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PECUNIARY KNOWLEDGE EXTERNALITIES: EVIDENCE FROM EUROPEAN REGIONS

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Pecuniary Knowledge Externalities: Evidence from European Regions[1]

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ABSTRACT. The paper investigates the effects of agglomeration and specialization of technological activities on regional productivity growth, applying the notion of pecuniary knowledge externalities. The latter are indirect interdependencies between firms mediated by the price system. Pecuniary knowledge externalities enable to appreciate both the positive and negative effects associated with the regional concentration of knowledge generating activities. Our analysis leads to specify the hypothesis of an inverted U-shaped relationship between the agglomeration of innovation activities and productivity growth. The empirical investigation, based upon 138 European regions in the years 1996 through 2003, supports the hypothesis that agglomeration yields diminishing positive net effects beyond a maximum. The homogeneity of knowledge generating activities however reduces absorption costs and hence rises the net benefits at each agglomeration level.

Keywords: Geographical agglomeration; Knowledge spillovers; Patents; Pecuniary knowledge externalities; Total factor productivity

JEL Classification codes: O30; O31; O33

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1 Introduction

This paper elaborates the hypothesis that the agglomeration of knowledge generating activities yields both positive and negative effects. It identifies both the positive externalities that emerge within regional clusters in terms of easier access to technological knowledge spilling in the local atmosphere, and the negative factors associated to higher absorption and congestion costs. The notion of pecuniary knowledge externalities enables the assessment of their combined effects in terms of a quadratic relationship between the regional concentration of knowledge generating activities and the net benefits from knowledge externalities. In order to test this hypothesis we investigate the relationship between agglomeration of technological activities and the growth of total factor productivity (TFP) for 138 European regions, observed in the time span ranging from 1995 to 2003. We find evidence of an inverted U-shaped relation between technological agglomeration and productivity growth, in particular with respect to the net positive effects of MAR externalities on productivity growth, rather than Jacobs' externalities. More precisely, regions that are specialized in homogeneous technological fields benefit from agglomeration of knowledge generating activities activity to a greater extent than regions where the pattern of specialization is less homogeneous and more diversified. The rest of the paper is organized as follows. Section 2 spells out the hypothesis and provides its foundations. Section 3 articulates the methodology adopted to measure TFP following the growth accounting approach, presents the data set used for the empirical analysis and exhibits the econometric results of our study. Section 4 concludes.

2 Pecuniary knowledge externalities

For quite a long time the notion of technological externalities, as distinct from pecuniary externalities, has been applied successfully to investigate the effects of the spatial concentration of knowledge generating activities on productivity growth and regional development. It emphasizes the idea that firms clustering in geographic spaces benefit from external economies and knowledge spillovers in particular, and grow faster than isolated firms. The implicit assumption underlying this approach is that technological knowledge spills freely in the atmosphere and firms can take advantage of it at no costs.

This literature, initiated by the path-breaking contributions of Zvi Griliches (1979 and 1992) and Adam Jaffe (1986) on the positive effects of proximity in knowledge space, focuses and elaborates on the advantages exerted by technological externalities on productivity growth of firms co-localized in the same geographical space. Here, within the received Marshallian tradition (Meade, 1952; Viner, 1932), technological externalities are qualified as 'untraded' interdependencies among firms. These interdependencies are not mediated by the price mechanism and do not bear any actual costs for the firms to exploit their gains.

According to the terminology introduced by Glaeser, Kallal, Scheinkman and Shleifer (1992) in their seminal paper, the advantages of agglomeration stem from three types of knowledge externalities: the Marshall-Arrow-Romer (MAR) externalities, which derive from the concentration of firms within a single industry; the Jacobs externalities, which instead are associated with the diversity of firms and industries within a given region; and the Porter externalities, whose argument is that local competition among firms concentrated in the same industry favors local development. Along these lines, recently different studies empirically tested whether cross-fertilization of ideas, and consequently knowledge spillovers contribute regional productivity growth because of the technological homogeneity of firms clustered within the same industry, or rather because knowledge externalities are mobile across sectors and therefore benefit from the knowledge heterogeneity of the firms (e.g. Deckle, 2002; Dumais, Ellison and Glaeser, 2002; Rosenthal and Strange, 2003).

Influential endogenous growth theory models (e.g., Romer, 1986 and 1990; Aghion and Howitt, 1998; Jones, 2002) supported the existence of MAR externalities, with knowledge externalities benefiting firms within the same industry. More importantly, these models claimed knowledge is a quasi-public good, but as a matter of fact characterized it as information. Therefore, within well-defined geographical and technological spaces, knowledge and ideas are inputs that spill free across firms. The accumulation of labor, capital and R&D is the unique requirement for knowledge spillovers and learning from external sources to take place. Knowledge spillovers exert positive and unconditional effects on output and productivity growth. Firms co-located in the geographical and technological space are able to take advantage from knowledge spillovers without occurring in any learning or transaction costs.

