_0	0.81*** (0.11)	0.90** (0.11)	0.85*** (0.12)	0.84*** (0.11)	0.90*** (0.10)	0.87*** (0.11)
β_1	0.02 (0.03)	0.00 (0.03)	0.02 (0.03)	0.12** (0.065)	0.05 (0.06)	0.13* (0.07)
β_2	0.091** (0.040)	0.05 (0.04)	0.09** (0.04)			
β_3	0.00 (0.08)	-0.06 (0.07)	0.02 (0.08)	0.01 (0.12)	0.05 (0.07)	0.02 (0.13)
β_4	0.00 (0.08)	0.06 (0.07)	0.00 (0.08)			
β_{4+}	0.05 (0.04)	0.04 (0.04)	0.05 (0.04)	0.02 (0.04)	0.03 (0.04)	0.03 (0.05)
Average Country R&D	1.00*** (0.18)	1.03*** (0.18)	0.99*** (0.18)	0.91*** (0.17)	1.20*** (0.18)	0.90** (0.18)
R^2	0.71	0.75	0.71	0.71	0.74	0.70
Observations	86	86	86	86	86	86

[1] Human capital is the share of workers in the region with college degree
[2] Infrastructure is the density in the region of roads and railways

Table 4c: Employment in Services as instrument:

Preferred specification, weighted IV estimation: Instruments= Empl. in Services
Indep. Variable Log(R&D employment)
Standard errors in parenthesis

Dep. Var: log (Patents)	I (100 Km cells) Basic	II Controlling for Human Capital [1]	III Controlling for infrastructures [2]	As in I (200 Km cells)	As in II (200 Km cells)	As in III (200 Km cells)
β_0	0.93*** (0.10)	0.96*** (0.10)	0.90*** (0.11)	0.96*** (0.10)	0.99*** (0.10)	0.97*** (0.10)
β_1	0.01 (0.03)	0.00 (0.03)	0.00 (0.03)	0.12*** (0.06)	0.07 (0.05)	0.13** (0.065)
β_2	0.09** (0.04)	0.06 (0.04)	0.09*** (0.04)			
β_3	0.01 (0.07)	-0.04 (0.07)	0.02 (0.08)	0.02 (0.12)	0.05 (0.11)	0.01 (0.12)
β_4	0.02 (0.07)	0.07 (0.07)	0.01 (0.07)			
β_{4+}	0.02 (0.04)	0.00 (0.04)	0.02 (0.04)	0.00 (0.04)	0.00 (0.04)	0.00 (0.04)
Average Country R&D	0.67 (0.19)	0.96*** (0.19)	0.68*** (0.19)	0.60*** (0.18)	0.94*** (0.19)	0.60*** (0.19)
R^2	0.71	0.75	0.71	0.71	0.74	0.70
Observations	86	86	86	86	86	86

[1] Human capital is the share of workers in the region with college degree
[2] Infrastructure is the density in the region of roads and railways

Table 4d: Demand for intermediates as instrument:

Preferred specification, weighted IV estimation: Instruments= Demand for intermediates as of IO matrix

Indep. Variable Log(R&D employment)

Standard errors in parenthesis

<table>
<tr><th>Dep. Var:
log (Patents)</th><th>I (100 Km cells)
Basic</th><th>II
Controlling for Human Capital [1]</th><th>III
Controlling for infrastructures[2]</th><th>As in I
(200 Km cells)</th><th>As in II
(200 Km cells)</th><th>As in III
(200 Km cells)</th></tr>
<tr><td>β_0</td><td>1.09***
(0.11)</td><td>1.07**
(0.10)</td><td>1.11***
(0.11)</td><td>1.11***
(0.19)</td><td>1.14***
(0.21)</td><td>1.11***
(0.16)</td></tr>
<tr><td>β_1</td><td>0.00
(0.03)</td><td>0.00
(0.03)</td><td>0.00
(0.03)</td><td rowspan="2">0.10
(0.07)</td><td rowspan="2">0.05
(0.07)</td><td rowspan="2">0.12
(0.07)</td></tr>
<tr><td>β_2</td><td>0.07***
(0.035)</td><td>0.06*
(0.035)</td><td>0.08***
(0.04)</td></tr>
<tr><td>β_3</td><td>0.06
(0.07)</td><td>0.00
(0.07)</td><td>0.06
(0.08)</td><td rowspan="2">0.01
(0.15)</td><td rowspan="2">0.01
(0.17)</td><td rowspan="2">0.01
(0.14)</td></tr>
<tr><td>β_4</td><td>0.03
(0.07)</td><td>0.07
(0.07)</td><td>0.02
(0.07)</td></tr>
<tr><td>β_{4+}</td><td>0.01
(0.04)</td><td>0.01
(0.04)</td><td>0.00
(0.04)</td><td>0.10
(0.54)</td><td>0.03
(0.60)</td><td>0.03
(0.42)</td></tr>
<tr><td>Average Country R&D</td><td>0.54***
(0.19)</td><td>0.80***
(0.19)</td><td>0.54***
(0.20)</td><td>0.59***
(0.19)</td><td>0.87***
(0.23)</td><td>0.57***
(0.16)</td></tr>
<tr><td>R^2</td><td>0.75</td><td>0.78</td><td>0.72</td><td>0.67</td><td>0.67</td><td>0.74</td></tr>
<tr><td>Observations</td><td>86</td><td>86</td><td>86</td><td>86</td><td>86</td><td>86</td></tr>
</table>

