Közgazdasági és Regionális Tudományok Intézete
Pécsi Tudományegyetem, Közgazdaságtudományi Kar

MŰHELYTANULMÁNYOK

# AGGLOMERATION AND INTERREGIONAL NETWORK EFFECTS ON EUROPEAN R&D PRODUCTIVITY

**Attila Varga- Dimitrios Pontikakis- George Chorafakis**

**2010/3**

**2010. június**

# Agglomeration and interregional network effects on European R&D productivity

**ATTILA VARGA**

Department of Economics and Regional Studies, Faculty of Business and Economics, University of Pécs
Pécs, Hungary
E-mail: vargaa@ktk.pte.hu

**DIMITRIOS PONTIKAKIS**

Institute for Prospective Technological Studies, Joint Research Centre, European Commission
Seville, Spain

**GEORGE CHORAFAKIS**

Research Directorate-General, European Commission
Brussels, Belgium
*and*
Department of Geography, University of Cambridge
Cambridge, United Kingdom

## Abstract

This paper explores the effects of intra-regional agglomeration and interregional networking on the productivity of R&D across EU regions. The paper is based on the spatial econometric modelling framework presented in Varga (2000), and further develops a methodology for estimating the dynamic effects of agglomeration and interregional networks on R&D productivity in regional knowledge creation (measured by patent applications and publications) at the level of EU regions. This empirical modelling framework is applied to classify EU regions into different tiers according to the strengths of their agglomeration effects. These effects are then compared to the network effects of interregional connectedness as reflected in regional participation in the EU Framework Programme for Research. The estimated model is used then for an assessment of the impacts of EU Framework Programme expenditures on technological development and for carrying out policy impact simulations.

## Acknowledgements

Collaborative research leading to this paper started when Attila Varga visited the European Commission's Institute for Prospective Technological Studies in Seville in 2008. Funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 216813 is gratefully acknowledged. We wish to thank Péter Járosi (Faculty of Business and Economics, University of Pécs) for programming the dynamic policy simulations in MATLAB. The regionalisation of FP6 participations (used in the simulations) was done jointly by one of the authors and Joaquín M. Azagra-Caro (CSIC). We also wish to express our thanks to participants at all the seminars, workshops and conferences where earlier versions of this paper were presented (KITE, University of Newcastle; EC-JRC Institute for Prospective Technological Studies, Seville; EC-DG Regional Policy, Brussels; METU TEKPOL, Ankara; II. World Conference of the Spatial Econometrics Association, New York; II. Conference of the Hungarian Society for Economics, Budapest; Regional Studies Association Annual Conference, Leuven; Annual Meetings European Regional Science Association, Łódz; DIME Workshop "Measuring, mapping and modelling technical change", Sant'Anna School of Advanced Studies, Pisa; KRTI, University of Pécs, Faculty of Business and Economics).

# Agglomeration and interregional network effects on European R&D productivity

## 1 Introduction

A point of departure for this paper is a seeming ‘paradox’ which has repeatedly drawn the attention of economists and economic geographers: On the one hand, regional economies tend to become increasingly interconnected and integrated in the global production of scientific and technological knowledge, as reflected in the increasing volumes of interregional collaboration in scientific publications, co-patenting, R&D joint ventures, and other forms of inter-firm or academia-industry R&D collaboration, as well as in the intensified internationalisation of R&D activities (Luukkonen *et al.*, 1992; Caloghirou *et al.*, 2004; EC, 2009). On the other hand, the production of scientific and technological knowledge is unevenly distributed in geographical space, as it tends to concentrate in a relatively small number of regional clusters which form the core of the centre-periphery structure of the global knowledge economy (e.g. Varga, 1999).

Generic studies of regional economies exhibiting this local-global duality are abundant in the economic geography literature; regional economies of this type have been described, among others, as ‘sticky places in a slippery space’ (Markusen, 1996), or ‘Neo-Marshallian nodes of global networks’ (Amin & Thrift, 1992). Empirical studies in this direction with a specific focus on scientific and technological knowledge are still, however, relatively scarce.

This paper aims to contribute to this strand of literature by examining from an empirical point of view the economic effects of this local-global duality of regions, and more specifically, the co-existence of localised and geographically mediated effects of agglomeration on the one hand, and of global, geographically non-embedded effects of networking on the other, on the knowledge economy.

The main contributions of this paper are in the following three aspects: First, it develops an integrated empirical model within which agglomeration and network effects on R&D productivity in the creation of technological and scientific knowledge are tested empirically using European regional data. Second, the model considers both static and dynamic agglomeration effects; i.e. the cumulative impacts on regional knowledge production are also examined. Third, the results of the empirical model are used to perform a policy-impact analysis.

The second section of the paper briefly presents the theoretical context of the main issues the paper touches upon and the related literature; the third section introduces the empirical model; the fourth explains data and methodology; the fifth presents the empirical results; a policy simulation follows in the sixth section; and the paper concludes with a summary and some reflections on the policy implications of the analysis.

# 2 The theoretical context

## 2.1 Agglomeration effects

Agglomeration economies are external economies of scale which emerge in geographical space. Alfred Marshall (1920) first distinguished between the traditional ‘internal’ economies of scale, coming from the expansion of the scale of operation of a firm, and ‘external’ economies induced by spatial proximity, which arise from the expansion of whole industries. Intra-industry, spatially concentrated, ‘Marshallian’ externalities are known as ‘localisation economies’; inter-industry externalities, also mediated by geographical space, are known as ‘urbanisation economies’. Glaeser *et al.* (1992) distinguish between a ‘Marshall-Arrow-Romer’ (MAR) type of externalities caused by intra-industry, usually vertical knowledge spillovers within the same value chain, and a ‘Jacobs’ type of externalities (Jacobs, 1969), caused by inter-industry, horizontal knowledge spillovers between parallel value chains; the former is a dynamic form of localisation while the latter of urbanisation economies.

Agglomeration externalities are thought to be induced by labour pooling, or more generally the localised accumulation of human capital, the emergence of ‘untraded interdependencies’, informational externalities (Dosi, 1988; Storper, 1997), and trust, or more generally the accumulation of social capital, and the density of markets for intermediate products and outputs. Agglomeration economies are widely recognised as being capable of increasing firms’ productivity via several different routes; empirical studies have demonstrated both the direct causal effects of agglomeration on firm productivity, as well as its indirect effects through wages, firm birth or employment (Rosenthal & Strange, 2004).

Innovation and, consequently, R&D investment are commonly considered as key factors for increasing the productivity of firms, as well as of regional and national economic systems. The effect of agglomeration economies on the innovative capacities of firms or of entire economic systems and, in particular, on the regional knowledge production process, is a factor which has been taken into account – albeit tangentially – in several empirical studies (examples include Jaffe, 1989; Audretsch & Feldman, 1994; Anselin *et al.*, 1997; Crescenzi *et al.*, 2007). However, an explicit analysis of the role agglomeration plays in the efficient deployment of R&D in regional economies still remains an underexplored topic. Among the exceptions is Varga (2000; 2001), who tests econometrically in a knowledge production function (KPF) setting the role of agglomeration in the R&D productivity of the universities using data on US metropolitan statistical areas. The study finds the existence of a 'critical mass' of advanced technology firms, private research labs and business services directly associated with a sizable labour pool in the urban high-technology sector as being a prerequisite for a significant impact of university R&D on regional innovation. Further studies in this strand include Koo (2005), who developed an endogenous approach, Acs & Varga (2005) on the roles of agglomeration and entrepreneurship in Europe, and Goldstein & Drucker (2006) on the impact of city size on regional economic roles of US universities. It is also worth mentioning here Feldman (1994), who brought attention from a more qualitative and case-specific point of view to the then suboptimal regional role of John Hopkins University in transferring knowledge to the local economy. The study points to the relatively underdeveloped technology sector in the region as perhaps the main reason of this anomaly. This case suggests that even a university with outstanding research activity is not capable of transferring substantial knowledge to the local economy without a concentration of innovative firms and private research labs ready to absorb that knowledge or business services participating in the various stages of the innovation process.

## 2.2 Network effects

The properties and effects of social networks have been studied extensively from various perspectives. This emerging sub-field of the social sciences was explored by sociologists and anthropologists (e.g. Granovetter, 1973; White, 1992), as well as mathematicians and physicists (e.g. Barabási & Albert, 1999; Newman, 2000), long before the important effects of networking on fundamental economic processes drew the attention of economists and economic geographers. More recently the realisation of the essential role of networks in the learning process of economic agents, and in particular of the firms; in the formation of inter-firm strategic alliances and the accumulation of social capital; and finally – and probably most importantly – in the diffusion of knowledge spillovers, the generation of scientific and technological knowledge and, consequently, the innovation process, has led to a proliferation of papers in economics and economic geography on theoretical and empirical aspects of knowledge networks.

A strand of this literature approaches specific aspects of knowledge, innovation and R&D networks from a theoretical perspective. Examples include various theoretical models of inter-firm network formation through strategic R&D collaboration and search for knowledge spillovers (Goyal & Moraga-Gonzalez, 2001; Cowan, 2004; Andergassen *et al.*, 2005; Cowan & Jonard, 2006). Other papers examine theoretically inter-firm networks and their innovative performance from the perspective of strategic management (Hite & Hesterly, 2001; Stuart & Sorenson, 2007). A different strand of network literature focuses from an empirical perspective on the structure and properties a specific types of knowledge networks, notably research collaboration networks such as co-patenting (Balconi *et al.*, 2004; Carayol & Roux, 2007); co-authorship (Newman, 2001; Wagner & Leydesdorff, 2005; Fafchamps *et al.*, 2006); and EU Framework Programme (FP) collaboration networks (Barber *et al.*, 2006; Billand *et al.*, 2008). Some papers specifically focus on the role of networks in the transmission of scientific and technological knowledge from academia to industry; Varga & Parag (2009), for example, examine the impact of the co-publication network structure on university patenting.

Finally, an increasing number of studies approach the issue from a spatial perspective, where 'spatial' should be interpreted both in the context of geographical and 'relational' space, focusing on the distinct effects of geographical and relational proximity. Johansson & Quigley (2004) compare from a theoretical perspective the parallel developments in the economics of agglomeration and of networks, arguing for the substitutability of agglomerations by networks. Gastner & Newman (2006) model geographically embedded networks and examine their costs and benefits. Breschi & Lissoni (2005) test the existence and magnitude of localised knowledge spillovers by using patent data to control for the mobility of inventors across companies and space, to conclude that access to local pools of knowledge is not ensured by mere geographical proximity but requires active participation in knowledge exchange networks. Ponds *et al.* (2007; 2009) analyse the role of geographical proximity for collaborative scientific research between universities, firms and public research institutes using co-publication data, and demonstrate that collaboration between different kinds of organisations is more geographically localised than collaboration between organisations that are similar due to institutional proximity. Maggioni *et al*. (2007) examine the relative significance of geographical and relational spillovers among European regions for their innovative capacities by econometrically comparing participation in two research networks, namely those of FP5 and of EPO co-patent applications; the main idea of the paper is that knowledge is created when crucial actors co-locate in geographical space, thus giving birth to regional clusters, industrial districts, excellence centres, etc., and is subsequently diffused either due to spatial contiguity or through a-spatial networks. Autant-Bernard *et al.* (2007) examine empirically using FP6 participation data to what extent network and geographical effects are determinants of collaboration along with other microeconomic factors, to conclude that the probability of collaboration is influenced by the individual’s position in the network and that social (i.e. relational) distance matters probably more than geographical distance. The present paper belongs to this last strand of literature.