Clearly, the new growth theory was implemented upon the line of analysis put forward by Nelson (1959) and Arrow (1962), and subsequently developed in the methodology by Griliches (1979 and 1992) and Jaffe (1986). In these earlier studies knowledge was seen as a public good, and knowledge externalities are a direct consequence of well-known characteristics of technological knowledge: non-divisibility, non-appropriability, non-rivalry in use, non-excludability. Imitators can take advantage from technological knowledge produced by innovators without paying any costs. In this vein, Grossman and Helpman (1994) highlighted that innovators can retain only a portion of the stream of economic benefits that stem from the use of the technological knowledge they generated.

So far we have outlined the basic tenets of the traditional analysis of technological externalities, where technological knowledge generated by a given firm is an unpaid factor that enters the production function of other firms. In this analysis, the market place is unable to provide both appropriate incentives and effective mechanisms to remunerate for private invention. The implications of such market failures call for public subsidies and public intervention in the generation of technological knowledge, and are appreciated in an extensive literature.

However, in the last decade, this analytical framework has been challenged by the discovery of the costs required for the exploration, identification, absorption, recombination and exploitation of knowledge externally available to firms.

A growing body of empirical literature shows that the gains from knowledge externalities by both users and imitators are not free. Knowledge does not spill over spontaneously. Its identification, access and exploitation by third parties require some dedicated resources and an array of costs is typically relevant: imitation costs (Mansfield, Schwartz and Wagner, 1981), absorption costs (Cohen and Levinthal, 1989; Griffith, Redding and Van Reenen, 2003). The acquisition of external knowledge requires also qualified interactions with other agents (Guiso e Schivardi, 2007). The exploitation of knowledge externalities implies the commitment of resources that are necessary to searching, screening, understanding, absorbing, purchasing and acquiring knowledge generated by other firms. The capability of agents to access external technological knowledge depends on the network of relations and common codes of communication. These help to reduce information asymmetries, the scope for opportunistic behavior and create a context in which reciprocity, trust and generative relationship can be implemented (Cohen and Levinthal, 1990; Crémer, Garicano and Pratt, 2007).

A second line of enquiry has shown that the positive effects of knowledge externalities can be challenged by a number of factors. Negative effects and increasing costs can characterize agglomeration within geographic and technological clusters as a result of reduced appropriability of proprietary knowledge (Jaffe, 1986). Congestion problems and negative effects on technological learning and innovation can also easily arise due to excess proximity and agglomeration and consequently lock-in, inertia, higher communication costs, and redundant interaction structures between actors. As it is well known the number of communication channels that are necessary to interact increase exponentially with the number of agents. For instance, the analysis developed by Amiti and Cameron (2007) leads to expect that the wages of scientists and talented people are likely to increase with the increase in the density of knowledge generating activities.

Not only too little, but also too much proximity can be detrimental to the accumulation and creation of technological knowledge and the innovative capabilities of the firms (Boschma, 2005). Similarly, the variety of industry and technological fields characterizing a given region can threat the dynamics of knowledge externalities when the different sectors and technologies are not related each other and instead are distant and diverging (Frenken, Van Oort, Verburg, 2007).

In sum, both the learning from external sources and the 'absorption' of knowledge spillovers, entail specific costs for those firms willing to profit from technological interdependencies and qualified interactions with other firms. Such costs are likely to increase exponentially with the density of knowledge generating activities.

This growing evidence can be framed and elaborated by means of the notion of pecuniary externalities and its application to the study of knowledge externalities. We therefore revisit and give emphasis to the notion of pecuniary externalities as put forward by Scitovsky (1954). Pecuniary externalities consist of the indirect interdependences among actors that take place via the price system. Pecuniary externalities apply when firms acquire inputs (and sell output) at costs (prices) that are lower (higher) than equilibrium levels because of specific structural factors. As a consequence pecuniary externalities hold, instead of technological externalities (Scitovsky, 1954; Antonelli, 2008a and b).

We apply this notion, well distinct from that of technological externalities, and articulate its implications for the analysis of technological knowledge as an economic good. This perspective is motivated by the need of accounting for both boosting and limiting factors affecting the effects of knowledge externalities. While the former consist of the advantages associated with the opportunities each firm has to learn and 'absorb' technological knowledge generated elsewhere (i.e., other firms, universities, public R&D labs), the latter are represented by the additional costs engendered by the set up of the networking structure necessary to benefit from external sources of knowledge, and not only from in-house R&D investments.

In other words, we put emphasis on the costs firms are facing to access and exploit knowledge externalities. In this respect, knowledge cannot be treated as information, as it is done in both the public good and the new growth theory literature. Therefore, the traditional notion of technological knowledge cannot capture the effects of the resources that firms need to allocate in order to implement dedicated strategies of external learning, knowledge absorption and knowledge interactions. When the specificities of knowledge as an economic good are appreciated, externalities cannot be but pecuniary.

