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The Effects of R&D on Regional Invention and Innovation

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This paper examines the effects of regional R&D on patenting for Sweden within an accessibility framework. We use two measures of patenting: number of patents granted per capita and a composite of quality-adjusted patents which we regard as an innovation indicator, respectively. Three conclusions emerge. First, we find that the specification where innovations per capita is used as a dependent variable performs much better than with granted patents per capita for capturing relationships with regional R&D. In fact, quantile regressions over the distribution of different patenting and innovation levels per capita show that R&D efforts within regions affect innovations per capita positively, except for the regions with the lowest levels of R&D. The effects on granted patents per capita are less robust and depend inconsistently on the level of R&D. Secondly, accessibility to inter-regional R&D do not affect innovation significantly in our results, which suggests that effects are locally bounded. This implies that studies of the R&D-innovation relationship are plagued by misspecification, since studies tend to show that R&D-effects diffuse to other regions. This is also the case in our study; the inter-regional effects are an important factor for granted patents. Third, the share of university R&D of all regional R&D has no effect on patenting, which suggests that the two types of R&D are substitutes. In view of these results the recommendation must be to use quality-adjusted patents for regional innovation studies rather than patent grants.

Keywords: R&D, patenting, innovations, regions, spatial dependence.

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Olof Ejermo[1] and Urban Gråsjö[2]

Abstract

This paper examines the effects of regional R&D on patenting for Sweden within an accessibility framework. We use two measures of patenting: number of patents granted per capita and a composite of quality-adjusted patents which we regard as an innovation indicator, respectively. Three conclusions emerge. First, we find that the specification where innovations per capita is used as a dependent variable performs much better than with granted patents per capita for capturing relationships with regional R&D. In fact, quantile regressions over the distribution of different patenting and innovation levels per capita show that R&D efforts within regions affect innovations per capita positively, except for the regions with the lowest levels of R&D. The effects on granted patents per capita are less robust and depend inconsistently on the level of R&D. Secondly, accessibility to inter-regional R&D do not affect innovation significantly in our results, which suggests that effects are locally bounded. This implies that studies of the R&D-innovation relationship are plagued by misspecification, since studies tend to show that R&D-effects diffuse to other regions. This is also the case in our study; the inter-regional effects are an important factor for granted patents. Third, the share of university R&D of all regional R&D has no effect on patenting, which suggests that the two types of R&D are substitutes. In view of these results the recommendation must be to use quality-adjusted patents for regional innovation studies rather than patent grants.

Keywords: R&D, patenting, innovations, regions, spatial dependence.

Introduction

Innovation and inventive activity are measured in various ways.[3] Yet their geographical importance is not well known. Specific attention in the literature has been given two spatial aspects on innovation. First, its distribution has been examined. Here it is quite established that innovation tends to concentrate more than production. Secondly, the effect of regional R&D on innovation output has been examined. It is generally observed that knowledge activities have public good properties (Geroski, 1995), i.e. they may only imperfectly be appropriated by its producers and hence tends to diffuse and be used others. The third aspect of knowledge in space examinations concern the extent to which knowledge tends to spill over to the environment, i.e. its spatial reach and which sets of industries it spills over to.

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[3] An overview of pros and cons of innovation measures is given by Smith (2005).

The most common indicators of invention and innovation indicators are R&D and patents applied or alternatively granted patents. Given the alleged importance given to patent data as innovation indicators, this paper will take a step back to use a more qualified measure of innovation based on quality-adjusted patents. It uses a measure of innovations based on a composite index of quality indicators. The paper makes extensive use of databases developed in Ejermo (2004) to map patents to Swedish regions. This material was updated and improved in Ejermo (2007) to consider also the quality of patents.

The paper continues as follows. The next section gives an overview of the literature on the effects of R&D on patenting and innovation on the regional level, we continue by discussing in-depth our dataset for which has followed a series of progressions over time. In particular, we show how adding quality-adjustments to patents render them to be an innovation indicator. We then discuss how the interrelationships between knowledge resources can be modeled in geographical settings using an accessibility framework and specify our empirical model. We continue by estimating our model and discuss our results. Specific attention is given spatial autocorrelation and stability of parameters across different values of the dependent variables. Finally, we summarize the paper.

Literature review

It is a common observation that knowledge activities tend to be agglomerated, i.e. to be clustered and in particular in large urban regions. Large urban regions offer proximity advantages, which ease knowledge transfusion among economic actors (Vernon, 1962, Glaeser, 1999, Feldman and Audretsch, 1999) and create a proximity-based communication externality (Fujita and Thisse, 2002). In the last decades, there have been a number of empirical studies that explore the geographic aspects of knowledge spillovers and the localized relationships between private and university R&D and innovative firms.[4] The framework for analyzing the importance of knowledge and knowledge spillovers on innovative activity is usually based on the knowledge production function (KPF) of Griliches (1979).[5] Jaffe (1989) used a modified version when he introduced a geographical coincidence index between public and private sector research in the KPF setup. He found a strong relationship between corporate lab patenting and university research in the areas drugs, chemicals and electronics. Furthermore, it seemed that industrial R&D was stimulated by the presence of university research. Similar studies applying the KPF approach include Acs et al. (1992, 1994), Anselin et al. (1997, 2000), Autant-Bernard (2001) Fischer and Varga (2003) and Bottazzi and Peri (2003).

[4] Besides geographical proximity, several authors (Piore and Sabel, 1984) argue that cultural proximity, i.e. the sharing of the same norms and values, is an important factor in when sensitive valuable information is exchanged (for instance in a joint innovation project).

[5] Using the analytical distinction of Feldman (1999), it is possible to categorize studies of knowledge effects in regions into four tracks: (i) geographic knowledge production functions, (ii) paper trails left in patent citations, (iii) ideas in people or (iv) ideas in goods. Since this is a ‘KPF paper’, the focus in this section is on previous KPF studies.