[1] Human capital is the share of workers in the region with college degree

[2] Infrastructure is the density in the region of roads and railways

Table 5a:

Parametric Estimates: NL Instrumental Variables, Std. errors in parenthesis
The distance is expressed in hundredths of Km's

Dep. Var: log(Patents)	Exponential Decay $e^{\lambda_a(dist.)}$	Power Decay $\lambda_b^{(dist)}$	Inverse Decay $1/(dist*\lambda_c)$
β_o	0.97***	0.83***	0.82***
	(0.11)	(0.10)	(0.10)
λ_a	-3.9***		
	(1.1)		
λ_b		0.017	
		(0.01)	
λ_c			87.1
			(100)
Country R&D	0.87	0.21	0.24
	(0.50)	(0.20)	(0.26)
R^2	0.55	0.50	0.53
Tot. observations	86	86	86

Table 5b:

Point Estimates of elasticities, in percentage of innovation to R&D, Using the parameters' estimate from Table 5a.

Method/Distance	own	[100 Km]	[200 Km]	[300 Km]	[400 Km]	[more than 400 Km]
Exponential Decay	97%	2%	0.04%	0.00%	0.00%	0.00%
Inverse decay	83%	1.2%	0.5%	0.3%	0.2%	0.1%
Power decay	82%	1.7%	0.02%	0.00%	0.00%	0.00%
Non-Parametric, 100 Kms cells	91%	1%	8.5%	-3%	-5%	3%
Non-Parametric, 200 Kms cells	90%	9.6%	9.6%	-3%	-3%	3%

Distance in the Technological Space

The cells are:

b_1 , the closest [0.4-1.0] correlation

b_2 itermediate[0.2-0.4] correlation

b_3 far [0.0-0.2] correlation

Table 6a

Dep. Var: log (Patents)	**I OLS**	**II Population as IV**	**III Service as IV**	**IIII Demand as IV**
β_0	0.90***	0.77***	0.82***	0.98***
	(0.08)	(0.09)	(0.09)	(0.09)
β_1	0.28***	0.22***	0.24***	0.21***
	(0.05)	(0.06)	(0.06)	(0.06)
β_2	-0.10	-0.08	-0.10	-0.09
	(0.08)	(0.08)	(0.08)	(0.08)
β_3	0.03	0.05	0.02	0.00
	(0.03)	(0.03)	(0.03)	(0.03)
Average Country	0.41***	0.88***	0.67***	0.52***
R&D	(0.16)	(0.15)	(0.16)	(0 .16)
R^2	0.80	0.76	0.78	0.79
Observations	86	86	86	86

Appendix A: The model

A.1:Prices and Profits and Production

The market clearing condition for the manufacturing goods, equating the expenditure to the value of production in the regional market is:

$$\text{(1a)} \qquad P_{it} y_{it} = (1-g)\left[gS_i^g y_i^{-g} + P_{it} y_{it}\right] + (1-g) S_i^g y_i^{-g}$$

The term on the left hand is the total value produced by the manufacturing sector. The first term on the right hand is the demand of manufacturing for consumption and the second term is the demand of manufacturing as intermediate from the service sector. Solving for P_{it} we obtain equation (2) in the text.