The costs of the exploration, absorption, recombination and exploitation of knowledge that cannot be fully appropriated by "inventors", can be comprehensively described as the costs of external knowledge. They vary according to the characteristics of the system. The density of knowledge generating activities has a direct bearing on the levels of the cost of external knowledge (Antonelli, 2007 and 2008a).

Both the positive and negative effects on pecuniary knowledge externalities depend upon the density of innovative agents co-localized in the same region. It is clear that the larger is the density of innovative agents and the larger is the opportunity to access knowledge spillovers, but is also clear that the larger is the density of innovative agents and the larger are the costs of exploitation.

A simple geometrical exposition can help to clarify our analysis (see Figure 1). Let us define *NNR* the net benefits from pecuniary knowledge externalities:

$$NNR = CEQ - CKE \qquad (1)$$

According to Scitovsky, pecuniary externalities are described as the difference between equilibrium cost levels (*CEQ*) in perfect markets, were knowledge a capital good, and the actual costs of external knowledge (*CKE*). The latter are therefore lower than the equilibrium levels as an effect of externalities. Yet, they are affected by both the congestion costs (*CC*) engendered by too a high density of innovation agents in the system, and the costs necessary to effectively exploit external knowledge (*CI*):

$$CKE = CC(N) + CI(N,H) \qquad (2)$$

$d[CC(N)]/dN > 0$; $d^2[CC(N)]/dN > 0$
$d[CI(N,H)]/dN < 0$; $d^2[CI(N,H)]/dN < 0$
$d[CI(N,H)]/dH < 0$

Where *N* is the number of innovating agents within the system, and *H* stands for the homogeneity of technological activities in the innovation system.

Economic systems with different composition of knowledge generating activities and different characteristics of their networking structures are also characterized by different costs of external knowledge. In particular we assume that systems characterized by lower level of technological homogeneity (*H*) and greater variety, also experienced steeper costs curves. In Figure 1, $CKE(H_1) > CKE(H_2)$ and $H_1 < H_2$.

>>> INSERT FIGURE 1 ABOUT HERE <<<

As a benchmark we assume that the equilibrium levels of firm's costs (*CEQ*) do not depend on the number of innovating agents in the system and therefore can be represented by a straight line parallel to the horizontal axis, and higher than *CEK* between $N_{\min}$ and $N_{\max}$. This gives rise to the curve of *NNR*(*N*) characterized as follows:

$$dNNR / dN \begin{cases} > 0 & \forall N \in [N_{\min}, N^*) \\ = 0 & if \quad N = N^* \\ < 0 & \forall N \in (N^*, N_{\max}] \end{cases} \quad ;$$

$$d^2 NNR / N < 0 \qquad \forall N \in [N_{\min}, N_{\max}]$$

Combining the effects of factors affecting both positively and negatively knowledge externalities, from a theoretical viewpoint we are therefore able to qualify the relationship between agglomeration and productivity growth as a quadratic function. Positive net agglomeration effects are found only until a given threshold *N**. At *N** pecuniary knowledge externalities fetch their maximum. Too much agglomeration progressively dissipates the advantages in terms of knowledge externalities due to the increasing costs of external knowledge: beyond N* the increasing levels of the negative effects of agglomeration on the actual costs of external knowledge become stronger and stronger. Beyond N_{max} external knowledge costs more than in equilibrium conditions.

At each point in time firms are interested to take advantage of net pecuniary knowledge externalities available nearby their present location even if they are below the maximum levels available in remote locations because of relevant switching costs: firms cannot move freely in space. Hence we expect to identify firms after N=N*. Without limitations to mobility, instead, firms would try and select the locations where N=N* and abandon locations where N>N*.

Moreover, from our analysis it is clear that net pecuniary knowledge externalities should be higher in contexts characterized by greater technological homogeneity. The greater is the homogeneity of technological specialization, the greater and more persistent are also the positive effects of knowledge externalities. On the contrary, the greater is the variety of the technological base of the region, the more rapidly negative effects take place. In Figure 1, NNR(H_2) > NNR(H_1).

3 The evidence of pecuniary knowledge externalities

3.1 Methodology

This section provides the basic methodology to investigate the relationship between the net effects of pecuniary knowledge externalities and the agglomeration of technological activities. Knowledge externalities, lowering production costs of firms able to access them, are likely to affect the dynamics of productivity growth. Indeed, firms will experience a shift in their production function, increasing output without changing the scale of production factors.