The causal link between the degree of connectedness and innovativeness, productivity and competitiveness of firms and regions is relatively well documented. This causal relation makes possible, at least in theory, that even regional economies which exhibit weak agglomeration effects but are well embedded in global knowledge production networks be highly productive; this means that increasing interregional connectedness maybe an alternative explanation of regional R&D productivity to traditional agglomeration economies. The causal relationship between inter-regional connectedness and regional R&D productivity, however, has not been fully explored and measured. This paper hopes to fill part of this gap.

Furthermore, from a network perspective, even the agglomeration phenomena can be interpreted as a particular type of localised network effects, in which case locally agglomerated knowledge production systems could have a network representation, and the issue under question would be shifted from the nature of the agglomeration effect to the architecture of the network. It can be further argued that the underlying network architecture in each case is determined by the type of knowledge that is critical for the particular economic system.

### 2.3 Types of knowledge and types of research

Much of the knowledge required in the production of new technologies is tacit, that is, knowledge obtained by experience, embedded with individuals and diffusing primarily by way of interpersonal contact. In a technological setting, proximity to places with high concentrations of people possessing such knowledge becomes crucial. Contrarily, the diffusion of codified knowledge is generally not conditional on proximity. Modern ICTs facilitate its diffusion, and arguably the intensity of its use in knowledge production, to a greater extent than ever before. Indeed, the importance of locally contained knowledge in the formation of geographical clusters is well documented (Audretsch & Feldman 1996). As demonstrated by patent citations, for certain types of technological knowledge, diffusion is highly concentrated geographically (Jaffe et al. 1993).

Importantly, different types of research impose different requirements on scale and place a different emphasis on tacit knowledge, and by extension, proximity (Malmberg & Maskell, 1997). Taking into account the sharp differences in the worlds of scientific and technological research and using the terminology introduced by Stokes (1997), we consider two distinct types of research:

(a) *Edison*-type: research the products of which have clear economic applications, pursuing market-oriented innovation. Sometimes dubbed "competitive research" among EU policy analysts.

(b) *Pasteur*- (and implicitly Bohr[1]-) type: science-oriented research, mediated by the distinct rules and incentives of the modern scientific establishment. Sometimes dubbed 'pre-competitive research' among EU policy analysts (and referred as such in relevant EU treaties).

Given the different spatial diffusion dynamics of tacit and codified knowledge and the relative importance of tacit knowledge for Edison-type research, a preliminary hypothesis can be sketched: The prevalence of agglomeration over network effects (and vice versa) may correspond to qualitative differences in the type of research involved and its respective knowledge inputs requirements. To investigate such differences, our empirical analysis examines agglomeration and network effects for Edison- and Pasteur-type research separately.

## 2.4 Policy relevance

Besides its independent analytical value, the central question posed by this paper is of high relevance to ongoing discussions on the future directions of EU research and innovation policy. A recurrent debate in EU policy discussions is concerned with the optimal geographical and sectoral allocation of resources for research (see contributions to Pontikakis et al., 2009, especially by Foray and Cooke; for earlier accounts see Geroski, 1989a and 1989b, Matthews. and McGowan, 1992). This stems from a concern that EU research funds are spread too thinly across Europe without achieving economies of scale that would strengthen the overall competitiveness of the EU vis-à-vis its main technological and economic rivals, and without attaining the impact on growth and employment that is expected from them. A policy-induced geographical and sectoral concentration of R&D resources on the basis of existing patterns of technological specialisation, coined 'smart specialisation', is put forward as one possible solution to the perceived problem (Foray & van Ark, 2007; Foray, 2009).

---

[1] Following Mokyr (2002), we narrow down Stokes' (1997) three types to just two: As our concern is with economically useful knowledge, the distinction of importance is between R&D motivated primarily by a quest for fundamental understanding versus knowledge primarily motivated by profit (c.f. 'propositional' versus 'prescriptive' knowledge, in Mokyr (2002)).

An alternative policy prescription to increased concentration of R&D resources is to promote cross-regional research networks to connect complementary research capabilities not available within own regions. A policy of sustaining or even increasing the degree of connectedness in EU research, or ‘networked specialisation’ is therefore suggested as a possible alternative policy option (Georghiou *et al.*, 2008).

So far this debate rests on scattered sources of empirical evidence and lacks a comprehensive approach. By developing and testing an empirical model that considers the effects of both agglomeration and networking on R&D productivity this paper provides a framework within which alternative policy suggestions can be weighted against each other.

# 3 The empirical modelling framework[2]

Our starting point is the KPF initially specified by Romer (1990) and parameterised by Jones (1995). In the interpretation of the parameters we follow Varga (2006).

**Eq. 1:** $dA_i / dt = \delta H_{Ai}^{\lambda} A_i^{\varphi}$,

where dA/dt is the temporal change in technological knowledge, $H_A$ refers to research inputs (e.g. number of researchers or research expenditures), A is the total stock of already existing scientific and technological knowledge (knowledge codified into publications, patents etc.) and i stands for the spatial unit. Thus technological change is associated with contemporary R&D efforts and previously accumulated knowledge. The same number of researchers can have a varying impact on technological change depending on the stock of already existing knowledge. Two parameters in Eq. 1 are particularly important for this paper. The size of $\varphi$ reflects the impact of the transfer of codified knowledge. Since codification makes learning possible over large distances this parameter reflects knowledge flows with unlimited spatial accessibility. Regarding the parameter $\lambda$ the larger its size the stronger the impact the same number of researchers plays in technological change. Its value reflects the transfer of (codified and tacit) knowledge within the research sector and between the research sector and the rest of the innovation system. The literature on innovation systems highlights the importance of interactions among the various actors (e.g. Nelson 1993; Edquist, 1997). Thus knowledge transfer depends on the intensity of interactions among researchers ($H_A$), the size and

[2] This section draws significantly from Varga (2006).

quality of public research and the extent to which the private research sector interacts with it (especially with universities) by formal and informal linkages and also the development level of supporting/connected industries and business services and the integration of innovating firms into the system via links to them (Andersen, 1992; Cooke, 2001). Therefore, the characteristics of the broader innovation system play a key role in the productivity of research efforts, as reflected in the size of $\lambda$.

Some of the interactions of researchers are localised especially those that require tacit knowledge transfers or frequent connections in collaboration whereas others can be maintained over larger distances via for example formal research network linkages. The size of $\lambda$ is positively related to the concentration of innovation system actors in the proximity of research labs on the one hand and to the intensity of interactions through interregional research networks on the other. Thus we assume that both agglomeration and interregional research networking strengthen regional research productivity.

Theoretical and empirical literature on economic geography has highlighted the cumulative, self-reinforcing nature of agglomeration (e.g, Fujita, Krugman and Venables 1999, Fujita and Thisse 2003). In our modeling framework we assume that agglomeration of innovation system actors and resources also occurs in a cumulative, dynamic fashion. Research productivity (resulting either from agglomeration or from interregional research networking or from both) can be a revealing summary measure of a regional innovation system's qualities. Therefore regions with high research productivity act as centres of gravity for further research resources and footloose innovation actors; private R&D resources are attracted by expectations of high returns, as are greater portions of competitive public research funding. Thus we hypothesise that a gradual self-reinforcing process shapes the geographical structure of innovation.

The extent to which the processes described above work is not yet known. To the best of our knowledge this paper represents the first attempt to empirically investigate the role of static and dynamic agglomeration and interregional networking on research productivity. We test our hypotheses with a four-equation empirical model. This model is the extension of the static analysis developed and applied in Varga (2000, 2001).

In order to test empirically the hypothesised relationships we use the following econometric specifications. Using subscripts *i* and *N* to denote individual regions and nations (in our case EU member states) respectively, the empirical counterpart of the Romer (KPF)[3] is specified as:

**Eq. 2:** $\mathrm{Log}(K_i) = \alpha_0 + \alpha_1 \mathrm{Log}(RD_i) + \alpha_2 \mathrm{Log}(KSTCK_N) + \varepsilon_i$,

where K stands for new scientific-technological knowledge, RD is expenditure in research and development and KSTOCK represents already existing technological knowledge at the national level. We use the national patent stock as a proxy for codified technological knowledge reachable with unlimited spatial accessibility within the country.

Eq. 3 relates research productivity measured by $\alpha_{1,i}$ the parameter of the research variable in Eq 2 to agglomeration and interregional networking.

**Eq. 3:** $\alpha_{1,i} = \beta_0 + \beta_1 \mathrm{Log}(AGGL_{i,\,t\text{-k}}) + \beta_2 \mathrm{Log}(NET_{i,\,t\text{-k}})$

where $AGGL_i$ measures the agglomeration of innovation system actors in the region and NET is for interregional research networks.

Substituting Eq. 3 to Eq. 2 results in the following equation to be estimated:

**Eq. 4:** $\mathrm{Log}(K_{i,\,t}) = \alpha_0 + \beta_0 \mathrm{Log}(RD_{i,\,t\text{-k}}) + \beta_1 \mathrm{Log}(AGGL_i) * \mathrm{Log}(RD_{i,\,t\text{-k}}) +$

$\beta_2 (NET_{i,\,t\text{-k}}) * \mathrm{Log}(RD_{i,\,t\text{-k}}) + \alpha_2 \mathrm{Log}(KSTCK_{N,\,t\text{-k}}) + \varepsilon_i$,

Following on, to test also the cumulative nature of agglomeration the determinants of the location of R&D expenditures ($RD_i$) and further actors of innovation may be empirically modelled by:

**Eq. 5:** $d(RD_{i,t}) = \lambda_0 + \gamma_1 \alpha_{1,i,t\text{-k}} + \lambda_1 Z_{1,i,t\text{-k}} + u_i$

**Eq. 6:** $d(AGGL_{i,t}) = \xi_0 + \xi_1 RD_{i,t\text{-k}} + \xi_2 Z_{2,i,t\text{-k}} + \mu_i$

where variable $Z_1$ and $Z_2$ stands for additional control variables.

This framework allows for testing various alternative hypotheses.

First, by substituting agglomeration proxies for network proxies the same modelling framework can be used to compare the relative importance of agglomeration and network effects.

[3] This functional form is common in empirical specifications of Romer-type KPFs (see Porter and Stern, 2000; Furman et al., 2002; Varsakelis, 2006). Taking logarithms also has the added advantage of lessening the influence of outliers and allowing for direct comparisons of coefficients for variables expressed in different units of measurement.

Second, following the terminology concerning the different types of scientific and technological research presented in the introduction, we observe that Edison-type research frequently results in patents, while the findings of Pasteur-type research are commonly documented in scientific publications. We use patents and publications in separate KPFs to draw our comparisons.

# 4 Data and estimation issues

Our empirical analysis is based on a sample of 189 European regions (a mixture of NUTS2 and NUTS1 regions) where information was complete enough for the purposes of our study (see Appendix 2 for a list of regions). We use a mixture of panel (for the KPFs i.e. equation 4) and cross-sectional analysis (for the temporal change of R&D and employment equations i.e. equations 5 and 6) depending on the nature of the underlying question and data availability.