Acs et al. (1992) examine how different industries respond to the R&D-innovation relationship using the US small business administration innovation database for 1982, compared with Jaffe's (1989) (1989) patent exercise. Using the same database, Acs et al. (1994) find that small businesses innovate more relative to their (negligible) R&D efforts, seemingly through their greater abilitiy to assimilate knowledge from research institutions and larger corporations than larger firms. Anselin et al. (1997) study the degree of spatial spillovers between university research and high technology innovations, by applying the KPF approach at the level of both the state and the metropolitan statistical areas (MSA) in the US. They found evidence of local externalities between university research and high-technology innovations.

Anselin et al. (2000) implemented an approach on US data to formalize spatial externalities by combining spatial dependence and spatial heterogeneity in spatial regimes. They separate between "connected" and "isolated" MSAs, i.e. MSAs that are within or beyond a given distance threshold. Thus, the geographic reach of the knowledge spillovers is linked to a distance decay effect. Fischer and Varga (2003) also found evidence of a spatial decay effect, when they examined spillovers of knowledge from universities on patent application activity in 1993. Their sample consisted of firms belonging to one of six technology classes in 99 political units in Austria. Autant-Bernard (2001) and Bottazzi and Peri (2003) compare different geographical levels, by introducing external research stock occurring on the periphery of a particular area. A geographical area's innovation capacity is therefore related to internal R&D effort but also to spillovers flowing from research activities in neighbouring areas.

In a critical paper, Breschi and Lissoni (2001) argue that many empirical studies employing the popular knowledge production function to test for the existence of knowledge spillovers are not capable of explaining the underlying mechanisms that generate them. They maintain that the standard line of argument[6] used to explain the results of such studies would imply that knowledge that diffuses is a pure externality. The authors go on to conclude that a more careful scrutiny might reveal that it is actually pecuniary (rent) externalities, i.e. involuntary knowledge flows mediated by market mechanisms, or even managed knowledge flows with intentional appropriation purposes that matter.

A core definition when it comes to determine the reach of knowledge spillovers is that of functional region. Functional regions are based on the spatial interaction patterns of economic agents in a country. They are characterized by their density of economic activities, social opportunities and interaction options (Ciccone and Hall, 1996, Johansson, 1997). Density is a positive factor for the individual firm since it creates accessibility to suppliers, potential buyers and other actors. Accessibility is obtained by a combination of density and infrastructure, which facilitates particularly high factor mobility within the functional region's border. Disregarding fixed resources such as land and natural resources the major factor that

[6] Namely that knowledge that spills over is a pure public good (non-excludable and non-rival) but that it is essentially local since transmission demands spatial proximity.

sets the spatial border of a functional region usually is the labor force and its propensity to commute. The geographical interaction costs between different market places for work are for households, in principle, equal to the total costs for moving between market places, that is, between different labor markets. Earlier studies dealing with spatial knowledge spillovers have normally been based on a division in administrative regions, which do not need to be functional regions.

Despite the well-known fact that knowledge tends to spill over in space, there have been very few attempts to model the spillovers in continuous space. The reach of the spillovers from the knowledge source is often modeled with geographical concentric rings with distances reported in kilometers or even simpler with next neighbors. As an alternative, this study elaborates with an accessibility approach as an instrument to discount the spillover effects spatially. Gråsjö (2006) used this approach when he examined to what extent accessibility to university R&D and company R&D can explain patent production in Swedish municipalities. The empirical findings indicated that investments in company R&D have a positive impact on the patenting capacity in a municipality. However, there was no evidence that university R&D affects patent production. In accordance with the literature, the results also showed that spatial proximity matters for establishing a productive link between R&D efforts and the number of patent applications. Hence, knowledge flows transcend municipal borders, but tend to be bounded within functional regions.

Data

The most common inventive indicators are R&D and patent data. R&D data are a measure of input into innovation processes. However, they only imperfectly reflect innovation inputs. Branches with less formal innovation processes such as service sectors may have little connection with R&D, at least directly. Nevertheless, R&D is an important input into innovation processes in general (Freeman and Soete, 1997) and certainly important for industries with ample patenting. R&D data is to some extent available regionally, but sometimes knowledge about its location whereabouts is hampered by the so-called 'singapore effect', which refers to the possibility that R&D is registered at headquarters rather than where it is actively pursued. In the Swedish case, data on university R&D is given by Statistics Sweden on the county level. Business R&D is registered at head offices, but efforts made in Ejermo (2004) has allowed for data about the distribution of business and university R&D on finer levels, for local labor market regions and municipalities. This paper uses R&D in 72 Swedish regions. There are alternative measures for R&D given by Community Innovation Survey (CIS) data, such as innovation expenditures which is inclusive of R&D but broader. CIS data also show innovation results such as share of firms with product or process innovations or turnover due to product or process innovations. Unfortunately, CIS data are only given for very broad large NUTS2-regions. Internationally, there are few alternatives to R&D, patenting and CIS data. One important exception was given by Small Business Administration (SBA) data from 1982, used extensively by Zoltan Acs and David Audretsch and associates in a number of papers (e.g. Acs et al., 1992, 1994). This data show innovations as collected from trade journals and evaluated by experts. In Acs et al. (2002) the geographical distribution of these innovations is compared with patenting in Metropolitan Statistical Areas. The correlation was found to be around 0.7. This shows that patenting to a large extent may substitute for innovation.

The use of an innovation index

We use a different measure of innovation to examine if regional R&D has a differential effect on patenting and innovations. Innovations are measured by a composite index of quality indicators.

Roughly 99 % of patents granted at the European Patent Office (EPO) with at least one Swedish inventor were mapped to 72 Swedish regions in Ejermo (2007). Data were fractionalized based on the number of inventors listed on the patent.[7] Moreover, quality indicators of the granted patents were added. Many patents are never used for commercial purposes and have little value other than defensive, i.e. to hinder competitors from entering the market. In recent years, a number of contributions have been made which make patent data more useful as innovation indicators. In this spirit, Lanjouw and Schankerman (2004), Gambardella et al. (2005), Mariani and Romanelli (2006), 2006) and Hall et al. (2007) developed an index based on factor analysis that combined different quality indicators of patents into one. Lanjouw and Schankerman contended that their interpretation of this index was that it represented quality. Factor analysis uses the joint variation of the indicators to construct a component. We argue that it is nothing else than an innovation indicator, and will therefore refer to it as 'innovation'. The novelty of Ejermo (2007) was to use the innovation index in a regional setting and examine its consequences. That paper examined if the concentration changed when the innovation index was applied rather than just raw patent grants. It is well known from different indicators of innovation that innovation tends to cluster geographically more than production activities (e.g. Audretsch and Feldman, 1996, Kelly and Hageman, 1999, Ejermo, 2004). Ejermo (2007) found that the geographical concentration increased substantially using the innovation index. Moreover, the concentration of both patents granted and the innovation index increased over the examined period 1982-1999.