Therefore, in order to the estimate the effects of knowledge externalities we first need to measure total factor productivity (TFP), A_{it}, following the growth accounting approach (Solow, 1957; Jorgenson, 1995; OECD, 2001). Let us start by assuming that the regional economy can be represented by a Cobb-Douglas production function with constant returns to scale:

$$Y_{it} = A_{it} K_{it}^{1-\beta_{it}} L_{it}^{\beta_{it}} \tag{2}$$

where L_{it} is the total hours worked in the region i at the time t, K_{it} is the level of the capital stock in the region i at the time t, and A_{it} is the level of TFP in the region i at the time t.

The yearly output elastiticity of labour, β_{it}, is calculated for each region as the total income share of employment compensation[2]. Then the annual growth rate of regional TFP is calculated as usual in the following way:

$$\ln\left(\frac{A_i(t)}{A_i(t-1)}\right) = \ln\left(\frac{Y_i(t)}{Y_i(t-1)}\right) - (1-\overline{\beta})\ln\left(\frac{K_i(t)}{K_i(t-1)}\right) - \overline{\beta}\ln\left(\frac{L_i(t)}{L_i(t-1)}\right) \qquad (3)$$

Our basic hypothesis is that the positive effects of knowledge externalities dominate until a critical mass of agents within the system is reached. The further increase in the density of agents makes the networking and congestion costs grow more than the positive effects stemming from knowledge spillovers. Negative externalities are in turn mitigated by the positive effects played by the increasing homogeneity of technological activities within the area.

The test of such hypothesis needs for modelling the growth rate of TFP as a function of the density of technological activities, which we call D_{it}, and of an index of technological homogeneity of regions, which we call H_{it}. Moreover, it is usual in this kind of empirical settings to include the lagged value of TFP, $\ln A_{i,t-1}$, in order to capture the possibility of mean reversion. In general terms, this relationship can be written as follows:

$$\ln\left(\frac{A_i(t)}{A_i(t-1)}\right) = f(\ln A_{i,t-1}, D_{t-1}, H_{t-1}) \qquad (4)$$

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[2] In the discrete approximation of the Divisia index, the growth rate of the production factor is weighted by the two years average of the output elasticity. Therefore, in Equation (3) $\overline{\beta}$ is the two years average output elasticity of labour.

In particular, our line of reasoning leads us to characterize Equation (4) as follows:

$$f_D^{'}\begin{cases} >0 & if \quad D<D^* \\ <0 & if \quad D>D^* \end{cases}; \qquad f_D^{''}<0 \quad \forall D, \qquad f_H^{'}>0$$

Where D^* is the threshold level of the density of technological activities. A convenient way to represent such a kind of relationship can be found in the following structural equation:

$$\ln\left(\frac{A_i(t)}{A_i(t-1)}\right) = a + b\ln A_{t-1} + c_1 D_{t-1} + c_2 D_{t-1}^2 + dH_{t-1} + \rho_i + \sum \psi t + \varepsilon_{i,t} \qquad (5)$$

Where the error term is decomposed in ρ_i and $\Sigma\psi t$, which are respectively region and time effects, and the error component ε_{it}. Equation (5) proposes on the one hand a linear relationship between TFP growth and technological homogeneity according to which we expect $d > 0$. On the other hand it specifies a quadratic relationship between TFP growth and density, where we expect $c_1>0$ and $c_2<0$.

3.2 The data

In order to investigate the relationships between economic performances on the one hand, and the density and homogeneity of innovation activities on the other hand, the data were mainly drawn from the Eurostat regional statistics, obtaining an unbalanced panel of 138 European regions, observed in the time span ranging from 1995 to 2003.

As far as TFP is concerned, we need output, labour and capital services, and the labour and capital shares. As a measure of output we used the real GDP (2000 constant prices). Eurostat also provides with estimation of capital stock and employment, although it does not provide data about hours worked at the regional level. For this reason we used average hours worked at the country level provided by the Groningen Growth and Development Centre[3], and then calculate total hours worked. Although this does not allow us to appreciate cross-regional difference in average hours worked, nonetheless it allows us to account at least for cross-country differences. The labour share is calculated using data on the compensation of employees and the GDP, while capital share is calculated as 1 minus labour share.

As far as the explanatory variables are concerned, we need a measure of innovation activity. To this purpose we used the number of patent applications submitted to the European Patent Office (EPO), provided by the Eurostat regional science and technology indicators. Patent applications are assigned to regions according to inventor's address. Moreover each patent is assigned to one or more technological classes, according to the international patent classification (IPC) [4].

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[3] www.ggdc.net.

[4] Patent applications as economic indicators present well-known drawbacks. They can be summarized in their sector-specificity, the existence of non patentable innovations and the fact that they are not the only protecting tool. Moreover the propensity to patent tends to vary over time as a function of the cost of patenting, and it is more likely to feature large firms (Pavitt, 1985; Levin et al., 1987; Griliches, 1990). However, previous studies highlighted the usefulness of patents as measures of production of new knowledge, above all in the context of analyses of innovation performances at the aggregate regional level (Acs et al., 2002).