**Table 1 - Variables used in the study**

| *Variable name* | *Description* | *Source* |
| --- | --- | --- |
| $PAT_{i,t}$ | Number of patent applications to the European Patents Office (EPO) by region of inventor, sorted by date of application (priority year). Fractional counts. | Eurostat NewCronos database |
| $PUB_{i,t}$ | Number of publications in scientific journals in the Thomson ISI database (search criteria: article, letter, review) | RKF database (data processed by CWTS, Leiden University) |
| $GRD_{i,t}$ | Gross regional expenditures on R&D, in millions of Purchasing Power Standard (PPS) Euros. 1995 prices. | Eurostat NewCronos database |
| $KSTCK_{N,t}$ | National patent stocks for the five previous years, depreciated by 13% (PIM). | Authors' elaboration of Eurostat NewCronos |
| $EMPKI_{i,t}$ | Employment in technology and knowledge-intensive sectors. Measured in thousands of people. | Eurostat NewCronos database |
| $\delta_{i,t}$ | Index of agglomeration. Size-adjusted location quotient of employment in technology and knowledge-intensive sectors. | Authors' elaboration of Eurostat NewCronos |
| $NETGRD_{i,t\text{-}k}$ | Total of the (log of) R&D expenditures in network partner regions for each region as a proxy for interregional network effects. | Authors' elaboration of FP5 administrative database, DG RTD, Dir A |
| $PUBCORE_i$ / $RDCORE_i$ | Dummies taking a value of 1 for regions with a number of publications (PUBCORE) / gross R&D expenditures (RDCORE) greater than one standard deviation from the sample mean, zero otherwise. | Eurostat NewCronos database |

| | | |
|---|---|---|
| $PATHCORE_i$ / $RDHCORE_i$ | Dummies taking a value of 1 for regions with a number of patents (PATHCORE) / R&D expenditures (RDHCORE) greater than two standard deviations from the sample mean, zero otherwise. | Eurostat NewCronos database |
| $BETAPAT1998_i$ | R&D productivity estimates for Edison-type knowledge (patents) across European regions controlling for other factors. 1998 values. | Authors' estimates |
| $BETAPUB1998_i$ | R&D productivity estimates for Pasteur-type knowledge (publications) across European regions controlling for other factors. 1998 values. | Authors' estimates |
| DGRD01-98 | Temporal change in R&D expenditures over the period 1998-2001. ( = $GRD_{i,2001}$ - $GRD_{i,1998}$). | Eurostat NewCronos database |
| DEMPKI01-98 | Temporal change in employment in technology and knowledge-intensive sectors over the period 1998-2001. ( = $EMPHT_{i,2001}$ - $EMPHT_{i,1998}$). | Eurostat NewCronos database |

The time period under examination is determined by the duration of EU 5th Framework Programme (FP) spanning the years 1998-2002, as our measure of interregional networking draws on administrative data from this particular instrument. To reflect the interval between the performance of R&D and its translation into measurable outputs, the independent variables are lagged. There is no agreement in literature as to the ideal duration of a lag and attempts to estimate it empirically have been inconclusive (Hall, Griliches and Hausman, 1986). In practice, aggregate studies of KPFs with patents commonly employ two or three year lags (Furman, Porter and Stern, 2002; Furman and Hayes, 2004). Our own experimentation with lags of varying duration showed that they produce very similar results[4]. Temporally lagged dependent variables have the added advantage of lessening the potential for endogeneity problems. We therefore opted for the theoretically plausible two year lag. The combination of the boundaries set by duration of FP5 and the two-year lag mean that our panel runs for the three-year period 2000-2002 (1998-2000 for the independent variables). A summative description of the variables used in the study and the data sources can be found in Table 1(descriptive statistics in Appendix 1).

Further to this concise description a few additional words of clarification regarding the choice, construction and limitations of the variables are in order.

[4] This result repeats what is experienced with US data in a similar KPF context (Varga, Anselin and Acs 2005).

We use patent applications to the EPO (PAT $_{i,t}$) and scientific publications in ISI journals (PUB $_{i,t}$ ) as proxies for Edison- and Pasteur-type knowledge flows respectively. Although patent counts are far from a perfect proxy of innovation (e.g., among other things, not all innovations are patentable or patented, for a comprehensive assessment see Griliches, 1990), the patent examination process and the cost it implies for applicants, present a more or less objective yardstick of substantial novelty. Moreover, patents are the only measure that is available for a large number of European regions and over a number of years. The *'law of large numbers*' (Griliches, 1990) provides a justification for their use, especially, we may add, for large spatial units[5]. Comfortingly, previous research has shown that at the level of regions, patent counts correlate well with innovation counts (Acs, Anselin and Varga, 2002) and both measures provide very similar results in the KPF context. Likewise, the number of journal publications is a commonly used indicator of scientific output (van Raan, 2004). Publications are, arguably, a somewhat stronger proxy (as compared to patents) for the 'true' amount of (in their case Pasteur-type) knowledge flows, given the *de facto* requirement to publish the results of scientific R&D. Such bibliometric indicators though are not without problems themselves, including the possibility of bias in journal coverage and the distorting effects of evaluation mechanisms. In any case, while the possibility of such sources of bias could be relevant to inter-regional comparisons, in relation to our central question there are no strong reasons to think that it could affect pan-European trends.

Following Romer (1990), the importance of knowledge stocks (or a 'standing on the shoulders of giants' effect) for knowledge production has been verified empirically (Furman, Porter and Stern, 2002; Zucker et al. 2007). Three different types of national patent stocks were constructed and tested empirically: Patent stocks with no depreciation (Porter and Stern, 2000; Furman, Porter and Stern, 2002), and, using the perpetual inventory method (PIM), patent stocks with a 13 per cent (Park and Park, 2006) and a 15 per cent annual depreciation rate (Hall, 1993) respectively. Non-depreciated stocks are simply the cumulative number of patent applications from 1992 on, while PIM estimates of contemporary patent stocks are based on the following formula:

$$\text{PSTD}_{N,t} = \text{PSTD}_{N,t-1} * (1 - d) + \text{PAT}_{N,t}$$

[5] Invoking this assumption of course implies sidelining the important issue of patent quality, or the common observation that the economic value of patents is highly skewed: Insofar as we are concerned with the knowledge-generating sector and are not drawing inferences about the economy at large, this issue lies outside the scope of the present paper.

Where *d* is the depreciation rate (13 or 15 per cent). Initial stocks take into account compound annual growth in the five preceding years[6]. After testing all three variants and observing that results do not differ, our final estimates use the PIM stocks with a 13 per cent depreciation rate ($KSTCK_{N,\,t}$).

The region's level of agglomeration δ is proxied by a novel index of agglomeration of knowledge intensive employment. As most measures of absolute concentration of economic activity introduce multicollinearity, they are likely to be problematic in a regression context with interaction terms. Our index is a size-adjusted (in the spirit of the index developed by Elison and Glaeser (1997)) variation of the popular location quotient (LQ) measure and is calculated as:

$$\delta_i = [(EMPKI_i \,/\, EMPKI_{EU}) \,/\, (EMP_i \,/\, EMP_{EU})] \,/\, [1 - \sum_j (EMPKI_{i,j} \,/\, EMPKI_{j,EU})]*[1 - (EMP_i \,/\, EMP_{EU})],$$

where $EMPKI_j$ and EMPKI are employment in knowledge intensive economic sector j and the total of knowledge intensive sectors[7], EMP is total employment and the subscripts *i* and *EU* stand for region and EU aggregate respectively. Just like the LQ, δ has the interesting property of taking a value of 1 for regions with a level of agglomeration close to the EU average. However, unlike the LQ, in δ the denominator is designed in such a way as to penalise small regions, by yielding higher values for regions with a higher level of employment. As δ captures economic activity that is heavily involved not only in the production but also in the diffusion, assimilation and productive deployment of knowledge, we consider it an appropriate indicator for the agglomeration of innovation system actors .

With respect to our measure of interregional networking, we derive a measure from a database of collaborations in FP5. There are good reasons to expect that participations to the FP can be an appropriate proxy of the relational structure of

---

[6] Initial stock equals flows for first year divided by the sum of compound growth for the preceding five year period and the depreciation rate. Annual compound growth rates for the PIM variables were calculated for the 5 year period 1992-1997. Exceptions are Malta and Lithuania, where due to lack of data in the time series dimension, the preceding 4 year period (1993-1997) was used instead. For the non-depreciated stocks, a value of 1 was assumed in the case of Lithuania for 1992 (which is close to the average for that country in the following two years), while the 1998 value was estimated as the average of 1997 and 1999.

[7] The classification of knowledge intensive economic sectors (devised by Eurostat) includes: high and medium high technology manufacturing, high technology services, knowledge intensive market services (NACE 1.1 sectors 61, 62, 70, 71, 74), financial services (NACE 1.1 sectors 65, 66, 67), amenity services – health, education, recreation (NACE 1.1 sectors 80, 85, 92).

interregional knowledge diffusion across Europe. The FPs were designed to support ‘pre-competitive’, collaborative research with no national bias as to the types of technologies promoted and the distribution of funds. The pre-competitive character of supported research ensured that Community funding did not clash with the competition principles of the Common Market and did not function as a form of industrial subsidy; the collaborative character of research and the cost-sharing provisions were seen to guarantee the diffusion of technologies and the involvement of various types of actors from the whole technological knowledge creation spectrum, such as large and small firms, universities and public research institutes. One potential drawback of the FP as a data source is the fact that it is artificial; i.e. collaborating teams will not always coincide with naturally occurring networks of researchers. However, at as an aggregate level as that of a region and given the FP's overall gravity in European research[8], differences between the two are arguably negligible.

Using the FP5 database we have constructed an *n* by *n* matrix (where *n*=number of NUTS 2 regions in the sample) where a matrix element with a value 1 means a common FP project of two regions and zero otherwise. This matrix is used to calculate the total of the (log of) R&D expenditures in network partner regions for each region as a proxy for interregional network effects ($NETGRD_{i,\, t\text{-k}}$).

Tests on panel pooling, multicollinearity, heteroskedasticity, spatial dependence and endogeneity are run and, where appropriate, adjustments are made in the estimations.

## 5 Empirical results

Following the equations specified in section 2, we first estimate the KPF using patents as a proxy of Edison-type knowledge across European regions over the three year period 2000-2002 (Table 2). Regressions were estimated in Spacestat. To begin with, regression diagnostics indicate no problems with multicollinearity, as the multicollinearity condition number for all models is below the rule-of-thumb threshold of 30[9]. The first baseline model (1) confirms that, on average, lagged gross regional R&D expenditures (GRD) have a

---

[8] According to EC (2009: 103), European funding accounted for 12-15% of total R&D expenditures in Europe over the period 1996-2006, of which about half is channelled through the FP.