The innovation index consists of four indicators of quality: forward citations (*FCIT3)* – i.e. citations *to* a patent within three years from publication of the patent, backward citations (*BCIT*) – i.e. citations *made* by a patent, *FAMILY SIZE* – the number of countries protecting the same invention and *OPPOSITION* – whether a patent was opposed in European patent office proceedings. The rationale for these indicators are first, that number of citations to a patent shows that it has been useful for developing new technologies and possibly has had economic benefits. This is usually one of the definitions of an innovation indicator and usually considered to be a fundamental quality indicator for patents. The citations considered here are EPO and PCT-citations combined, since they are given according to the same praxis. Moreover, EPO- and PCT-citations to equivalent patents[8] are also counted, although they are

[7] For a patent with 1 inventor residing in the Gothenburg region, 1 in the Stockholm region and 1 in Denmark, Gothenburg gets 1/3 patent and Stockholm 1/3.

[8] Equivalent patents are those belonging to the same family such as a USPTO version of the EPO-patent considered.

not double-counted. That is, a patent A can cite patent B either in its EPO-version or a different (e.g. USPTO) version but the citation is only counted once. See OECD (2005) and Ejermo (2007) for further details. *BCIT* have a double role. On the one hand, a lot of backward citations show that a lot of technological activity is taking place, hence it signals technological opportunities and value. On the other hand, many backward citations may also indicate that the technological development is more derivative in nature. *FAMILY SIZE* shows that the patent was taken out in many countries and may indicate that the patent holders have large ambitions for marketing the product (or alternatively defend the patent) in many countries. Finally, a value of the variable *OPPOSITION* of 1 (0=no opposition) shows that the patent was considered worthwile to invalidate for competitors. Hence, it should be more valuable.

Although part of the variation in the different indicators may not be directly related to innovation, the combination of them gives a powerful intersection between variation that should be related to it. This is illustrated by the Venn diagrams given in Figure 1.

[Insert Figure 1 about here]

The hatched area shows the common variation. Even though some of the variation in e.g. *BCIT* is not related to innovation, it is not likely to be included in the joint variation and hence not captured by the indicator.

More technically[9], the indicators *FCIT3, BCIT, FAMSIZE* and *OPPOSITION* were regressed on yearly time dummies:

$$(1) \qquad y_{ki} = \sum_t \beta_t D_{ti} + u_{ki},$$

where i refers to the ith observation, y_{ki} is the kth indicator in logs and D_{ti} are dummy variables for each year t.

The residuals of the four indicators, u_{ki}, are then used to form a component according to:

$$(2) \qquad u_{ki} = \lambda_k q_i + \varepsilon_{ki},$$

where q_i is the component normalized to have unit mean and zero variance, λ_k are loading factors. The covariance matrix of the residuals is written:

$$(3) \qquad \Lambda = E[yy'] = \lambda\lambda' + \Phi$$

The matrix Φ represents the covariance between the ε terms. It is assumed diagonal. The common component is estimated by iterated principal-factoring which involves estimating the parameters λ_k and σ_k^2 that makes the theoretical covariance matrix as closely as possible resemble the observed correlation structure. The commonly used criteria in factor analysis is

[9] The technical description draws heavily from Ejermo (2007).

to retain those factors whose eigenvalues exceed one. For all factor analyses this criterion implied that one factor was chosen.

The quality component is given by:

$$E[\mathbf{q} \mid \mathbf{y}] = \boldsymbol{\lambda}'\boldsymbol{\Lambda}^{-1}\boldsymbol{\lambda} \quad (4)$$

Since we have logged our indicators, the antilogs of the above calculated values were used to form the innovation indicator.

Descriptive data

The geographical concentration of R&D and patent data is depicted in Figure 2, which shows the Lorenz curve distribution over 72 Swedish regions. This figure clearly shows that quality-adjusted patent grants (innovation) has the highest concentration, followed by university R&D, business R&D and granted patents.

[Insert Figure 2 about here]

The geographical distribution of granted patents and innovation is moreover shown on maps in Figure 3-Figure 4

[Insert Figure 3 about here]

[Insert Figure 4 about here]

Both maps show a strong concentration of patents granted per capita and innovation per capita to the largest regions Stockholm, Gothenburg and Malmö, though innovations per capita are even more concentrated than patent granted per capita. Summary statistics of the variables are given in Table 1 and Table 2 shows the correlation matrix of the average of the patent variables 1994-1999 and the R&D variables 1993-1999.

[Insert Table 1 about here]

[Insert Table 2 about here]

Modelling accessibility to knowledge resources

The accessibility concept

Most of the current Geographic Information Systems (GIS) functionality assumes that the entities in a spatial system can be expressed as coordinates in a Euclidean plane. That is, they all have coordinates positioning them with respect to a predetermined reference frame. However, representation in a Euclidean space is not always the most appropriate model (e.g. travel time distance and qualitative distances). The majority of the studies in the literature apply distances measured in kilometres in order to discount knowledge flows spatially.

However, if data are available, it is always better to use actual travel time between locations (Beckmann, 2000). Time distances takes differences in regional infrastructure into account. The inability to reveal such disparities is a major drawback of conventional geographical distance. Time distances are also crucial when it comes to attend to business meetings and to determine the spatial borders of labour markets (Johansson and Klaesson, 2001).