For the density of technological activity, *D*, we take the ratio between the regional levels of patent applications[5] and the regional level of employment. We therefore assume that knowledge externalities arise within regional areas, and that negative effects arise when the density of innovating agents within the production system is too high:

$$D_{i,t} = \frac{PAT_{it}}{L_{it}}$$

For the index of homogeneity, we calculated technological specialization of regions by using the Hirschman-Herfindal index (HHI). In particular, the IPC classification is organized at different levels of aggregation. We decided to take the one digit classification, so that eight classes can be distinguished, ranging from A to H. Therefore for each region at each year we were able to calculate the share of patents within each class. The index thus turns out to be:

$$HHI_{i,t} = \sum_{j=1}^{8} s_{i,j,t}^{2}$$

Where s_{ijt} is the share of technological class *j* in the overall set of patent applications at time *t* in region *i*. The higher (lower) the index, the higher (lower) the technological homogeneity of regions.

Table 1 shows the descriptive statistics for the key variables, reporting the within and between values for the 138 regions considered in our analysis. This

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[5] Due to the high variance of patenting activity over time, we decided to calculate the 5-years moving average at each year.

preliminary data reveal that the variables are characterized by a fairly significant degree of variance, both within and between regions. On average, the cross-regional dispersion is higher than that observed within regions over time. Moreover, the dispersion of the density index within regions is higher than that of the homogeneity index, while the reverse applies for what concerns the cross-regional variance.

>>> INSERT TABLE 1 ABOUT HERE <<<

To gain a better understanding of cross-regional differences in our sample, in Figure 2 we report the maps that assign the regions to the percentiles of the distribution of patent applications[6]. Such diagrams provide some interesting preliminary information. Fist of all, the 1996 evidence about France shows that all the French regions are below the 90th percentile. Germany contains most of the highest-level patenting regions. However, there is only one region above the 99th percentile, i.e. Rheinhessen, while the other regions in Bavaria and Baden-Württemberg are between the 90th and the 99th percentile. Three further regions appear in the uppermost group, i.e. the Noord-Brabant in the Netherlands and Oxfordshire and the East Anglia in the UK. Northern-Italy regions and the Abruzzi are below the 90th percentile, while the rest of Italy falls in the penultimate group. It is also fair to note that Northern-Finland and the Swedish regions of Mellansverige and Sydsverige moved upward in the second group. In 2003 some significant changes can be found. In particular, in

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[6] A percentile is the value of a variable below which a certain percent of observations fall. So the 20th percentile is the value (or score) below which 20 percent of the observations may be found. The 25th percentile is also known as the first quartile; the 50th percentile as the median.

Germany the Rheinhessen lost its position, while Stuttgart and Freiburg are in the first group, along with the Noord-Brabant. All other regions within the Bavaria, the Baden-Württemberg and North Rhine-Westphalia states are in the second group of regions, along with Herefordshire and East Anglia. It is quite interesting to note that the Oxfordshire moved downward to the third group. Moreover, most of Finnish regions are between the 90th and 99th percentile.

>> FIGURE 2 ABOUT HERE <<

This descriptive evidence shows that there is a significant variance across European regions for all variables. High levels of agglomerations seem to feature mostly some areas of the UK and Germany, along with some Swedish regions. Moreover, the density of innovating agents appears to vary to a great extent also over time, within the observed regional contexts. For this reason in what follows we will use panel data techniques in the econometric test.

3.3 Econometric results

In the empirical analysis we estimate the shape and the extent of positive feedbacks stemming from the agglomeration of innovation activities and the specialization of technological activity.

Table 2 shows the results of the econometric estimation of Equation (5). The first two columns propose a baseline model analyzing the effects of spatial agglomeration of innovation activity. In the linear specification, the coefficient for the density of patents is positive and significant, providing support to the idea that the agglomeration of innovating agents leads to productivity gains. In the second column we better qualify this relationship by introducing the quadratic specification. The estimates provide support to the idea that positive knowledge externalities apply only to a limited extent. Once a critical level of agents is reached in the system, search costs start growing more than proportionally. This is due to the increasing number of knowledge sources that need to be screened and push innovating agents to raise the amount of resources committed to the establishment and management of new communication channels.

In Models 3 to 5 we include the HHI accounting for the changes in the composition of the regional knowledge base. Let us recall that the higher the value of the index, the more homogeneous the technological activities within the region. Model 3 combines the linear specification for both the agglomeration and the specialization indicators. The coefficient for the two variables are positive and significant. This confirms the evidence about the positive effects from agglomeration, and provides supports for the idea that increasing technological specialization exerts boosting effects on productivity. Increasing homogeneity in the knowledge base is indeed likely to lower search costs, as long as it makes it easier for innovating agents to identify, access and absorb relevant technological knowledge available in the system.