[9] The multicollinearity condition number is the square root of the ratio of the largest to the smallest eigenvalue of the matrix X’X after standardization. As a rule of thumb values of the condition number exceeding 30 signals serious multicollinearity (Belsley, Kuh and Welsch, 1980)

**Table 2 - Regression Results for Log (Patents) for 189 EU regions, 2000-2002 (n=567)**

| Model | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Estimation | OLS | OLS | OLS | OLS | OLS | 2SLS- Spatial Lag (INV2) |
| Constant | -1.6421*** | -0.3107 | -0.5391* | -1.7864*** | -1.7227*** | -2.3006*** |
| | (0.1776) | (0.2316) | (0.2806) | (0.2381) | (0.2372) | (0.2743) |
| W_Log(PAT) | | | | | | 0.2455*** |
| | | | | | | (0.0631) |
| Log(GRD $_{t-2}$) | 1.0822*** | 0.8453*** | 0.9585*** | 0.7142*** | 0.6879*** | 0.7088*** |
| | (0.0308) | (0.0407) | (0.0886) | (0.0377) | (0.0384) | (0.0377) |
| Log(GRD $_{t-2}$)*Log($\delta_{t-2}$) | | 0.3242*** | 0.3222*** | 0.2443*** | 0.2136*** | 0.1439*** |
| | | (0.0389) | (0.0389) | (0.0351) | (0.0363) | (0.0396) |
| Log(GRD $_{t-2}$)* NETGRD $_{t-2}$ | | | -8.675E-05 | | | |
| | | | (6.03E-05) | | | |
| Log(KSTCK $_{t-2}$) | | | | 0.2502*** | 0.2536*** | 0.1804*** |
| | | | | (0.0203) | (0.0202) | (0.0272) |
| PAHTCORE | | | | | 0.4814*** | 0.4614*** |
| | | | | | (0.1568) | (0.1526) |
| $R^2$-adj | 0.69 | 0.72 | 0.72 | 0.78 | 0.78 | |
| Log Likelihood | -885.30 | -852.36 | -851.32 | -784.69 | -779.98 | |
| Sq. Corr. | | | | | | 0.80 |
| Multicollinearity Condition Number | 7 | 10 | 24 | 13 | 13 | |
| F on pooling (time) | 0.9071 | 0.6777 | 0.5644 | 0.8143 | 0.6425 | |
| F on slope homogeneity | 0.4815 | 0.7613 | 0.5836 | 0.6485 | 0.4645 | |
| White test for heteroscedasticity | 0.7529 | 1.0462 | 12.8409 | 3.6634 | 12.1852 | |
| LM-Err | | | | | | |
| Neighb | 111.78*** | 69.36*** | 66.85*** | 26.95*** | 23.46*** | |
| INV1 | 252.17*** | 129.64*** | 117.26*** | 29.87*** | 26.13*** | |
| INV2 | 215.12*** | 121.59*** | 114.45*** | 32.40*** | 29.24*** | |
| LM-Lag | | | | | | |
| Neighb | 142.53*** | 100.88*** | 99.03*** | 24.99*** | 25.89*** | |
| INV1 | 247.03*** | 159.07*** | 153.47*** | 28.16*** | 27.96*** | |
| INV2 | 237.99*** | 148.93*** | 145.48*** | 31.42*** | 30.95*** | |

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: Neigh is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; W_Log(PAT) is the spatially lagged dependent variable where W stands for the weights matrix INV2. *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$. In model (6) the Durbin-Wu-Hausman test for Log(GRD$_{t-2}$) and Log(GRD$_{t-2}$)*Log($\delta_{t-2}$) does not reject exogeneity. The instruments were selected following the 3-group method. For the spatial lag term the instruments are the spatially lagged explanatory variables.

significant relationship with contemporary patent flows. Moreover, the proximity of the estimated coefficient to unity suggests that innovation flows throughout European regions are on average about proportionate to R&D inputs.

Model 2 includes the product of lagged R&D expenditures and δ. Model 2 suggests that agglomeration has a positive, statistically significant and quantitatively distinct effect on R&D productivity, confirming the significance of agglomeration effects. Interpreted from an innovation systems perspective, this finding reflects the importance of knowledge interactions between different

**Table 3 - Regression Results for Log (Publications) for 189 EU regions, 2000-2002 (n=567)**

| Model | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Estimation | OLS | OLS | OLS | OLS | OLS | 2SLS Heteroscedasticity Robust |
| Constant | 1.4026*** | 2.3886*** | 2.196*** | 2.3395*** | 2.4568*** | 2.6137*** |
| | (0.1298) | (0.1645) | (0.202) | (0.1711) | (0.1697) | (0.3199) |
| Log(GRD $_{t-2}$) | 0.942*** | 0.445*** | 0.480*** | 0.4158*** | 0.4523*** | 0.4317*** |
| | (0.0225) | (0.0597) | (0.633) | (0.066) | (0.0602) | (0.1262) |
| Log(GRD $_{t-2}$)*Log(δ $_{t-2}$) | | | -0.0462 | | | |
| | | | (0.0282) | | | |
| Log(GRD $_{t-2}$)* NETGRD $_{t-2}$ | | 0.0004*** | 0.0004*** | 0.0004*** | 0.0004*** | 0.0003*** |
| | | (4.40E-05 ) | (4.40E-05) | (4.56E-05) | (4.68E-05) | (9.26E-05) |
| Log(KSTCK $_{t-2}$) | | | | 0.01758 | | |
| | | | | (0.01689) | | |
| PUBCORE | | | | | 0.2247** | 0.3293*** |
| | | | | | (0.1032) | (0.0977) |
| $R^2$-adj | 0.76 | 0.79 | 0.79 | 0.79 | 0.79 | |
| Log Likelihood | -707.30 | -670.05 | -668.70 | -669.51 | -667.89 | |
| Sq. Corr. | | | | | | 0.79 |
| Multicollinearity Condition Number | 7 | 22 | 23 | 27 | 24 | |
| F on pooling (time) | 0.6694 | 0.9269 | 0.6712 | 0.7141 | 0.7055 | |
| F on slope homogeneity | 0.2059 | 0.357 | 0.2752 | 0.2683 | 0.2501 | |
| White test for heteroscedasticity | 44.575*** | 77.378*** | 84.013*** | 92.231*** | 86.884*** | |
| LM-Err | | | | | | |
| Neighb | 0.7199 | 0.7727 | 0.7518 | 0.9808 | 0.5749 | |
| INV1 | 3.3586* | 2.5407 | 1.8767 | 3.4006* | 2.6595 | |
| INV2 | 0.3687 | 0.9367 | 0.8782 | 1.2604 | 1.020 | |
| LM-Lag | | | | | | |
| Neighb | 12.214*** | 3.0067* | 2.4689 | 4.2311** | 3.7861* | |
| INV1 | 1.6479 | 0.0642 | 0.4640 | 0.061 | 0.0069 | |
| INV2 | 5.2928** | 0.6649 | 0.1242 | 1.9522 | 1.1352 | |

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: Neigh is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$. In Model 5 the Durbin-Wu-Hausman test for Log($GRD_{t-2}$) and Log(GRD $_{t-2}$)* NETGRD $_{t-2}$ rejects exogeneity at the level of $p < 0.1$. In Model 6 the instruments were selected following the 3-group method.

institutional actors engaged in knowledge-intensive economic activities (e.g. users versus producers, academic institutions, government actors etc) for innovation (Andersen, 1992; Nelson, 1993; Edquist, 1997; Cooke, 2001). The importance of co-location is also suggestive of the significance of tacit knowledge (Malmberg and Maskell, 1997).

Model 3 tests the significance of network effects, by including the product of gross R&D expenditure of region *i* times the (logarithm of the) value of the sum of R&D expenditures of those regions with which region *i* had at least one joint research project in FP5 (Log(GRD)* $NETGRD_{t-2}$). The product term is statistically insignificant. This result suggests that R&D expenditures of collaborating regions do not affect R&D productivity in the region[10].

Model 4 introduces national patent stocks (PSTCK), indicating that historically accumulated technological knowledge has a positive, statistically significant and quantitatively distinct effect on regional patenting. Interestingly, the coefficient of Log(GRD)*Log(δ) drops from around 0.32 in models 2 and 4 to about 0.24, suggesting that codified knowledge spillovers capture at least some of the effects attributed to agglomeration in the previous models. In models (1-5) the LM-tests confirm the presence of a strong spatial dependence even after controlling for model variables. Spatial lag dependence captured by the square inverse distance matrix is the most significant thus it is used in the final estimated model. Though the explanatory variables lag two years behind the dependent variable and as such no endogenous relationship is expected in the equation, stability in the spatial structure of R&D in a medium term might be the source of correlation between the explanatory variables and the error term. However the D-W-H test does not reject exogeneity for the regional left hand side variables[11].

Given that error terms are not distributed normally the appropriate regression is the spatial lag model estimated with the instrumental variables methodology (2SLS). In model (6), controlling for spatial dependence, the substantive results remain unaffected, although the value of the coefficient for the agglomeration interaction term is smaller. The dummy variable PATHCORE (with 1 for regions with more than two standard deviations above the EU average patent applications and 0 otherwise) enters the equation with significant coefficients in models 5 and 6 suggesting remarkable differences between high and low patenting regions in Europe. It is worth noting that all models explain 70 per cent or more of the variation in regional patenting.

Table 3 estimates the KPF with scientific publications as the dependent variable. In all models, regression diagnostics indicate no problems with multicollinearity and, as with patents, the KPFs explain more than 70 per cent of variation in the data. Gross regional R&D expenditures explain most of the variation, with a coefficient in model 1 (0.94) suggestive of almost constant returns to scale. Strikingly, agglomeration effects appear to have no statistically significant influence on scientific R&D productivity (included either with or without the

---

[10] Of course, this does not conclusively disprove the existence of interregional network effects (possibly by other means) not captured by our coarse proxy.

[11] The 3-group method suggested by Kennedy (1998) was followed in instrument selection. For each variable the instrument takes the value -1, 0, or 1 according to whether the value of the instrumented variable is in the lower, middle or upper third of its ranking.

cross product variable Log(GRD $_{t-2}$)* NETGRD $_{t-2}$ as it is in Model 3), while network effects (Models 2 to 6) exert a statistically significant and quantitatively distinct influence on scientific R&D productivity.

Therefore, in the case of Pasteur-type research, interregional networking is more important than local agglomeration. In other words, regions can perform research efficiently even in the absence of local agglomeration. The fact that none of the spatial dependence measures is statistically significant, confirms the importance of codified (as opposed to tacit) knowledge for scientific research. No significant spatial dependence is found but heteroscedasticity remains persistently present throughout the models. Given that exogeneity is not rejected by the D-W-H test for the variables Log(GRD$_{t-2}$) and Log(GRD$_{t-2}$) *WFP5_Log(RD$_{t-2}$) the final model (6) is run with 2SLS with heteroscedasticity robust error terms. The dummy variable PUBCORE (with 1 for regions with more than one standard deviations above the EU average publications output and 0 otherwise) enters the equation with significant coefficients in models 5 and 6 suggesting remarkable differences between high and low publishing regions in Europe. All the substantive relationships are confirmed.

In Table 4 we now move on to test the effect of R&D productivity on the temporal change of regional R&D expenditures (Eq. 5). The equation with changes in R&D expenditures from 1998 to 2001 shows the highest fit thus we report the results for this setup here. The results confirm that the spatial allocation of R&D expenditures is conditioned by R&D productivity, both technological (BETAPAT) and scientific (BETAPUB). This supports our hypothesised cumulative agglomeration effect behind the temporal changes in regional R&D expenditures.

The dummy variable RDHCORE (with 1 for regions with more than two standard deviations above the EU average R&D expenditures and 0 otherwise) enters the equation with significant coefficients in models 3 and 4 suggesting remarkable differences between high and low R&D performing regions in Europe. Thus we could take this result as an indication of a “spatial regime effect” favouring high R&D activity regions in the temporal distribution of additional research expenditures. It is noteworthy that spatial dependence is not an issue in any of the models in Table 3, suggesting that the relationship is localised within the boundaries of the region.

**Table 4 - Regression Results for (GRD2001-GRD1998) for EU regions (n=189)**

| Model | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Estimation | OLS | OLS | OLS | OLS-Heteroscedasticity Robust (White) |
| Constant | -604.429*** | -735.41*** | -299.107*** | -299.107*** |
| | (90.8252) | (101.405) | (78.3494) | (68.7176) |
| BETAPAT1998 | 1145.6*** | 910.258*** | 351.824*** | 351.824*** |
| | (147.511) | (167.819) | (125.294) | (118.165) |
| BETAPUB1998 | | 364.853*** | 190.322** | 190.322*** |
| | | (131.181) | (93.4943) | (69.8948) |
| RDHCORE | | | 360.98*** | 360.98*** |
| | | | (26.3212) | (47.4151) |
| $R^2$-adj | 0.24 | 0.27 | 0.63 | 0.63 |
| White test for heteroscedasticity | 52.3206*** | 57.8899*** | 42.2263*** | |
| LM-Err | | | | |
| Neighb | 0.1133 | 0.0231 | 0.0674 | |
| INV1 | 0.0092 | 0.1976 | 1.1476 | |
| INV2 | 0.0895 | 1.8205 | 0.9415 | |
| LM-Lag | | | | |
| Neighb | 0.0960 | 0.0434 | 0.1026 | |
| INV1 | 2.6971 | 0.9635 | 1.9972 | |
| INV2 | 0.5956 | 0.5309 | 1.9896 | |

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: Neighb is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix. *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$.