Given the production function in equation (1) the demand curve for each intermediate will be $p_{it}(s) = P_{it} a L_{it}^{1-a} x_{it}^{a-1}(s)$ where p_{it}(s) is the price of the s-th intermediate good in region i at time t. The optimal pricing rule is:

$$\text{(2a)} \qquad p_{it} = \frac{1}{a} w_t$$

where we have assumed perfect mobility of skilled workers across regions and therefore a unique wage w_t for all regions. The demand for the single firm will be:

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

The profit of each monopolist in the i-th region, therfore is:

$$\text{(4a)} \qquad p_{it} = \frac{1-a}{a} w_t x_{it}$$

Now consider the production function of the composite good. A share (1-α) of the total value added is paid to unskilled worker while the remaining share α is paid as wage to the skilled workers and profits to the producers of intermediates. Therefore:

$$\text{(5a)} \qquad \int_0^{A_i} p_{it}\,di + \int_0^{A_i} w_{it}x_{it}\,di = aP_{it}y_{it}$$

and using (4a) plus the fact that all firms are similar we get:

$$\text{(6a)} \qquad p_{it} = \frac{a(1-a)P_{it}y_{it}}{A_{it}}$$

In equilibrium, as all firms have the same size, we may write the manufacturing output as:

$$\text{(7a)} \qquad y_{it} = L^{1-a}A_i x_{it}^a$$

using (3a) and (7a) we can solve for x_{it} and we get:

$$\text{(8a)} \quad x_{it} = C_x w_t^{\frac{1}{a-1}} S_i^g A_i^{-g}$$

where we have collected all constant terms into the term C_x . Using (8a) and (7a) to solve (6a) the expression of profits becomes as in (4) in the main text.

A.2: Derivation of the balanced growth path

The relevant knowledge for catch-up spillovers is defined as A_{it}^S equal to:

$$\text{(9a)} \qquad A_{it}^S = \prod_{j=1}^{N} A_{jt}^{M_{ij}} \quad \text{where} \quad \sum_{j=1}^{N} M_{ij} = 1$$

The M_{ij} is a weight which captures the contribution of region j knowledge on the creation of region i new knowledge.

If we call g_x the rate of change of the variable x, then we can take the rate of change on each side of expression (5) in the text, and we have:

(10a) $$\dot{g}_{A_i} = g_{A_i}\left[e_I g_H + (1-e_f)g_{\bar{A}} - e_f g_{A_i}\right] \qquad \text{for i= 1,2…N}$$

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 is:

(11a) $$g_A = \frac{e_I g_H}{1-e_{f1}-e_{f2}}$$

Expression (11a) says that the average rate of growth will depend on the growth rate of the skilled labor force, amplified by the productivity of R&D in innovation, and by the spillovers from existing knowledge. The result, that the growth rate depends only on the growth of human capital and not on the investment in R&D (which, as we will see, determines relative innovation intensities), is a consequence of the assumption of decreasing returns in the innovation-production function, which makes the model similar to Jones (1996). If we log-linearize expression (5) around the BGP we have that the system can be written in vector form as:

(12a) $$\underline{\dot{g}_A} = \left[e_{f2}M + (e_{fi}-1)I\right]\left(\underline{g_A} - \underline{\overline{g_A}}\right)$$

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 in square brackets, which are the sum of the characteristic roots of the two matrices, are therefore negative (given the conditions on the elasticities) and the differential system of equations (12a) is stable[33]. If we define with $\overline{A} = \prod_{1}^{N} A_i^{1/N}$,

the BGP, denoting with ε_λ the elasticity of the λ function with respect to n, the following log-linear equation will hold:

$$\text{(15a)} \quad \log(g_A) = c + e_l \log(n_i) + (e_{f1} - 1)\log(A_i) + e_{f2} \sum_{j=1}^{N} M_{i,j} \log(A_i)$$

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

$$\text{(16a)} \quad \log(\underline{A}) = \underline{c} + \tfrac{e_l}{1-e_{f1}} \left(I - e_{f2} M\right)^{-1} \log(\underline{n})$$

Finally, recall that in BGP the flow of new knowledge is just proportional to the stock of exiting knowledge, so that we get :

$$\text{(6)} \quad \log(\dot{\underline{A}}) = \underline{c}' + \tfrac{e_l}{1-e_{f1}} \left(I - e_{f2} M\right)^{-1} \log(\underline{n})$$

where the vector of constants $\underline{c}$' is equal to $\underline{c}$ + log(g_A), which represents the relative patenting of one region with respect to the average.

A.3: Value of a patent

In order to determine the value of a patent, which will provide the input to calculate the reward to R&D workers, we consider the present discounted stream of profits, which are generated by the invention. Using (4) as the expression of profits for a typical producer in region i at time t, collecting all the constant and using the fact that all variables grow at constant exponential rate in BGP we obtain the following general expression as value of the patent in region i:

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

$$V_{it} = \int_{s=t}^{\infty} e^{-r(s-t)} p_i(s)\,ds =$$

(17a)

$$= C_v w(t)^{\frac{a(1-g)}{1-a}} A_i(t)^{(1-ga)(1-g)-1} S_i^{g(1-ga)}$$

The return from innovation (value of a patent) is the present discounted value of a firm's profits using the market rate r. A larger relative number of firms in the local market (A_I) squeezes the profits of a firm and therefore the value of a patent, while a larger local demand (S_i) will increase the profits of a firm and therefore the value of a patent. Using (17a) in BGP, the equilibrium condition on the labor market is:

(18a) $$w(t) = \left(\frac{g_A A_i}{n_i}\right) C_v w(t)^{\frac{a(1-g)}{1-a}} A_i(t)^{(1-ga)(1-g)-1} S_i^{g(1-ga)}$$

Solving (18a) for $n_{i,}$ substituting $a_i \overline{A} = A_i$, taking logs and compacting all constant terms into one constant, we can re-write this equilibrium condition in vector form obtaining equation (7) in the text.