>>> INSERT TABLE 2 ABOUT HERE <<<

In Model 4 the linear specification for the HHI is combined with the quadratic specification for the density index. The results appear to be fairly persistent. On the one hand, the coefficients for the density are indeed statistically significant, and indicate the existence of an inverted U-relationship between the agglomeration of innovation activities and productivity growth. On the other hand the coefficient for the homogeneity index is again positive and significant. This amounts to say that advantages stemming from increasing technological specialization are likely to mitigate the effects of negative externalities stemming from too much agglomeration. Although the increase in the number of innovating agents engenders the rise of search costs, the convergence towards a core technological specialization enhances absorptive capacity and hence lowers absorption costs. Finally, to check the results in Model 5 we combine the quadratic specification for both the density and the homogeneity index. The outcome is basically the same as the previous model, as the quadratic term on HHI is not statistically significant, while the sign and significance on the other variables are fairly similar.

4 Conclusions

Building upon the notion of pecuniary knowledge externalities, as distinct from technological externalities, we have been able to specify a quadratic relationship between the concentration of innovative activities at the regional level and their net positive effects. We were able to qualify the relationship between knowledge externalities and agglomeration as a quadratic function.

Agglomeration yields positive net knowledge externalities only until a given threshold. Too much agglomeration progressively dissipates the advantages in terms of knowledge externalities due to the increasing costs of the actual assimilation and recombination of external knowledge.

The paper has provided a strong test for the hypotheses that a quadratic relationship takes place between technological concentration and total factor productivity growth for 138 European regions, in the time span ranging from 1995 to 2003.

The quadratic specification is a powerful result because it enables to identify the shifting relative advantage of regions in the location of knowledge generating activities.

The identification of the notion of relative advantage in the location of knowledge generating activities enables to identify the regions where it is not appropriate to invest in knowledge generating activities, the regions where it is 'more' convenient to invest in knowledge generating activities, and the regions where it would be better to reduce the levels of knowledge generating activities.

The strong econometric results enable to appreciate the implications of the quadratic specification in terms of output elasticity to additional knowledge generating activities. It is clear in fact that by definition in a quadratic function the second derivative is stronger the smaller the level of the concentration. Hence the paper suggests that the output elasticity of additional research activities is higher in peripheral rather than in core regions.

Moreover, we find evidence that the positive effect of knowledge externalities on productivity growth are stronger where there high levels of specialization in homogeneous technological fields. Regions where knowledge generating activities insist in a limited scope benefit from agglomeration more than regions where the composition is less homogeneous and more diversified. Our evidence suggests, in other words, that Jacobs pecuniary externalities apply only in a limited range of knowledge fields.

At a more practical level the quadratic specification and the results of the estimates according to which the maximum is well within the actual data, is a powerful and quite innovative tool to articulate the view that the dissemination of research activities may yield better results than their concentration. The implications for both innovation and regional policy in fact are relevant. First, it is not efficient to create excessive agglomeration of knowledge generating activities within a given region: beyond the threshold negative effects of agglomeration begin to take place. Second and most important, it is also clear that all investments in knowledge generating activities are much more profitable, at the margin, in regions with lower level of agglomeration. Third, the specialization of knowledge generating activities reduces the costs of external knowledge and favors the increase of the optimum size of clusters. Innovation and regional policy willing to exploit the positive effects of knowledge externalities stemming from the concentration of technological activities should design appropriate investment incentives to: I) favor the dissemination of knowledge generating activities in regions with low levels of concentration in knowledge generating activities II) prevent their excess concentration in a few spots and III) increase the specialization of regions within well identified knowledge fields.

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Figure 1 - Positive and negative effects on pecuniary knowledge externalities