In Table 5 we present our estimated model for temporal change in the agglomeration of innovation actors measured by knowledge intensive employment (Eq. 6). It is clear that strong path dependence is at work in the dynamic distribution of knowledge intensive employment, however besides this path dependency the size of regional R&D is also a determining factor as to the direction where knowledge intensive employment agglomerates. Similar to the results in Table 5 regions with above average R&D expenditures (RDCORE) follow a different pattern in attracting knowledge intensive employment. Both spatial dependence and heteroscedasticity are present consistently throughout models 1 to 3, which are corrected in the final spatial error heteroscedasticity robust estimation of model 4.

**Table 5 - Regression Results for (EMPKI2001-EMPKI998) for EU regions (n=189)**

| Model | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Estimation | OLS | OLS | OLS | ML – Spatial Error (INV2) with Heteroscedasticity weights |
| Constant | 5399.78* | 8821.36*** | 9955.96*** | 11168.3*** |
| | (3032.61) | (3314.62) | (3267.78) | (2879.48) |
| EMPKI1998 | 0.071*** | 0.054*** | 0.032*** | 0.0262** |
| | (0.006) | (0.009) | (0.012) | (0.011) |
| EMPKI1998*GRD1998 | | 3.788E-06** | 5.043E-06*** | 5.624E-06*** |
| | | (1.582E-06) | (1.604E-06) | (1.604E-06) |
| RDCORE | | | 19896.5*** | 21321.1*** |
| | | | (6614.64) | (6366.96) |
| LAMBDA | | | | -0.0181** |
| | | | | (0.009) |
| $R^2$-adj | 0.41 | 0.42 | 0.45 | 0.45 |
| Multicollinearity Condition Number | 2 | 4 | 6 | |
| White test for heteroscedasticity | 27.37*** | 28.182*** | 34.522*** | |
| LM-Err | | | | |
| Neighb | 0.922 | 0.164 | 0.042 | |
| INV1 | 0.052 | 0.023 | 0.28 | |
| INV2 | 1.008 | 3.263* | 5.878** | |
| LM-Lag | | | | |
| Neighb | 2.181 | 1.846 | 1.916 | |
| INV1 | 0.479 | 0.043 | 0.645 | |
| INV2 | 4.000* | 4.574** | 4.316** | |

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: LAMBDA is the spatial autoregressive coefficient; Neighb is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$.

# 6 Simulation analysis: Static and dynamic agglomeration and interregional network effects on R&D productivity

The empirical findings so far suggest that regional productivity in Edison-type research (patenting) is influenced by agglomeration but not by interregional networking, whereas regional productivity in Pasteur-type research is influenced by interregional networking but not by agglomeration. How strong are the agglomeration and network effects in each individual region in Europe? Which regions are leading and which ones are lagging behind?

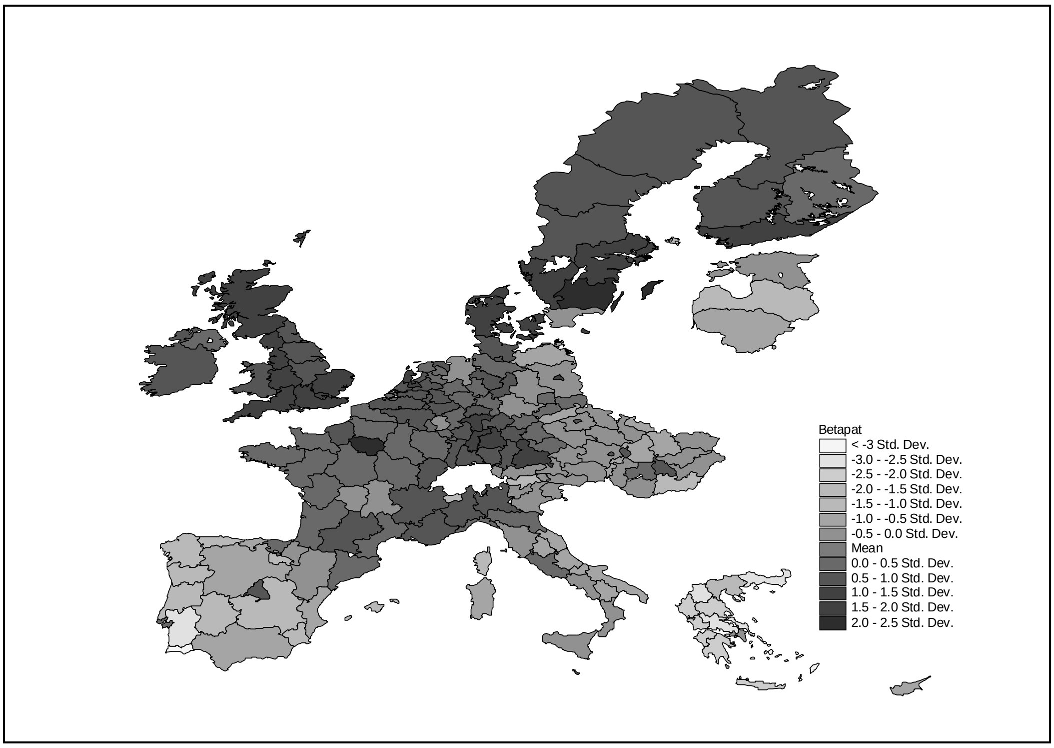
On the basis of the above models, we estimated the annual average regional productivity of research in innovation and scientific output for each region using the following formulas:

$BETAPAT_i = 1.164*[(0.7088 + 0.1439 * \mathrm{Log}(\delta_{i, t-2}))]$[12]

$BETAPUB_i = [0.4317 + 0.0003 * \mathrm{WFP5\_Log}(RD_{i, t-2}]$

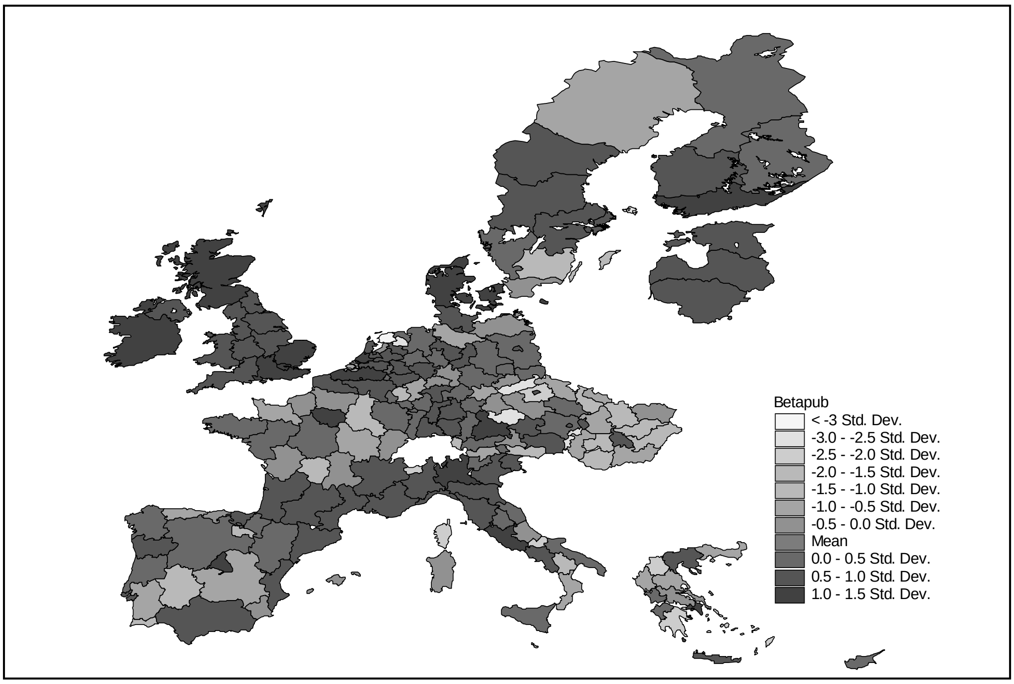
Our estimates are depicted in the two maps, expressed in standard deviations from the European mean (Figure 1 and 2). R&D productivity in Edison-type research is more concentrated spatially with core regions in South-West Germany, North-Western Europe (including the South of the UK) and the capital city regions. R&D productivity in Pasteur-type research spreads more evenly with less clear spatial concentration patterns indicating that connectedness into interregional scientific networks increases research efficiency in publications even if agglomeration of innovative activities is at a low level. Importantly, capital cities in East-Central and South Europe are also among the above average R&D productivity regions both in patenting and in publication.

**Figure 1: Regional productivity in Edison-type research (patenting)**




[12] The estimated parameters in Table 2 are multiplied with 1.164. This term is called “spatial multiplier” (Anselin 2003). It reflects the interdependence among regions in patenting. Interdependence decreases with distance as represented by the squared inverse distance weights matrix in Table 2. Thus patenting activity is influenced not only by R&D in the region but also by R&D carried out in other regions in the sample following a distance decay pattern.

**Figure 2: Regional productivity in Pasteur-type research (publications)**




Equations 2 to 6 with estimated parameters in Tables 2 to 5 reflect the dynamic nature of the impacts of R&D support policies. In a relatively short run this support affects patenting directly while in the longer run it also strengthens concentration of research and knowledge intensive employment in the region which further impacts knowledge production indirectly (via additional R&D and increased values of the parameters BETAPAT and BETAPUB). This dynamic feature is represented by Figure 3 where the first 7 time periods are shown (without continuing the impacts throughout additional periods).

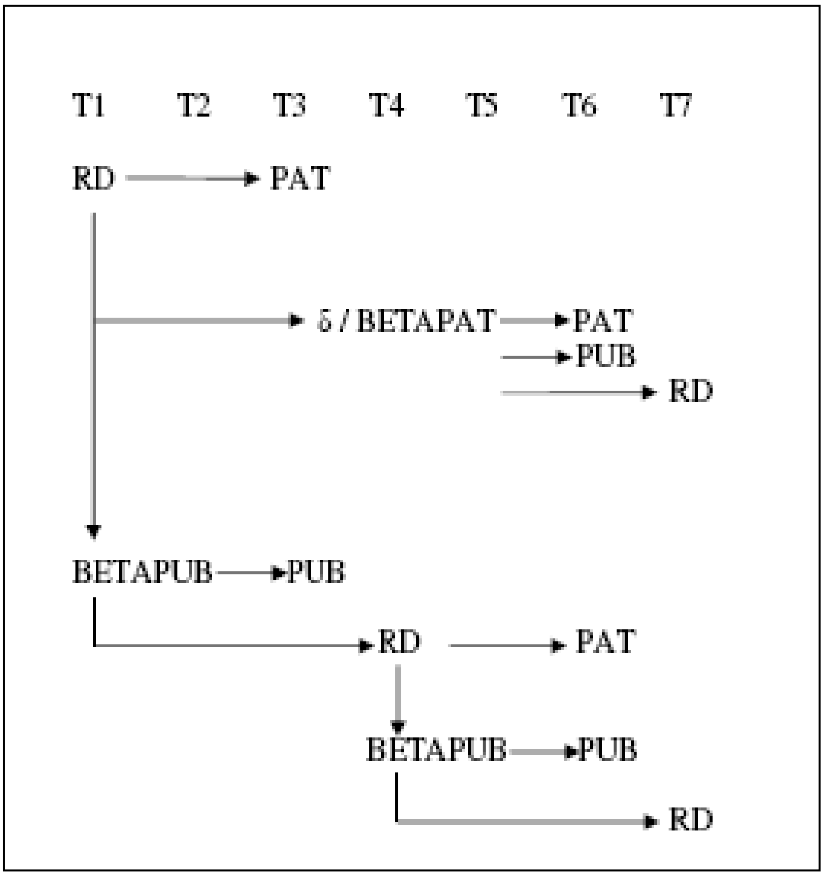
The econometric estimates allow us to explore counterfactual scenarios and characterise the effects of policy interventions. We produce a simulation of the likely impact of FP6 (2002-2006[13]) funding on patent applications of European regions using the empirically verified relationships and estimated coefficients. We split European regions into four tiers according to their scores on the agglomeration index ($\delta$). Regions with values of the agglomeration index of more than one standard deviation above the mean belong to the first tier. Second tier regions exhibit agglomeration values between the mean and the mean plus one standard deviation. Third tier regions are half standard deviation value below the mean whereas the rest of the regions belong to the fourth tier.

