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Sectoral Knowledge Production in Swedish Regions 1993-1999[1]

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SECTORAL KNOWLEDGE PRODUCTION IN SWEDISH REGIONS 1993-1999[Ψ]

Martin Andersson & Olof Ejermo

Abstract

This paper attempts to explain knowledge production in Swedish functional regions as measured by the number of patent applications. Recognizing that technological opportunity differs across sectors, a sectoral analysis is conducted. The Knowledge Production Function (KPF) approach is applied in order to relate patent applications to a number of relevant knowledge sources. The empirical analysis makes use of an aggregate KPF for each sector and region. In the interpretation of the results, the recent critique of KPF approaches is recognized. The stock of patent applications is included as an explanatory variable in the analysis. The results show that the patent stock of a region contains much of the information needed in order to explain current patenting activity. This is interpreted as suggesting strong effects of path dependence.

JEL classification: O31, H41, O40

Keywords: knowledge production function, sectoral analysis, patents, R&D, knowledge flows, externalities

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1. INTRODUCTION

Whether the focus is on the regional or the national level, practically all theories of growth and innovation developed in the last decades emphasize the role of knowledge. Knowledge is, for example, a core variable in the formal endogenous growth literature (e.g. Romer 1986, 1990, Aghion & Howitt, 1998), as well as in less formal traditions such as the innovation system literature, (e.g. Lundvall 1995, Edquist 1997a, 1997b). A fundamental message from this literature is that innovation and economic growth are processes that depend on knowledge production activities.

It is widely accepted that knowledge diffusion, whether working through market mechanisms or spillovers, plays a crucial role in the creation of new knowledge. Such diffusion is geographically bounded to the extent that the transmission of knowledge is distance sensitive. Glaeser *et al* (1992, p.1127), for instance note: "…intellectual breakthroughs must cross hallways and streets more easily than oceans and continents". Studies of knowledge production in large aggregated geographical units can therefore fail to recognize that the production of knowledge may be concentrated to particular regions or geographical areas. Disregarding the role of proximity implies that important elements in the process of knowledge production may be neglected.

Using a knowledge production function (KPF) framework, initiated by Griliches (1979, 1984), this paper aims to explain knowledge production, measured by the number of patent applications for Swedish functional regions in the period 1993-1999. No one seems yet to have systematically examined knowledge production for Swedish regions. An additional merit is that the paper accounts for sectors at the regional level. Broadly speaking, two branches of the literature put different emphasis on KPF schemes. On the one hand, industry-oriented research such as Breschi *et al* (2000), Fai & von Tunzelmann (2001), as well as others (Griliches 1990; Desrochers 1998, 2001) underlines that the propensity to patent varies across sectors for a number of reasons, and is therefore industry-specific. One important reason is that *technological opportunity* differs for different sectors (Breschi *et al* 2000). On the other hand, regional KPF studies tend to neglect, or suppress, the industry dimension. Our conclusion from this two-pronged literature is therefore that both aspects are important and we therefore study sectors at different aggregation levels across regions.

Another way in which industry-studies have influenced our thinking concerns the possibility of *path-dependence*, such that past innovation intensity in regions (sectors) predicts the current and future rate of innovation in the same regions (sectors). In view of this, we account for past innovative activity in our KPF model by using the number of patent applications in previous years. In our view, the lack of such a variable in earlier studies is a potential source of misspecification.

In addition to the considerations above, we alter the analysis by introducing a precise spatial structure. Our regional unit of analysis is the local labor-market region, which is characterized by high intensity of economic interaction. This contrasts many studies employing administrative regional units. Local labor-market regions are further assumed to be linked to each other in a manner determined by the time distance between them, which accounts for the influence of time on the possibility for interaction. In this way, we intend to shed light on how internal and external sources of knowledge influence Swedish patent activity.