One way of modelling spatial knowledge spillovers is to use an accessibility indicator, which almost always expresses a "mass of attraction" discounted by the difficulty of reaching it (e.g. in terms of money, time distance or physical distance). The "mass of attraction" in knowledge spillovers is for instance the amount of R&D conducted at a location Hansen (1959, p. 73) argued that accessibility can be seen as the "potential of opportunities for interaction". A wide variety of ways to measure accessibility can be found in the literature. The one used in this paper can be referred to a class called gravity-based measures (see e.g. Handy and Niemeier, 1997 , or Baradaran and Ramjerdi, 2001). Equation (5) shows a general form for the gravity-based measures.

$$(5) \qquad A_i = \sum_{j \in L} O_j f(t_{ij}, \lambda),$$

where A_i is the accessibility in location i, L is a set of locations (e.g. a region or a country), O_j represents the mass of opportunities available (regardless of if they are chosen or not). $f(t_{ij}, \lambda)$ is the distance discounting function (other names are distance decay, impedance or friction function). t_{ij} is a variable that represents cost (e.g. time distance) between location i and j, and λ is the cost parameter usually estimated from a destination choice model (see Johansson et al., 2002, for the Swedish case).

There are several advantages of using an accessibility measure like the one in Equation (5) to model knowledge flows. Accessibility provides a connection between the functional and the spatial component of an urban system (Bertuglia and Occelli, 2000). It defines the range and temporal organization of economic opportunities available in space as well the cost of overcoming space in order to explore the opportunities in different locations. Accessibility accounts for the size of an opportunity in a location and discounts the value of the opportunity with time distance in a way that reflects the willingness to explore that opportunity given its size and distance. Accessibility is also a robust operational measurement tool which makes spatial proximity operational (Karlsson and Manduchi, 2001).[10]

In this study, the set L, Sweden, is divided into several subsets, functional regions, i. The opportunities O_j are conducted R&D in region j. The distance discounting function, $f(t_{ij}, \lambda)$, is a negative exponential function and t_{ij} is travel time between region i and j.[11] Besides

[10] The accessibility approach has, beside the authors, been used and further developed by several scholars at Jönköping International Business School (JIBS), see e.g. Johansson et al. (2002, 2003); Andersson and Karlsson (2004, 2005); Karlsson and Pettersson (2005).

[11] The negative exponential function, $e^{-\lambda t}$, of distance or travel time is closely tied to travel behaviour theory and often produces good results when compared with other measures (Handy and Niemeier, 1997, Kwan, 1998, Song, 1996). Several other forms of distance decay functions have been used in accessibility studies. An inverse

calculating accessibility values between different regions, it is also possible to express an intra-regional accessibility with travel time t_{ii}. Hence, for a region i we have the following total accessibility

$$(6) \qquad A_i = O_i e^{-\lambda_1 t_{ii}} + \sum_j O_j e^{-\lambda_2 t_{ij}}$$

The distance discounting functions ($e^{-\lambda_1 t_{ii}}$ and $e^{-\lambda_2 t_{ij}}$) in (6) have merited special consideration.[12] It consists of weighed travel times between and within functional regions. We use the fact that each region consists of a number of municipalities, for which we have road travel times for travelling between and within all Sweden's municipalities. Thus, a *number* of road travel times exist *within* each region and also *for each pair* of regions. We use commuting as weights of these possibilities such that:

$$(7) \qquad \lambda_1 t_{ii} = \frac{\sum_r M_{rr} \lambda_L t_{rr} + \sum_r \sum_s M_{rs} \lambda_R t_{rs}}{\sum_r \sum_s M_{rs}}, \qquad r, s \in i$$

and

$$(8) \qquad \lambda_2 t_{ij} = \frac{\sum_r \sum_k M_{rk} \lambda_X t_{rk}}{\sum_r \sum_k M_{rk}}, \qquad r \in i, \quad k \in j,$$

where M_{rr} = number of commuters within municipality *r,* M_{rs} = number of commuters between municipality *r* and *s* (in region *i*), M_{rk} = number of commuters between municipality *r* (in region *i*) and *k* (in region *j*), t_{rr} = commuting time within municipality *r,* t_{rs} = commuting time between municipality *r* and *s,* t_{rk} = commuting time between municipality *r* and *k,* λ_L = local cost parameter for travels within a municipality, λ_R = intra-regional cost parameter for travels between municipalities within a region, λ_X = inter-regional cost parameter for travels between municipalities located in separate regions.

The cost parameter takes three different values (λ_L =0.025, λ_R = 0.096 and λ_X =0.050) depending on the spatial level.[13] It may look strange that the intra-regional accessibilities have the highest parameter value. But the intra-regional commuting trips, which are in the time span from approximately 15 to 45 minutes, are the ones that are most time sensitive. That is, increased commuting time in this time span will hold back the propensity to travel the most.

Thus, $\lambda_1 t_{ii}$ and $\lambda_2 t_{ij}$ are the most representative commuting road travel time within region *i* and between region *i* and *j*, respectively. If the two terms on the right hand side in (6) are used

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power function, $c^{-\alpha}$, was for example been used by Hansen (1959). Ingram (1971) used a modified version of the Gaussian function, $e^{-d^2/v}$.

[12] This approach was used originally in Ejermo and Karlsson (2006).

[13] Johansson et al. (2003) estimated these cost (or time sensitivity) parameters by using data on commuting flows within and between Swedish municipalities in 1990 and 1998.

separately in a knowledge production function as explanatory variables, it is possible to identify potentially important intra-regional and inter-regional knowledge flows.[14]

Empirical model

To compare to what extent R&D explains granted patents and innovations in Swedish municipalities, the following model is estimated:

$$(4) \qquad Y_i = a + b_1 A_{ii} + b_2 S_{ii}^{uni} + b_3 A_{ij}^{*} + b_4 S_{ij}^{uni*} + b_5 S_i^{agr} + b_6 S_i^{pub} + u_i,$$

where the dependent variable Y_i is patents granted per capita and innovations per capita in the estimated Models (1)-(2), A_{ii} is intraregional accessibility to total, business and university R&D combined, S_{ii}^{uni} is the share of intraregional accessibility that comes from university R&D, A_{ij}^{*} is interregional accessibility to total R&D and S_{ij}^{uni*} is the share interregional accessibility coming from university R&D. Moreover we include the share of employees in primary, S_i^{agr}, and the public sector S_i^{pub} as control variables.[15,16]

Regression results

Least squares regressions

Estimation results are shown in Table 3. Total intra-regional accessibility to R&D affects positively and strongly significantly the number of granted patents per capita and innovations per capita. The share of university R&D has no effect on patenting regardless of specification. This means that in this setting, R&D can be used as a substitute between business and university R&D. Moreover, interregional accessibility to R&D only affects patenting in Model 1, granted patents per capita. At the same time, the share of interregional accessibility to university R&D has no effect on patenting.