---

[13] This is lagged by one year (i.e. 2003-2007) in the simulations, better reflecting the period during which the bulk of the funds was spent.

How effective are European regions in utilising R&D subsidies awarded from the EU Framework Programs in patenting? Are there differences across regions? How persistent are the impacts over time? The estimated system of equations allows us to calculate a measure of the productivity of FP6 research support in patent applications for each tier and for each year of intervention (2003-2007) and beyond. Simulation results are depicted in Figure 4. Regional productivity of FP6 in patenting is measured by the elasticity of patents with respect to FP6 R&D subsidies[14].

**Figure 3: The dynamic impacts of R&D promotion (followed only for the first seven periods)**

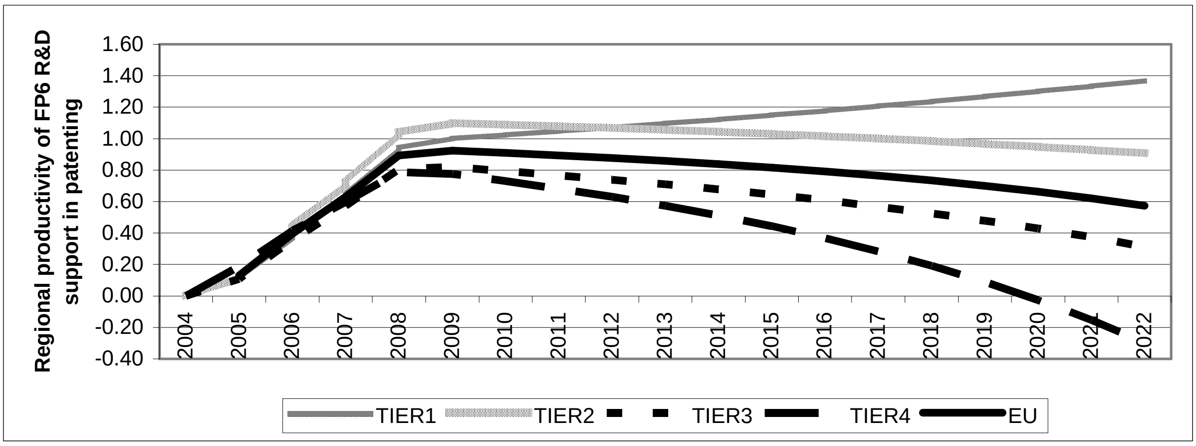



It is clear from Figure 4 that there are differences across EU regions in the effectiveness of utilizing FP6 R&D subsidies in patenting. Though these differences are relatively minor in the period of intervention (2003-2007) differences in the persistency of the effects are rather significant. Whereas in Tier2 to Tier4 regions the impact of FP6 R&D subsidies on patenting fades

[14] Regional productivity of FP6 R&D support in patenting = [(Estimated number of regional patent applications with FP6 – Estimated number of regional patent applications without FP6)/Estimated number of regional patent applications without FP6] / [(Estimated value of regional R&D expenditures with FP6 – Estimated value of regional R&D expenditures without FP6)/Estimated number of regional R&D expenditures without FP6]

away slowly after 2008, Tier1 regions exhibit a persistent (even slightly increasing) impact on patenting. It is the differences in the strengths of the dynamic agglomeration forces that explain the differences in the effectiveness of absorbing R&D subsidies. Whereas Tier1 regions are strong enough to attract additional R&D and human capital that allows them to increase the impact of subsidies on patenting agglomeration forces in the rest of the regions are not sufficient enough to maintain even the initial impacts over time.

**Figure 4: Dynamic agglomeration effects: Regional productivity of FP6 R&D support in Edison-type research (patenting)**




## 7 Summary and policy discussion

This paper has examined empirically the comparative influence of agglomeration and networking on regional R&D productivity in the European Union. The typical data constraints have been tackled by developing and calculating original indices of regional agglomeration of knowledge-producing capabilities using employment data, and of interregional networking in R&D using data on R&D collaborations under FP5. The empirical estimation of a system of equations first proposed in Varga (2006) has shed light on three major areas of interest: The relationship between regional agglomeration and interregional networking on the one hand and R&D productivity on the other; the relationship between R&D productivity and temporal changes in regional R&D expenditures; the relationship between R&D expenditures and the generation of knowledge-intensive employment. More specifically, we have estimated KPFs across a number of European regions over three years testing the influence of agglomeration and networking on the production of Edison- and Pasteur-type knowledge. We found that agglomeration is an important predictor of R&D productivity in the case of Edison-type research while interregional networking is an important determinant of R&D productivity in the case of Pasteur-type research. Importantly, the two determinants were never *jointly* significant (i.e. interregional networking and agglomeration were not statistically significant for Edison- and Pasteur-type research respectively) – a finding that is robust to numerous equation specifications and the choice of stepwise inclusion. This finding indicates that in a knowledge production context, and contrary to what may happen in other areas of economic activity (Johansson and Quigley, 2004), agglomeration and networking are neither substitutes nor complements but operate at distinct parts of the knowledge production process.

The sharp contrast between the worlds of Pasteur and Edison raises additional questions that cannot be fully explored here. One may speculate that the distinction is due to a 'hard' constraint on the codifiability of knowledge (Roberts, 2000) and a 'soft' constraint on the willingness of R&D-performing actors to codify knowledge, given the different 'rules of the game' prevalent in the worlds of Pasteur and Edison. Of course, the importance of co-location for knowledge production activities that are heavily dependent on tacit knowledge is recognised in the literature (Malmberg and Maskell, 1997). In the world of Edison, appropriability concerns and a strategy of selective secrecy may also provide part of the explanation. To contrast with, the world of Pasteur, characterised by fuller disclosure, *de facto* codifiability and the importance of reputation dynamics, access to (not necessarily local) networks makes an important difference.

Our findings with respect to the importance of spatial dependence are in agreement with the above picture: In common with other studies (Paci and Usai, 2000; Maggioni et al., 2007), we find evidence of strong spatial dependence in the production of Edison-type knowledge. As far as the production of Pasteur-type knowledge is concerned though, spatial dependence is either absent or plays a much weaker role.

Moreover, using the same sample of regions, we have tested empirically the influence of R&D productivity on the temporal change of R&D expenditures. Our findings indicate that the spatial allocation of further R&D expenditures is explained by manifested technological and scientific R&D productivity and a spatial regime effect whereby regions with levels of R&D expenditure that are significantly higher than the sample average get more funds. We find no evidence of spatial dependence, perhaps a reflection of the high concentration of R&D inputs.

Finally, our empirical test of the relationship between R&D expenditures and the generation of knowledge intensive employment has identified a strongly path-dependent process at work. Past levels of knowledge intensive employment explain most of the regional variation over time. R&D expenditures though play an important, albeit minor, role in that relationship, as evidenced by the statistically significant interaction between employment and R&D. A spatial regime is also present, whereby regions with levels of R&D expenditure that are significantly higher than the sample average experience greater increases in knowledge intensive employment.

Taken together, the above findings uncover the principal components of regional knowledge production processes across European regions in a dynamic setting. They therefore allow us to explore counterfactual scenarios and characterise the effects of policy interventions. A simulation of the likely impacts of FP6 funds on R&D productivity demonstrates that the dynamic effect is greater in regions with high agglomeration.

A first direct policy conclusion is that the geographical concentration of resources for pre-competitive, Pasteur-type research is at best irrelevant for the generation of new scientific knowledge: In the complex European knowledge production landscape regions potentially contribute to the creation of scientific knowledge irrespective of their degree of agglomeration. On the other hand, direct funding for competitive, Edison-type research, which from a different perspective can be seen as an indirect form of industrial subsidy not particularly favoured by the EU competition rules, will inevitably come mostly from national sources. It would make more sense, and would probably be more efficient, if this type of funding is directed in a way that favours highly agglomerated knowledge hubs.

A second policy conclusion is drawn from the results of the simulations, which show that the positive effects of collaborative funding instruments, such as the FP, are sustained longer in regions with already high levels of human capital: This indicates that additional attention should be paid to less-advanced regions with the provision of ‘structural’ funding complementary to the FP, which will be intended to increase the accumulation of human capital and the knowledge capacities of the regions.

## References


Acs, Z., and Varga, A. (2005): Entrepreneurship, agglomeration and technological change. *Small Business Economics 24*: 323-334.

Acs, Z., Anselin, L., and Varga, A. (2002): Patents and innovation counts as measures of regional production of new knowledge. *Research Policy 31*: 1069-1085.

Amin, A., and Thrift, N. (1992): Neo-Marshallian nodes in global networks. *International Journal of Urban and Regional Research 16*(4): 571-587.

Andergassen, R., Nardini, F. and Ricottilli, M. (2005): Firms' network formation through the transmission of heterogeneous knowledge. Working Paper No. 543, Università degli Studie, Dipartimento di Scienze Economiche.

Andersen, E.S. (1992): Approaching the national systems of innovation from the production and linkage structure, in Lundvall, B. Å. (ed.): *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter.

Anselin, L. (2003): Spatial externalities, spatial multipliers, and spatial econometrics. *International Regional Science Review* 26(2): 153-166.

Anselin, L., Varga, A. and Acs, Z. (1997): Local geographic spillovers between university research and high technology innovations. *Journal of Urban Economics 42*: 422–448.

Audretsch, D., and Feldman M. (1996): R&D spillovers and the geography of innovation and production. *American Economic Review 86*: 630-640.

Autant-Bernard, C., Billand, P., Frachisse, D., and Massard, N. (2007): Social distance versus spatial distance in R&D cooperation: Empirical evidence from European collaboration choices in micro and nanotechnologies. *Papers in Regional Science 86*(3): 495-519.

Balconi, M., Breschi, S., and Lissoni, F. (2004): Networks of inventors and the role of academia: an exploration of Italian patent data. *Research Policy 33*(1): 127-145.

Barabási, A., and Albert, R. (1999): Emergence of scaling in random networks. *Science 286*(5439): 509-512.

Barber, M.J., Krueger, A., Krueger, T., and Roediger-Schluga, T. (2006): Network of European Union-funded collaborative research and development projects. *Physical Review E 73*(3): 036132/1-13.

Belsley, D., Kuh, E., and Welsch, R. (1980): *Regression Diagnostics, Identifying Influential Data and Sources of Collinearity*. New York: Willey.

Besussi, E. (2006): Mapping European research networks. Working Papers Series, No. 103, Centre for Advanced Spatial Analysis, University College London.

Billand, P., Frachisse, D., and Massard, N. (2008): The Sixth Framework Program as an affiliation network: representation and analysis. FEEM Fondazione Eni Enrico Mattei Research Paper Series, No. 32.2008.