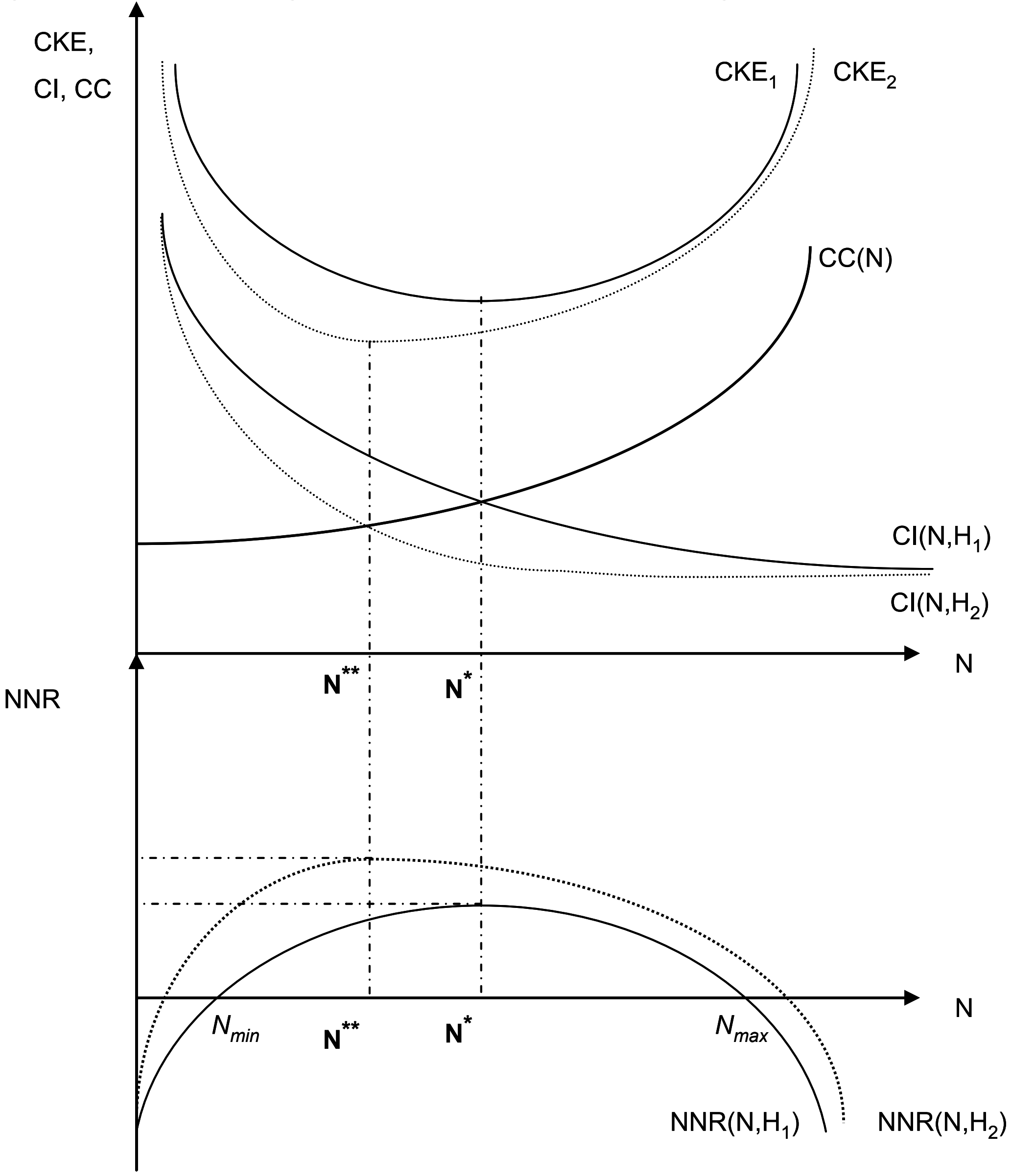
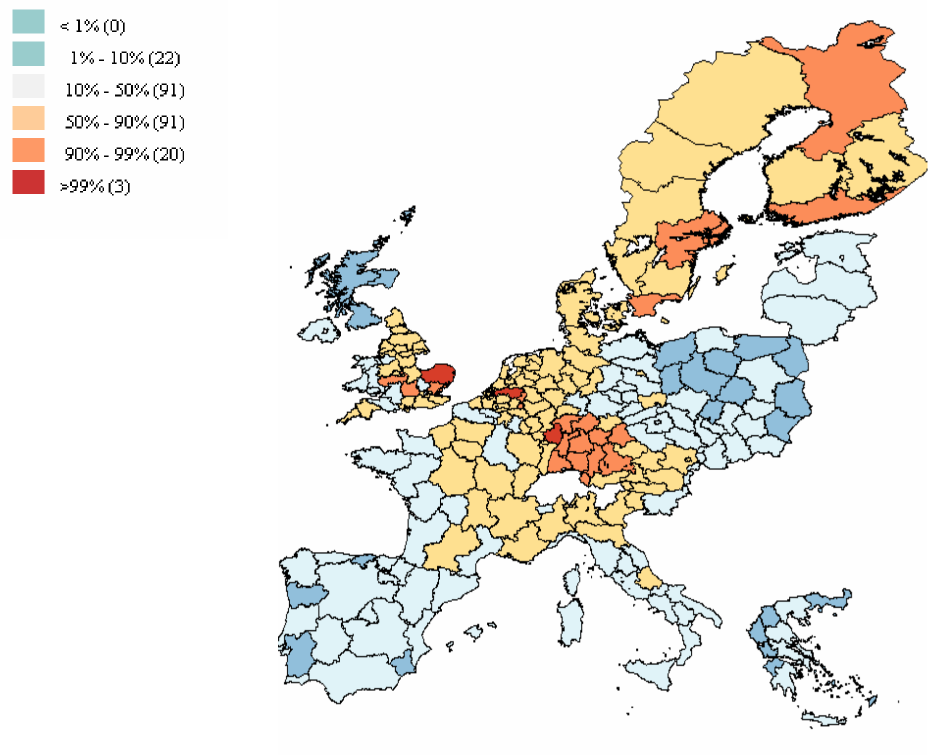