[Insert Table 3 about here]

As expected, the share of employees in primary sectors and public sectors have a negative influence on the results. However, the parameter estimates are only statistically significant (10 percent level) for primary sector. The model is much better explained, R^2 is 0.95, when innovations per capita is used. It is 'only' 0.55 with grants per capita.

Table 3 also shows the results of spatial autocorrelation tests. The results show that spatial autocorrelation is not a problem in this setup.

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[14] An example of how to interpret the marginal effects of accessibility variables is given in Appendix.

[15] The per capita measure is per 100 000 inhabitants.

[16] First, we included the share of employees with higher education, S_i^{edu}. This variable was highly correlated with intraregional accessibility to R&D, and in the end we decided to drop this variable from our model specifications.

Quantile regressions

It is a reasonable assumption that R&D does not affect patent production and innovation homogenously across regions. In order to empirically assess this, we analyze the heterogeneity among regions with the quantile regression technique (Koenker and Bassett, 1978). With the use of this method we investigate how the impact R&D varies among regions at different levels of the dependent variables. The main advantage with the quantile regression technique is its semi-parametric nature, which relaxes the restrictions on the parameters to be constant across the entire distribution of the dependent variables. An important motivation for quantile regression has been its inherent robustness to outlying observations in the response variable. The quantile regression estimator gives less weight to outliers of the dependent variable than least squares estimators.[17] Besides being robust to outliers, the technique is also robust to potential heteroscedasticity. This is achieved because the parameter estimates for the marginal effects of the explanatory variables are allowed to differ across the quantiles of the dependent variable.

Regressions are conducted for every fifth quantile (Q5, Q10, … , Q95) for all regions (n=64). The regressions results are presented graphically in Figure 5-Figure 6. In order to solve potential heteroscedasticity problems, bootstrap with 3,000 replications are conducted.[18] The 95% confidence band from bootstrapped estimation errors are shown as the shaded (grey) area. Consequently, given a specific quantile, if both the upper and the lower confidence limit are above zero, then the parameter estimate is positive and statistically significant.

[Insert Figure 5 about here]

In Figure 5 it can be observed that the intra-regional accessibility to R&D has a positive impact on granted patents per capita. However, the marginal effects are not statistically significant (5% level) for all regions (especially for the regions corresponding to the higher quantiles). Hence, it cannot be proven that local accessibility to R&D has an effect on the patenting capacity in the regions where the number of patents per capita is high. On the other hand, the inter-regional accessibility to R&D is positive and statistically significant for all conditional quantiles. The largest effect can be found for regions in the upper tail of the distribution of the dependent variable. The share of primary sector employees is also

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[17] The θth regression quantile of the dependent variable y is the solution to the minimization of the sum of absolute deviations residuals

$$\min_{\beta} \frac{1}{n}\left(\sum_{i:y_i \geq x_i'\beta} |y_i - x_i'\beta| \theta + \sum_{i:y < x_i'\beta} |y_i - x_i'\beta| (1-\theta) \right)$$

Different quantiles are estimated by weighing the residuals differently. For the median regression, all residuals receive equal weight. However, when estimating the 75th percentile, negative residuals are weighed by 0.25 and positive residuals by 0.75. The criterion is minimized, when 75 percent of the residuals are negative. In contrast to OLS, the equation above cannot be solved explicitly since the objective function is not differentiable at the origin, but it can be solved with linear programming (see e.g. Buchinsky, 1998).

[18] The standard errors are usually underestimated for data sets with heteroscedastic error distributions (Rogers, 1992). Therefore, standard errors will be obtained by bootstrapping the entire vector of observations (Gould, 1992). This procedure is automated in the STATA statistical package.

statistically significant for these regions, but insignificant for regions where the patenting per capita is lower. When innovations per capita are used as the dependent variable (Figure 6), it is only intra-regional accessibility to R&D that has a statistically significant impact. Here it is obvious that the marginal effects are increasing in magnitude; with the largest effects found in the regions corresponding to quantiles in the upper end of the distribution.

[Insert Figure 6 about here]

Conclusions

Much research has been done on the geographical reach of 'knowledge spillovers' and the majority of studies use R&D and patent data for measuring inventive and innovative activity. In this paper we find that some of the results from the literature may be sensitive to the use of patent as indicators of innovative activity. In particular we find after changing from granted patents per capita to innovations per capita as dependent variable, that the specification where we use innovations has a much higher explanatory power for the whole model than has grants. We have run quantile regressions to gauge the stability of estimated parameters. We find that a large part of the explanatory power rests in the fact that the estimated effect from intraregional R&D becomes much more stable and consistently significant over the range of values of the dependent variable as we use innovations. Similar to earlier studies, we find that interregional effects are an important explanatory factor for granted patents. However, when using innovations, interregional R&D no longer affects the dependent variable significantly, which suggests that the true effects on innovations are more locally bounded. This implies that studies of the R&D-innovation relationship may be plagued by misspecification. Finally, we find that the share of university R&D of all regional R&D has no effect on patenting, which suggests that the two types of R&D are substitutes. In view of these results the recommendation must be to use quality-adjusted patents for regional innovation studies rather than patent grants.