Breschi, S., and Lissoni, F. (2005): Mobility and social networks: localised knowledge spillovers revisited. *CESPRI Working Paper 142*. Università Commerciale "Luigi Bocconi".

Carayol, N., and Roux, P. (2007): The strategic formation of inter-individual collaboration networks. Evidence from co-invention patterns. *Annales d'Économie et de Statistique 87/88*: 275-301.

Cooke, P. (2001): Regional innovation systems, clusters and the knowledge economy. *Industrial and Corporate Change 10*(4): 945- 974.

Cowan, R. & Jonard, N. (2006): Innovation networks and the distribution of knowledge. Paper presented at the DRUID Summer Conference on: *Knowledge, Innovation and Competitiveness: Dynamics of Firms, Networks, Regions and Institutions*, June 18-20, Copenhagen, Denmark. http://www2.druid.dk/conferences/viewpaper.php?id=145&cf=8

Cowan, R. (2004): Network models of innovation and knowledge diffusion. Maastricht Economic Research Institute on Innovation and Technology (MERIT), Research Memoranda Series, No. 16.

Dosi, G. (1988): Sources, procedures, and microeconomic effects of innovation. *Journal of Economic Literature 26*(3): 1120-1171.

Caloghirou, Y., Vonortas, N.S. and Ioannides, S. (2004) (eds): *European Collaboration in Research and Development*. Northampton: Edward Elgar.

Crescenzi, R., Rodríguez-Pose, A., and Storper, M. (2007): The territorial dynamics of innovation: a Europe-United States comparative analysis. *Journal of Economic Geography 7*: 673-709.

EC (2009): A more research-intensive and integrated European Research Area, Science, Technology and Competitiveness key figures report 2009/2009. EUR 23608, Luxembourg, Office for Official Publications of the European Communities.

Edquist, C. (ed.) (1997): *Systems of Innovation*: *Technologies, Institutions and Organizations*. London: Pinter.

Ellison, G., and Glaeser, E. (1997): Geographic concentration in US manufacturing industries: a Dartboard approach. *Journal of Political Economy 105*(5): 889–927.

Fafchamps, M., van der Leij, M., and Goyal, S. (2006): Scientific networks and co-authorship. University of Oxford, Department of Economics, Economics Series Working Papers, No. 56.

Feldman, M. (1994): The university and economic development: the case of Johns Hopkins University and Baltimore. *Economic Development Quarterly 8*: 67-66.

Foray, D. and Van Ark, B. (2007): Smart specialisation in a truly integrated research area is the key to attracting more R&D to Europe. Policy Brief No 1, http://ec.europa.eu/invest-in-research/pdf/download_en/policy_brief1.pdf

Foray, D. (2009): Understanding “Smart Specialisation. in Pontikakis, Kyriakou and van Bavel (eds.) (2009): The Question of R&D Specialisation: Perspectives and policy implications, *JRC Scientific and Technical Reports*, No. 51665, EUR 23834, Luxembourg: Office for Official Publications of the European Communities, http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2339

Furman, J. L., Porter, M. E. and Stern, S. (2002): The determinants of national innovative capacity. *Research Policy*, 31: 899-933

Furman, J.L. and Hayes, R. (2004): Catching up or standing still? National R&D productivity among ‘follower’ countries, 1978-1999. *Research Policy*, 33: 1329-1354.

Fujita, M, Krugman, P, Venables, A (1999): The Spatial Economy. MIT Press. Cambridge, London.

Fujita M and Thisse J (2002): *Economics of Agglomeration. Cities, Industrial Location, and Regional Growth*. Cambridge University Press Cambridge, MA, London, England.

Gastner, M.T., and Newman, M.E. (2006): The spatial structure of networks, *European Physical Journal B 49*(2): 247-252.

Georghiou, L., Cooke, P., Cozzens, S., Dearing, A., Henriques, L., Langer, J., Laredo, P., Sanz Menendez, L., Weber, M. (2008): Challenging Europe's Research: Rationales for the European Research Area (ERA), Report of the

ERA Expert Group, http://ec.europa.eu/research/era/pdf/eg7-era-rationales-final-report_en.pdf

Geroski, P. A. (1989a): European industrial policy and industrial policy in Europe. *Oxford Review of Economic Policy 5*(2): 20-36.

Geroski, P. A. (1989b): The choice between diversity and scale, in Davis, E., Geroski, P. A., Kay, J. A., Manning A., Smales, C., Smith, S. R. and Szymanski, S. (eds.) (1992): Myths and Realities, Centre for Business Strategy, London Business School, pp. 29-45.

Glaeser, E.L., Kallal, H.D., Scheinkman, J.A., and Shleifer, A. (1992): Growth in cities. *Journal of Political Economy 100*(6): 1126-1152.

Goldstein, H., and J. Drucker (2006): The economic development impacts of universities on regions: do size and distance matter? *Economic Development Quarterly 20*(1): 22-43.

Goyal, S., and Moraga-Gonzalez, J.L. (2001): R&D networks, *RAND Journal of Economics 32*(4): 686-707.

Granovetter, M.S. (1973): The strength of weak ties, *American Journal of Sociology 78*(6): 1360-1380.

Griliches, Z. (1990): Patent statistics as economic indicators: A survey, *Journal of Economic Literature 28*: 1661-1707.

Hall, B.H., Griliches, Z. and Hausman, J.A. (1986): Patents and R and D: is there a lag?, *International Economic Review* 27(2): 265-283.

Hall, B.H. (1993): The Stock Market's Valuation of R&D Investment During the 1980's. *The American Economic Review* 83(2):259-264.

Hite, J.M., and Hesterly, W.S. (2001): The evolution of firm networks: from emergence to early growth of the firm, *Strategic Management Journal 22*(3): 275–286.

Jacobs, J. (1969): *The economy of cities*. New York: Random House.

Jaffe, A. (1989): Real effects of academic research, *American Economic Review 79*: 957-970.

Jaffe, A., Trajtenberg, M., and Henderson, R. (1993): Geographic localization of knowledge spillovers as evidenced by patent citations, *Quarterly Journal of Economics 108*: 577–598.

Johansson, B., and Quigley, J.M. (2004): Agglomeration and networks in spatial economies, *Papers in Regional Science 83*(1): 165-176.

Jones, C. (1995): R&D-based models of economic growth, *Journal of Political Economy 103*(4): 759-784.

Kennedy, P. (1998): *A guide to econometrics*. Malden: Blackwell Publishing.

Koo, J. (2005): Agglomeration and spillovers in a simultaneous framework, *Annals of Regional Science 39*: 35-47

Luukkonen, T., Persson, O. and Sivertsen, G. (1992): Understanding patterns of international scientific collaboration. *Science, Technology and Human Values 17*(1): 101-126.

Maggioni, M.A., Nosvelli, M., and Uberti, T.E. (2007): Space versus networks in the geography of innovation: a European analysis. *Papers in Regional Science 86*(3): 471-493.

Malmberg, A., and Maskell, P. (1997): Towards an explanation of regional specialization and industry agglomeration. *European Planning Studies 5*(1): 25-41.

Markusen, A. (1996): Sticky places in slippery space: A typology of industrial districts. *Economic Geography 72*(3): 293-313.

Marshall, A. (1920): *Principles of economics*. London: Macmillan.

Matthews, M. and McGowan, F. (1992): Reconciling diversity and scale: some questions of method in the assessment of the costs and benefits of European integration. *Revue d'économie industrielle 59*(1): 222-234.

Mokyr, J. (2002): *The Gifts of Athena*. Princeton: Princeton University Press.

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

Newman, M.E.J. (2000). Models of the small world: A Review. *Journal of Statistical Physics 101*(3-4): 819-841.

Newman, M.E.J. (2001): The structure of scientific collaboration networks. *PNAS 98*(2): 404-409.

Paci, R., and Usai, S. (2000): Externalities, knowledge spillovers and the spatial distribution of innovation. *GeoJournal 49*(4): 381-390.

Park, G., and Park, Y. (2006): On the measurement of patent stock as knowledge indicators. *Technological Forecasting and Social Change 73*: 793-812.

Ponds, R., van Oort, F., and Frenken, K. (2007): The geographical and institutional proximity of research collaboration. *Papers in Regional Science 86*(3): 423-443.

Ponds, R., van Oort, F.G., and Frenken, K. (2009): Internationalization and regional embedding of scientific research in the Netherlands, in A. Varga (ed.): *Universities and Regional Development*. Cheltenham: Edward Elgar, 109-137.

Pontikakis, D., Kyriakou, D. and van Bavel, R. (eds.) (2009): The question of R&D specialisation: Perspectives and policy implications. *JRC Scientific and Technical Reports*, No. 51665, EUR 23834, Luxembourg: Office for Official Publications of the European Communities, http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2339

Porter, M. E. and Stern, S. (2000): Measuring the 'ideas' production function: evidence from international patent output, *NBER Working Papers*, No. 7891, National Bureau of Economic Research

Roberts, J. (2000): From Know-how to Show-how? Questioning the Role of Information and Communication Technologies in Knowledge Transfer. *Technology Analysis and Strategic Management*, 12(4): 429-443

Romer, P. M. (1990): Endogenous technological change, *Journal of Political Economy 5*(98): S71-S102

Rosenthal, S., and Strange, W. (2004): Evidence on the nature and sources of agglomeration economies, in V. Henderson, and J. Thisse (eds.): *Handbook of Regional and Urban Economics*, 4: 2119-2171

Stokes, D. E. (1997): *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington: Brookings Institution Press

Storper, M. (1997): *The regional world*. London: Guilford Press

Stuart, T.E., and Sorenson, O. (2007): Strategic networks and entrepreneurial ventures, *Strategic Entrepreneurship Journal 1*(3-4): 211-227

Taylor, M.Z. (2009): International linkages and national innovation rates: an exploratory probe, *Review of Policy Research 26*(1-2): 127-149

Van Raan, A. F. J. (2004): Measuring science , in Moed, H. F., Glänzel, W. & Schmoch, U. (eds), Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems, Dordrecht: Kluwer Academic Publishers, pp. 19-50

Varga, A. (1999): *Time-space patterns of US innovation: stability or change? A detailed analysis based on patent data.* In Fischer, Manfred, Louis Suarez-Villa and Michael Steiner (eds) Innovation, Networks and Localities, Springer, Berlin, 215-234

Varga, A. (2000): Local academic knowledge transfers and the concentration of economic activity, *Journal of Regional Science 40*(2): 289-309

Varga, A. (2001): Universities and regional economic development: does agglomeration matter?, in B. Johansson, C. Karlsson and R. Stough (eds.): *Theories of Endogenous Regional Growth – Lessons for Regional Policies*, Berlin: Springer, 345-367

Varga, A. (2006): The spatial dimension of innovation and growth: empirical research methodology and policy analysis, *European Planning Studies 9*: 1171-1186

Varga, A., Anselin, L. and Acs, Z. (2005): *Regional innovation in the US over space and time*. In Maier G, Sedlacek S (Eds.) Spillovers and Innovation: City, Environment, and the Economy. Interdisciplinary Studies in Economics and Management. Springer, Wien, New York 93-104

Varga, A., and Parag, A. (2009): Academic knowledge transfers and the structure of international research networks, in A. Varga (ed.): *Universities and Regional Development*. Cheltenham: Edward Elgar, 138-159

Varsakelis, N.C. (2006): Education, political institutions and innovative activity: a cross-country empirical investigation, *Research Policy 35*: 1083-1090

Wagner, C.S., and Leydesdorff, L. (2005): Network structure, self-organization, and the growth of international collaboration in science, *Research Policy 34*(10): 1608-1618