Figure 2 - Regional Distribution of Patent Applications per Worker (percentiles)



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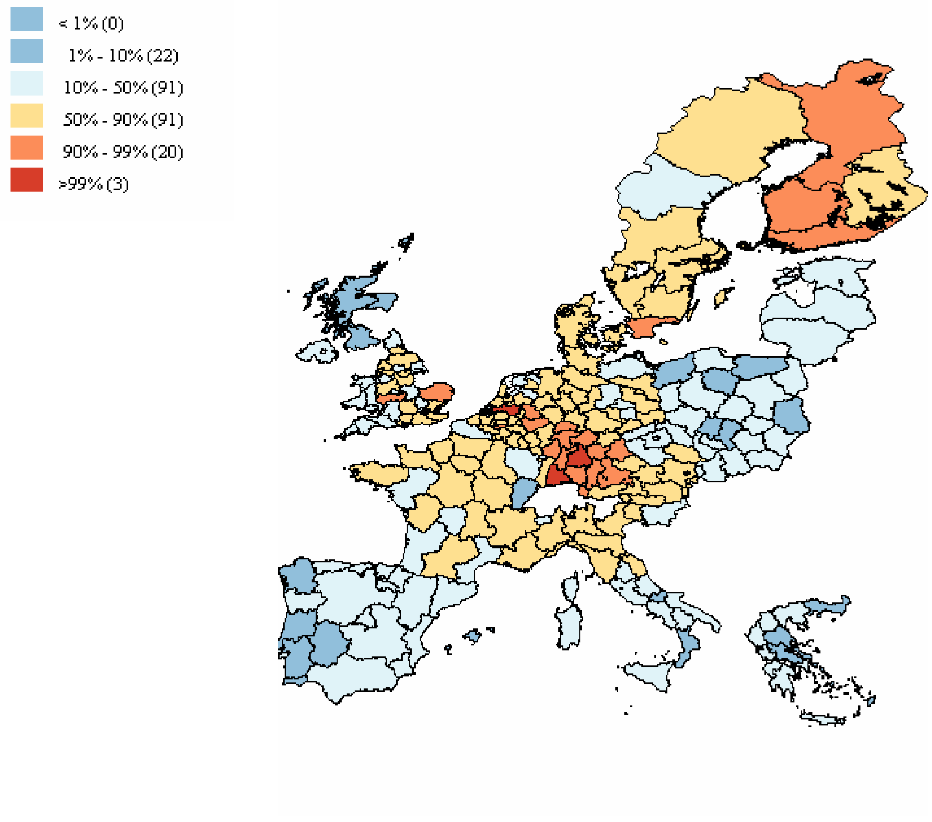

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Table 1 - Descriptive Statistics for the Key Variables

	Mean	St. Deviation		Min	Max
		Within	Between		
Growth rate of TFP (log differences)	0.025	0.023	0.033	-0.048	0.151
Growth rate of capital (log differences)	0.021	0.078	0.067	-0.422	0.369
Growth rate of labour (log differences)	0.009	0.015	0.009	-0.083	0.108
Patents per million employees	2445.5	594.9	2197.4	16.71	17681.2
Technological homogeneity	0.234	0.064	0.087	0.138	0.99

Table 2 - Region TFP growth, panel data fixed effects estimates

	Model 1	Model 2	Model 3	Model 4	Model 5
$\ln A_{t-1}$	0.049**	0.048**	0.046**	0.042**	0.043**
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
D_{t-1}	$6.97 \cdot 10^{-6}$ ***	$0.025 \cdot 10^{-3}$ ***	$6.78 \cdot 10^{-6}$ ***	$0.028 \cdot 10^{-3}$ ***	$0.029 \cdot 10^{-3}$ ***
	$(2.52 \cdot 10^{-6})$	$(2.52 \cdot 10^{-6})$	$(2.51 \cdot 10^{-6})$	$(6.79 \cdot 10^{-6})$	$(6.81 \cdot 10^{-6})$
D_{t-1}^2		$-1.68 \cdot 10^{-9}$ ***		$-1.74 \cdot 10^{-9}$ ***	$-1.79 \cdot 10^{-9}$ ***
		$(5.08 \cdot 10^{-10})$		$(5.06 \cdot 10^{-10})$	$(5.07 \cdot 10^{-10})$
HHI_{t-1}			0.027**	0.028***	0.66*
			(0.011)	(0.010)	(0.035)
HHI_{t-1}^2					-0.034
					(0.031)
R^2	0.25	0.26	0.25	0.27	0.27

Note: * $p<0.1$; ** $p<0.05$; *** p<0.0.01. Standard errors between parentheses. All regressions include time dummies.