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Appendix

The marginal effect of the terms in (6) answers the question "What is the effect on the dependent variable if the accessibility to an opportunity (e.g. R&D) increases by 1?" The natural subsequent question is then: "How can an accessibility increase by 1 be accomplished?" The accessibility is affected by the size of the opportunity and commuting time within a region or between regions. Let us focus on the size of the opportunity and make the assumption that $\lambda_1 t_{ii} = 0.01 \cdot 30$ and $\lambda_2 t_{ij} = 0.05 \cdot 90$. With these values an intra-regional accessibility increase by 1 is accomplished if the opportunity increases by 1.35. The computation is straightforward and looks like this

$$\exp(-\lambda_1 t_{ii}) \Delta O_i = \exp(-0.01 \cdot 30) \cdot \Delta O_i = 1$$

and then solving for ΔO_i,

$$\Delta O_i = \frac{1}{\exp(-0.01 \cdot 30)} = 1.35$$

The corresponding calculation for the inter-regional accessibility is as follows

$$\exp(-\lambda_2 t_{ij}) \sum_j \Delta O_j = \exp(-0.05 \cdot 90) \cdot \sum_j \Delta O_j = 1$$

$$\sum_j \Delta O_j = \frac{1}{\exp(-0.05 \cdot 90)} = 90$$

Thus, if commuting time between region *i* and all other regions *j* is 90 minutes, then the sum of all opportunities in regions *j* has to increase by 90 in order to achieve an inter-regional accessibility increase by 1.

Tables and Figures

Figure 1. Venn diagram of the overlap between different indicators. The circles do not necessarily represent actual variation.

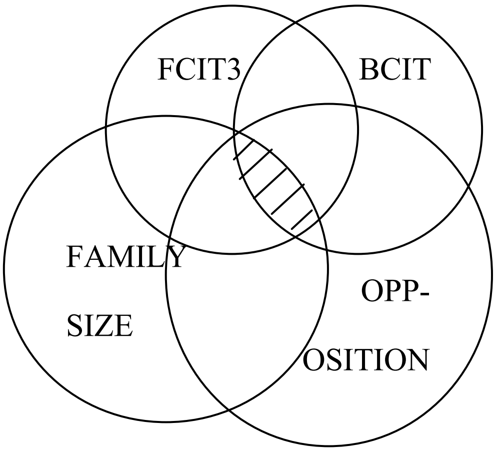

Figure 2. Lorenz curves of the distribution of innovation efforts and invention and innovation.

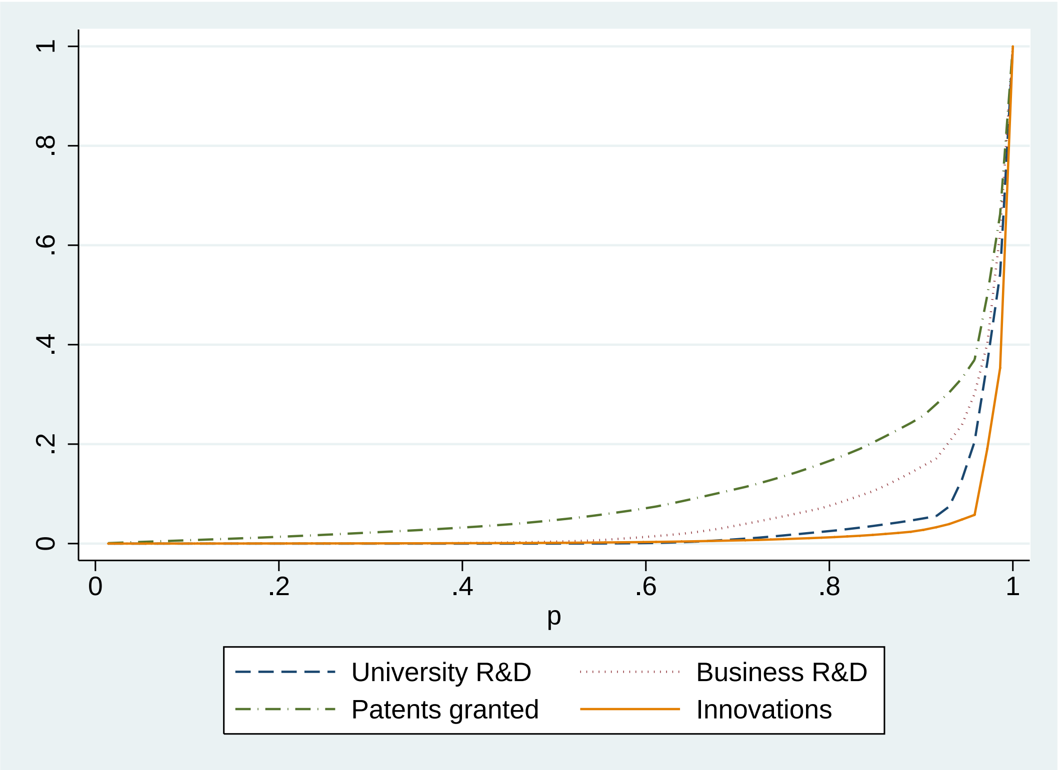

Figure 3. Granted patents per capita.

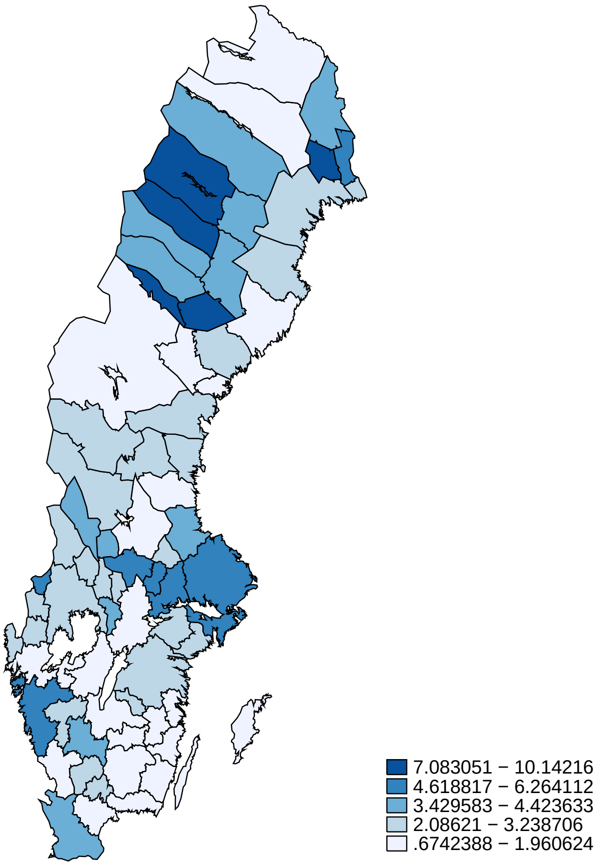

Figure 4. Innovations per capita.