It needs to be mentioned, however, that KPF frameworks have recently come under attack from researchers as not being able to get through the black box of how knowledge is created in firms and transmitted within and between regions. Under the heading of knowledge spillovers, several externality effects are grouped together. These externality effects include the exchange of personnel from firms to universities (or vice versa), pecuniary externalities (rent spillovers), reverse engineering and so on. The disentangling of such processes is difficult to achieve, but some analyses in this vein has been carried out by Zucker, Darby & Armstrong (1998), Zucker, Darby & Brewer (1998), Almeida & Kogut (1999) and Møen (2000). While we agree on the main line of criticism, we think that the KPF approach still has its virtues, because patent and R&D data are still the most easily accessible information, offering substantial quantities (which increase the precision in the statistical analysis) and can be used to study aggregate flows of knowledge. Furthermore, KPF approaches reveal the "functional relationship" between knowledge inputs and output indicators in a systematic way. Thus, KPF approaches are complementary to case studies, which better capture micro aspects of knowledge diffusion.

The paper proceeds by summarizing the most important elements of the theory of externalities. Moreover, it reviews the literature on knowledge production functions and regional spillovers and it continues by discussing the criticism of this approach. As a next step the presentation suggests some alternative ways of examining knowledge spillovers. Then we introduce the model we use to estimate knowledge production functions for Swedish functional regions. Finally, we report and assess the statistical results and formulate conclusions.

2. REGIONAL KNOWLEDGE FLOWS

2.1 Externalities in Regions

The literature on knowledge externalities points to several different factors of importance for the diffusion of knowledge in regions. Cameron (1998) classifies externalities into four groups: (i) standing on shoulders, (ii) surplus appropriability, (iii) creative destruction and (iv) stepping on toes. *Standing on shoulders* happens as the costs of rival firms are reduced due to knowledge dissemination and a shared labour pool market. By definition, such spillovers are largely local. Marshall's (1920) seminal book *Principles of Economics* discusses how labour markets, specialized intermediary inputs and knowledge spillovers combine to create powerful localization forces. *Surplus appropriability* occurs when the innovator does not reap all the benefits of an innovation. This effect arises due to market imperfections, because ideas are embodied in (intermediary) goods, giving them a higher value than what is reflected in their price. *Creative destruction* happens when new modes of production out-compete older ones. *Stepping on toes* occurs due to congestion or network externalities[2]. Knowledge spillover is in the literature in principle equivalent to Cameron's (1998) standing on shoulders type of externality. Griliches (1992) terms the first category idea spillovers, or pure knowledge spillovers, and the second rent spillovers.

The literature has accredits several different mechanisms to be important for knowledge spillovers in regions. Geographical proximity between actors is unanimously maintained to be crucial, since knowledge is most easily exchanged

[2] Stepping on toes could result in positive spillovers in communication examples: more telephone users increase the functionality of telephones.

through personal interactions. Knowledge flows are, at least to some extent, spatially bounded. In this context, it is usually claimed that relevant knowledge in innovation processes is often tacit. According to Dosi (1988, p.1126), tacitness refers to "those elements of knowledge, that persons have, which are ill-defined, uncodified, and which they themselves cannot articulate, and which differ from person to person, but which to some extent can be shared by collaborators who have common experience". Lorenzen (1996) maintains that the main communication channels for tacit knowledge are those that involve FTF-contacts, such as employee mobility, informal personal relations and supervision. In principle, the importance of tacit knowledge is based on the assumption that exchange (or spillovers) of completely codifiable knowledge does not necessitate geographical proximity. It could just as well be exchanged through various forms of telecommunications.