A.4:Equilibrium growth rates in BGP

We can easily characterize the growth rate in BGP of the model. We already know the growth rate of $A_{i,}$ the stock of knowledge (and of intermediate patented goods) in each region. Taking growth rates of (3), (7a) and (8a) wand solving we are able to find the growth rates of wage and manufacturing output as a function of the growth rate of A:

$$g_y = \frac{1}{1-g} g_A$$

$$g_w = \frac{(a-1)[1-(1-g)(1-ga)]}{1-g} g_A$$

Also it is easy to derive that the growth rate of the service output is:

$$g_X = (1-g)g_y = g_A$$

Appendix B: the case of permanent effect of R&D on growth

Using the same structure of the innovation function as in (2), but specifying it differently we may find a model in which the common growth rate of regional innovation and productivity, depends on the investment in R&D of the regions, but still there is convergence towards a BGP. In particular in this case the spillovers of knowledge across regions are interpreted as catch-up of one region technology versus those of the regions it has interaction with. In particular we can specify the change in knowledge as:

(1b) $$\frac{\dot{A}_{it}}{A_{it}} = l(n_{it}) f\left(\frac{A^{S}{}_{i,t}}{A_{i,t}}\right) \qquad f' > 0$$

The variables are defined as before, but now the rate of growth of knowledge depends on R&D employment and on a function f, of technological "catch-up" relative to the regions whose knowledge spills into region i. Assuming zero growth of the skilled labor force, and defining with ε_f the elasficity of function f, the dynamics of knowledge are given by:

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

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:

(3b) $$\overline{g_A} = l(\bar{n})\bar{a}^{(\bar{t}-1/N)}$$

where $\bar{n} = \prod_1^N n^{1/N}$ and $\bar{a}^{(\bar{t}-1/N)} = \prod_1^N a_i^{\overline{t_i}-1/N}$ and $\overline{t}_i = \sum_{j=1}^{N} t_{j.i}$.

Expression (3b) 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 $\overline{t_i} = 1/N$ or all the regions are the same then the common growth rate will simply become $l(\overline{n})$. If we log-linearize the expression (2b) around the BGP we have that the system can be written in vector form as:

(4b) $$\underline{\dot{g}_A} = e_f (M - I)(\underline{g_A} - \underline{\overline{g_A}})$$

which is very similar to (12a). 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 (4b) is stable.

In BGP will therefore hold the following condition:

(5b) $$\log(g_A) = \log(l) + e_l \log(n_i) + e_f \log(a_i) - e_f \sum_{j=1}^{N} t_{i,j} \log(a_i)$$

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

(6b) $$\log(\underline{a}) = \underline{c} + \tfrac{e_l}{e_f}(I - M)^{-1} \log(\underline{n})$$

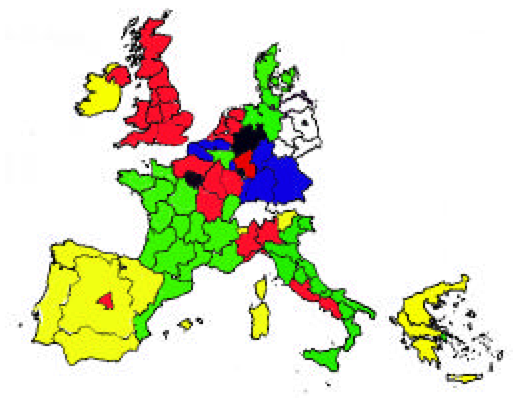
Finally, in BGP :

(7b) $$\log(\underline{\dot{a}}) = \underline{c'} + \tfrac{e_l}{e_f}(I - M)^{-1} \log(\underline{n})$$

This last expression is rather similar to (6), except that we have imposed that the coefficient of I and of M are the same, as the relevant term for the spillovers is simply the ratio of outside and inside knowledge. We consider this as a special case of our more general specification, which we estimate.

Figure 1[34]

Population density (quintiles in decreasing order)



[34] black: top
blu second
red third
green fourth
yellow fifth.

Figure 2

Intensity of R&D (spending in real terms) Quintiles