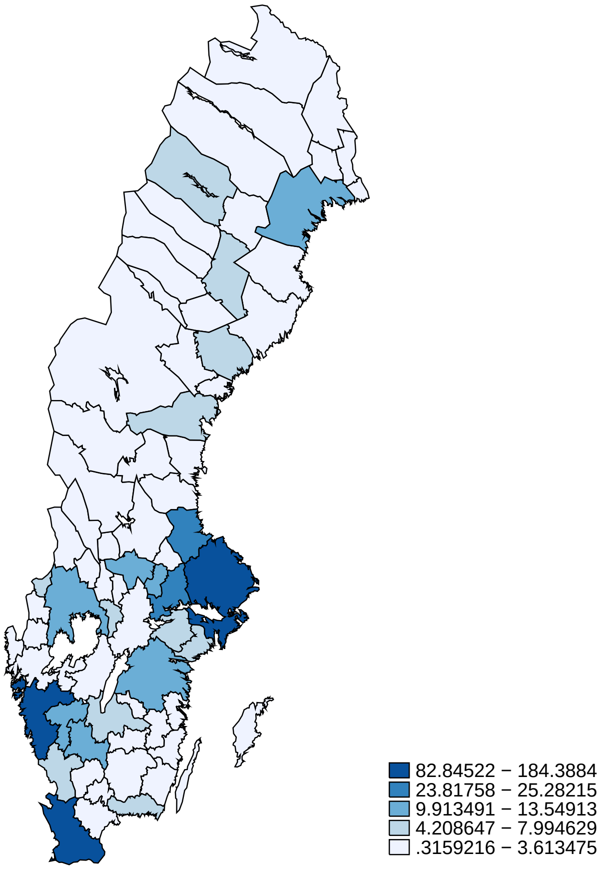

Figure 5. Quantile regression results. Dependent variable: granted patents per capita.

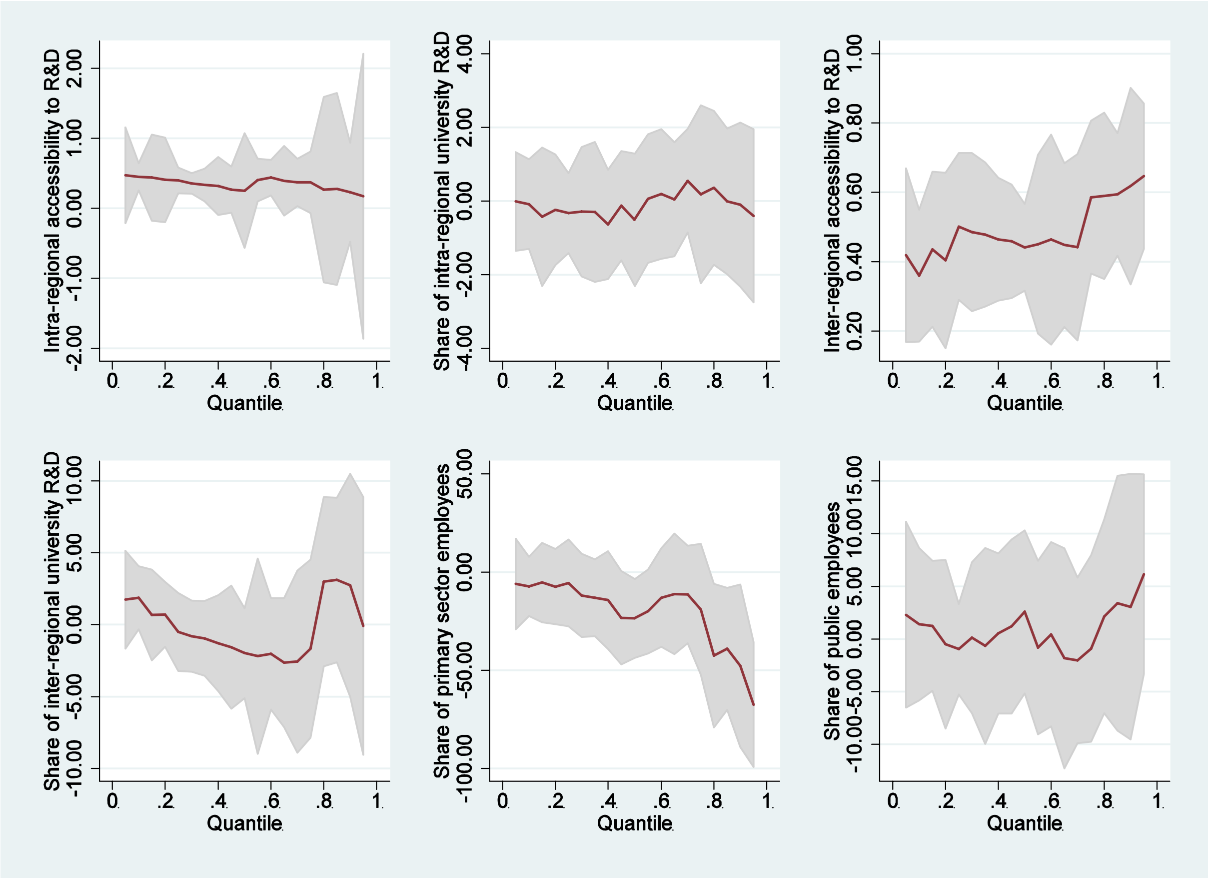

Figure 6. Quantile regression results. Dependent variable: innovations per capita.