White, H.C. (1992): *Identity and Control*. Princeton: Princeton University Press

Zucker L.G. Darby, M.R.,Furner, J., Liu R.C. and Ma, H. (2007): Minerva unbound: Knowledge stocks, knowledge flows and new knowledge production, *Research Policy*, Vol. 36, No. 6, pp. 850-863

## Appendix 1: Descriptive Statistics

| *Variable* | *Mean* | *S.D. (overall)* | *S.D. (between)* | *S.D. (within)* | *Min* | *Max* | *n* |
|---|---|---|---|---|---|---|---|
| PAT | 318.4363 | 536.1444 | 535.7374 | 38.08507 | 0.01 | 3460.89 | 567 |
| PUB | 1921.995 | 2531.388 | 2528.203 | 196.7256 | 1 | 22022 | 567 |
| GRD | 693.127 | 1169.854 | 1170.091 | 65.43073 | 1 | 11436 | 567 |
| PSTCK | 27429.94 | 33173.6 | 33045.87 | 3509.518 | 6 | 98481 | 567 |
| EMPKI | 346197.6 | 364772.9 | 365110.3 | 14992.06 | 2696 | 2552324 | 567 |
| $\delta$ | 0.968575 | 0.293157 | 0.291911 | 0.032097 | 0.275 | 1.982 | 567 |
| NET | 781.1124 | 229.4251 | 229.724 | 7.015673 | 55.167 | 1045.984 | 567 |
| PATCORE | 0.275132 | 0.446975 | | | 0 | 1 | 567 |
| RDCORE | 0.291005 | 0.454627 | | | 0 | 1 | 567 |
| PUBCORE | 0.349206 | 0.47714 | | | 0 | 1 | 567 |
| PATHCORE | 0.10582 | 0.307879 | | | 0 | 1 | 567 |
| RDHCORE | 0.10582 | 0.307879 | | | 0 | 1 | 567 |
| PUBHCORE | 0.10582 | 0.307879 | | | 0 | 1 | 567 |
| BPAT98 | 0.649286 | 0.034698 | | | 0.52492 | 0.72627 | 189 |
| BPUB98 | 0.754445 | 0.090864 | | | 0.46707 | 0.85308 | 189 |

# Appendix 2: List of regions

| NUTS Code | Region | NUTS Code | Region |
|---|---|---|---|
| AT11 | Burgenland | DE26 | Unterfranken |
| AT12 | Niederösterreich | DE27 | Schwaben |
| AT13 | Wien | DE30 | Berlin |
| AT21 | Kärnten | DE4 | Brandenburg |
| AT22 | Steiermark | DE50 | Bremen |
| AT31 | Oberösterreich | DE60 | Hamburg |
| AT32 | Salzburg | DE71 | Darmstadt |
| AT33 | Tirol | DE72 | Gießen |
| AT34 | Vorarlberg | DE73 | Kassel |
| BE1 | Région de Bruxelles-Capitale | DE80 | Mecklenburg-Vorpommern |
| BE2 | Prov. Antwerpen | DE91 | Braunschweig |
| BE3 | Prov. Brabant Wallon | DE92 | Hannover |
| CY00 | Kypros / Kibris | DE93 | Lüneburg |
| CZ01 | Praha | DE94 | Weser-Ems |
| CZ02 | Střední Čechy | DEA1 | Düsseldorf |
| CZ03 | Jihozápad | DEA2 | Köln |
| CZ04 | Severozápad | DEA3 | Münster |
| CZ05 | Severovýchod | DEA4 | Detmold |
| CZ06 | Jihovýchod | DEA5 | Arnsberg |
| CZ07 | Střední Morava | DEB1 | Koblenz |
| CZ08 | Moravskoslezsko | DEB2 | Trier |
| DE11 | Stuttgart | DEB3 | Rheinhessen-Pfalz |
| DE12 | Karlsruhe | DEC0 | Saarland |
| DE13 | Freiburg | DED1 | Chemnitz |
| DE14 | Tübingen | DED2 | Dresden |
| DE21 | Oberbayern | DED3 | Leipzig |
| DE22 | Niederbayern | DEE | Sachsen-Anhalt |
| DE23 | Oberpfalz | DEF0 | Schleswig-Holstein |
| DE24 | Oberfranken | DEG0 | Thüringen |
| DE25 | Mittelfranken | DK00 | Danmark |
| | | | |
| EE00 | Eesti | FR41 | Lorraine |
| ES11 | Galicia | FR42 | Alsace |
| ES12 | Principado de Asturias | FR43 | Franche-Comté |
| ES13 | Cantabria | FR51 | Pays de la Loire |
| ES21 | País Vasco | FR52 | Bretagne |
| ES22 | Comunidad Foral de Navarra | FR53 | Poitou-Charentes |
| ES23 | La Rioja | FR61 | Aquitaine |

| | | | |
|---|---|---|---|
| ES24 | Aragón | FR62 | Midi-Pyrénées |
| ES30 | Comunidad de Madrid | FR63 | Limousin |
| ES41 | Castilla y León | FR71 | Rhône-Alpes |
| ES42 | Castilla-La Mancha | FR72 | Auvergne |
| ES43 | Extremadura | FR81 | Languedoc-Roussillon |
| ES51 | Cataluña | FR82 | Provence-Alpes-Côte d'Azur |
| ES52 | Comunidad Valenciana | FR83 | Corse |
| ES53 | Illes Balears | GR11 | Anatoliki Makedonia, Thraki |
| ES61 | Andalucía | GR12 | Kentriki Makedonia |
| ES62 | Región de Murcia | GR13 | Dytiki Makedonia |
| FI13 | Itä-Suomi | GR14 | Thessalia |
| FI18 | Etelä-Suomi | GR21 | Ipeiros |
| FI19 | Länsi-Suomi | GR23 | Dytiki Ellada |
| FI1A | Pohjois-Suomi | GR24 | Sterea Ellada |
| FI20 | Åland | GR25 | Peloponnisos |
| FR10 | Île de France | GR30 | Attiki |
| FR21 | Champagne-Ardenne | GR42 | Notio Aigaio |
| FR22 | Picardie | GR43 | Kriti |
| FR23 | Haute-Normandie | HU10 | Közép-Magyarország |
| FR24 | Centre | HU21 | Közép-Dunántúl |
| FR25 | Basse-Normandie | HU22 | Nyugat-Dunántúl |
| FR26 | Bourgogne | HU23 | Dél-Dunántúl |
| FR30 | Nord - Pas-de-Calais | HU31 | Észak-Magyarország |
| HU32 | Észak-Alföld | NL13 | Drenthe |
| HU33 | Dél-Alföld | NL21 | Overijssel |
| IE | Ireland | NL22 | Gelderland |
| ITC1 | Piemonte | NL23 | Flevoland |
| ITC2 | Valle d'Aosta/Vallée d'Aoste | NL31 | Utrecht |
| ITC3 | Liguria | NL32 | Noord-Holland |
| ITC4 | Lombardia | NL33 | Zuid-Holland |
| ITD1 | Provincia Autonoma Bolzano/Bozen | NL34 | Zeeland |
| ITD2 | Provincia Autonoma Trento | NL41 | Noord-Brabant |
| ITD3 | Veneto | NL42 | Limburg (NL) |
| ITD4 | Friuli-Venezia Giulia | PT11 | Norte |
| ITD5 | Emilia-Romagna | PT15 | Algarve |
| ITE1 | Toscana | PT16 | Centro (P) |
| ITE2 | Umbria | PT17 | Lisboa |
| ITE3 | Marche | PT18 | Alentejo |
| ITE4 | Lazio | SE01 | Stockholm |
| ITF1 | Abruzzo | SE02 | Östra Mellansverige |
| ITF2 | Molise | SE04 | Sydsverige |

| | | | |
|---|---|---|---|
| ITF3 | Campania | SE06 | Norra Mellansverige |
| ITF4 | Puglia | SE07 | Mellersta Norrland |
| ITF5 | Basilicata | SE08 | Övre Norrland |
| ITF6 | Calabria | SE09 | Småland med öarna |
| ITG1 | Sicilia | SE0A | Västsverige |
| ITG2 | Sardegna | SK01 | Bratislavský kraj |
| LT00 | Lietuva | SK02 | Západné Slovensko |
| LU00 | Luxembourg (Grand-Duché) | SK03 | Stredné Slovensko |
| LV00 | Latvija | SK04 | Východné Slovensko |
| MT00 | Malta | UKC | Northumberland and Tyne and Wear |
| NL11 | Groningen | UKD | Cumbria |
| NL12 | Friesland | UKE | West Yorkshire |
| UKF | Lincolnshire | | |
| UKG | Shropshire and Staffordshire | | |
| UKH | East Anglia | | |
| UKI | Inner London | | |
| UKJ | Surrey, East and West Sussex | | |
| UKK | Cornwall and Isles of Scilly | | |
| UKL | West Wales and The Valleys | | |
| UKM | Eastern Scotland | | |
| UKN | Northern Ireland | | |

## A KRTI eddig megjelent műhelytanulmányai

**Varga Attila:** From the geography of innovation to development policy analysis: The GMR-approach (2007/1)

**Bessenyei István:** Növekedési pólusok a térben és a társadalomban (2007/2)

**Darvas Zsolt - Schepp Zoltán:** Kelet-közép-európai devizaárfolyamok előrejelzése határidős árfolyamok segítségével (2007/3)

**Varga Attila:** GMR-Hungary: A Complex Macro-Regional Model for the Analysis of Development Policy Impacts on the Hungarian Economy (2007/4)

**Reiff Ádám - Zsibók Zsuzsanna:** Az infláció és az árazási magatartás regionális jellemzői Magyarországon, mikroszintű adatok alapján (2008/1)

**Varga Attila - Parag Andrea:** Egyetemi tudástranszfer és a nemzetközi kutatási hálózatok szerkezete (2008/2)

**Schepp Zoltán - Szabó Zoltán:** Felsőoktatás-politika és állami finanszírozás: a 2007. évi felvételi tanulságai a gazdaságtudományi alapképzésben (2008/3)

**Kaposi Zoltán:** Város és agrárrendszer a polgárosodás korában (1850-1914) (a mezőgazdaság változásai Nagykanizsán) (2008/4)

**Barancsuk János:** Néhány gondolat az „árelfogadó” és „ármeghatározó” fogalmak jelentéséről (2009/1)

**Kiss Gy. Kálmán:** A szövetkezeti bank megteremtésének kísérlete Magyarországon (2009/2)

**Zeller Gyula:** Létezik-e a Smith probléma, avagy mennyire egységesek Adam Smith nézetei? (2009/3)

**Járosi Péter - Atsushi Koike - Mark Thissen - Varga Attila:** Regionális fejlesztéspolitikai hatáselemzés térbeli számítható általános egyensúlyi modellel: a GMR-Magyarország SCGE modellje (2009/4)

**Mellár Tamás:** Felemás magyar modernizáció (2009/5)

**Szabó Zoltán:** Az új paternalizmus: a nem-racionális hitelfelvevői magatartás és a túlzott eladósodás néhány gazdasági viselkedéstani összefüggése (2009/6)

**Erdős Katalin-Varga Attila:** Az egyetemi vállalkozó: legenda vagy valóság az európai regionális fejlődés elősegítésére? (2009/7)

**Sebestyén Tamás:** Innovation and Diversity in a Dynamic Knowledge Network. (2010/1)

**Mellár Tamás:** Válaszút előtt a makroökonómia? (2010/2)

**Attila Varga- Dimitrios Pontikakis- George Chorafakis:** Agglomeration and interregional network effects on European R&D productivity (2010/3)