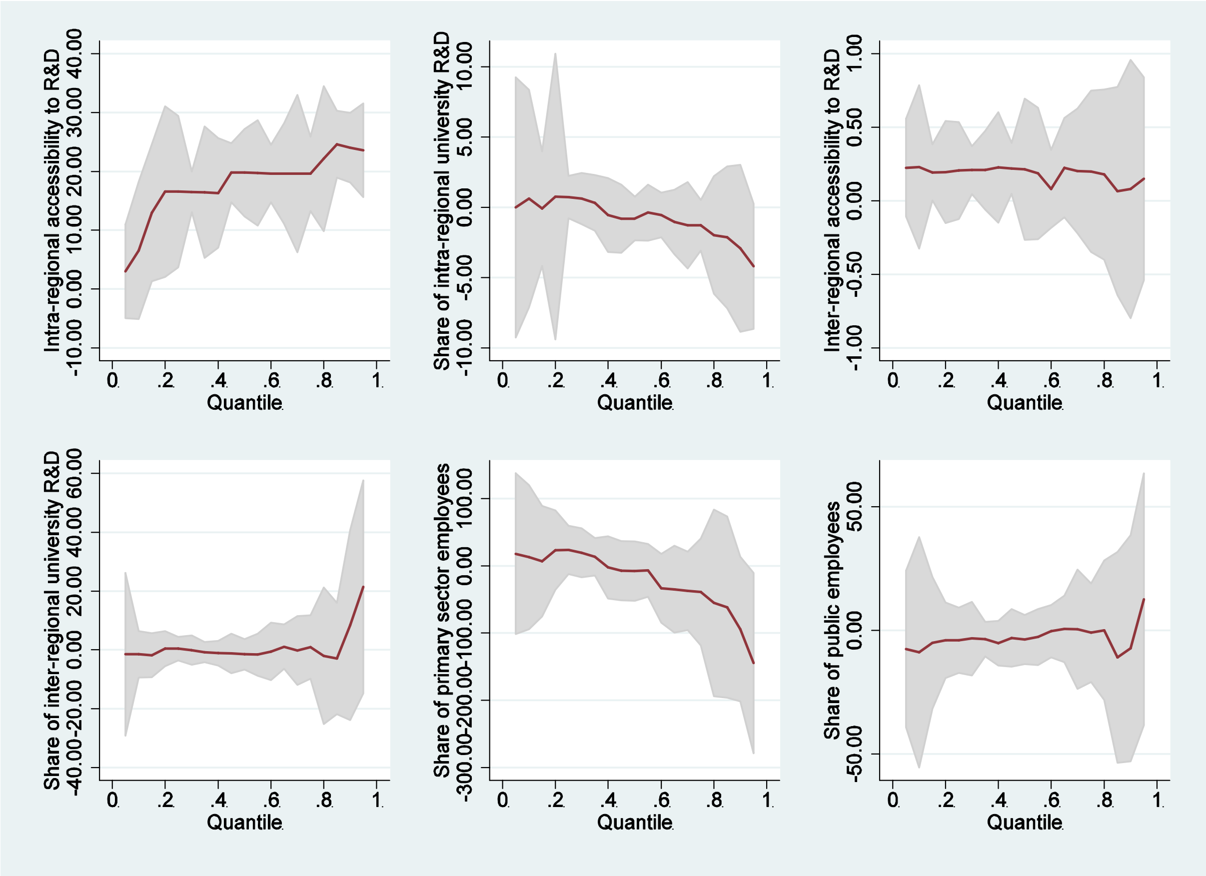

Table 1. Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Grants	72	4.1536	13.6838	0.2775	100.9510
Grants per capita	72	3.0546	1.8910	0.6742	10.1422
Innovations	72	81.8334	468.4468	0.0967	3811.1055
Innovations per capita	72	9.0796	25.9669	0.3159	184.3884
A_{ii}	72	0.3877	1.3502	0.0000	9.2500
S_{ii}^{uni}	64	0.2254	0.3120	0.0000	1.0000
A_{ij}^{*}	72	2.4045	3.3927	0.0089	17.0456
S_{ij}^{uni*}	72	0.1892	0.1122	0.0065	0.5178
S_{i}^{edu}	72	0.0446	0.0155	0.0237	0.1075
S_{i}^{pub}	72	0.4153	0.0637	0.2479	0.5525
S_{i}^{agr}	72	0.0371	0.0183	0.0073	0.0809

Table 2. Correlation matrix of variables.

	Grants	Grants per capita	Innovations	Innovations per capita	A_{ii}	S_{ii}^{uni}	A_{ij}^{*}	S_{ij}^{uni*}	S_{i}^{edu}	S_{i}^{pub}	S_{i}^{agr}
Grants	1.0000										
Grants per capita	0.1682	1.0000									
Innovations	0.9651	0.1557	1.0000								
Innovations per capita	0.9940	0.2212	0.9437	1.0000							
A_{ii}	0.9782	0.1518	0.9237	0.9721	1.0000						
S_{ii}^{uni}	0.0522	-0.0690	0.0649	0.0380	0.0698	1.0000					
A_{ij}^{*}	-0.1732	0.6589	-0.1163	-0.1613	-0.1790	-0.0886	1.0000				
S_{ij}^{uni*}	-0.1613	0.0962	-0.1674	-0.1515	-0.1885	-0.3160	0.2318	1.0000			
S_{i}^{edu}	0.6755	-0.2392	0.5906	0.6586	0.7080	0.1713	-0.4575	-0.3160	1.0000		
S_{i}^{pub}	-0.1297	0.0055	-0.0870	-0.1493	-0.1139	0.4979	0.2370	-0.2997	0.0621	1.0000	
S_{i}^{agr}	-0.3187	0.1157	-0.2474	-0.3355	-0.3334	-0.1189	0.4285	-0.0100	-0.3926	0.3943	1.0000

Table 3. Main regression results.

Model	(1)	(2)
Dependent variable	Grants/capita	Innovations/capita
A_{ii}	0.346800	18.717867
	(0.00)***	(0.00)***
S_{ii}^{uni}	-0.223561	-0.945465
	(0.70)	(0.66)
A_{ij}^{*}	0.459428	0.126019
	(0.00)***	(0.51)
S_{ij}^{uni*}	-0.399544	4.386932
	(0.79)	(0.50)
S_{i}^{agr}	-16.734755	-15.042691
	(0.06)*	(0.71)
S_{i}^{pub}	-0.768457	-12.070483
	(0.78)	(0.31)
Constant	2.834983	6.405578
	(0.02)**	(0.10)
Observations	64	64
R^2	0.52	0.95
Moran's I	-2.094 (1.964)	-0.216 (1.171)
Spatial error, LM	2.528 (0.112)	0.064 (0.800)
Spatial lag, LM	0.207 (0.649)	0.227 (0.634)

Robust p values in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

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