Tacit knowledge helps to explain the tendency of innovative activities to be concentrated in space, as found in the empirical literature. Moreover, geographical proximity is also seen as a means to achieve informal institutions, such as common conventions and rules. These are believed to facilitate interaction and collaboration. For example, Harrison (1996, p.235) states: "by increasing the likelihood of familiarity, proximity reduces the incidence of opportunistic behavior by suppliers, customers and even competitors, thus facilitating learning". Capello (2001) introduces the concept of relational proximity as encompassing relations developed by integration of firms and socio-cultural homogeneity. In the regional innovation system literature, local informal institutions play a prominent role by facilitating and stimulating interaction and consequently exchange of knowledge, (see e.g. Wiig & Wood, 1995). Of course, proximity is not the only relevant factor for knowledge production in regions. R&D, university research, skilled labor force and other types of knowledge handlers are obviously important for the production of new knowledge. A large set of knowledge handlers, with relevant training, influences the effectiveness of knowledge flows. For example, to be able to utilize knowledge emanating from universities, the staff of private companies should have relevant training (or education) and actively pursue the adoption of knowledge. The same is of course true for knowledge that flows from company to company, etc. The ability to obtain outside knowledge has been labeled absorptive capacity (Cohen & Levinthal, 1990).

The next section describes how the KPF approach has usually been applied in a regional context and reviews empirical results obtained in earlier studies.

2.2 Knowledge Production Approaches

The *knowledge production framework* is a versatile tool to model the "functional relationship between the inputs of the knowledge production process and its output that is economically useful new technological knowledge. The unit of analysis can equally be the firm (such as in Griliches, 1979) or larger geographic areas where innovating firms reside (such as a country, a state or a metropolitan area)", Acs *et al* (2002, p. 1074). Moreover, the dependent variable can equally well be production, as in the literature on inter-industry spillovers[3], or patents. This flexibility is also one of the drawbacks in the pertinent literature. While it is generally claimed that evidence of knowledge spillover is found, either between industries or from universities to firms

[3] Ejermo (2002b) and van Pottelsberghe (1997) provide overviews of this literature.

etc., it is not clear how the mechanisms for knowledge transfer occur. It is left open whether the mechanism is a spillover phenomenon or a market phenomenon where firms pay for the knowledge provision.

The empirical contributions to the study of localized knowledge flows include among others Jaffe (1989), Jaffe *et al* (1993), Anselin et al (1997), Maurseth & Verspagen (1999), Verspagen & Schoenmakers (2000), Acs *et al* (2002) and Fischer and Varga (2002). This list is by no means exhaustive. For instance, there is also a large literature on the importance of clustering/diversity for innovation output. We regard this line of research as being parallel to the literature on KPFs and don't discuss it here.

Jaffe (1989) examined the impact of university research on patenting of enterprises on the level of 29 US states for the years 1972-77, 1979, 1981 and 1983. The main estimated equation was[4]:

$$(1) \qquad \log(P) = \beta_{K1}\log(R) + \beta_{K2}\log(U) + \beta_{K3}\left[\log U \cdot \log C\right] + \varepsilon_K$$

where *P* is patents, *R* is industry R&D and *U* is university research. *C* is an index of geographic coincidence between university and industry research, aimed at reducing problems of the arbitrariness of using the state as the observational level. Also, the article recognized that there might be feedback loops running from university to industry research and vice versa, so the estimations were made with a three equation simultaneous system with instruments to mitigate such problems. Also, the analysis was divided into different technical areas. It was generally found that university research had a strong effect on patenting of enterprises, but only little influence could be found from industry research.

Jaffe *et al* (1993) examined the citation patterns of patents originating from universities or enterprises to see whether there is a localization effect within US states. Naturally, pre-existing patterns of agglomeration depending on other sources than the ones associated with the knowledge spillovers given by patent citations could explain the existence of such citations. To account for this problem, the authors constructed a control sample to compare if there were significant differences in matching by geographic region. Original and control samples were compared by checking the probability of a patent matching the originating patent by geographic area, conditional on its citing of the originating patent, with the control sample *not* conditioned in this way[5]. Jaffe *et al* (1993) found clear evidence of a localization effect of patent citations.

Maurseth & Verspagen (1999) and Verspagen & Schoenmakers (2000) also investigate citation patterns, but use the EPO patent-application database. Maurseth & Verspagen (1999) find compelling evidence of national barriers to citations. They find that citations occur much more frequently between regions within national states than between regions belonging to different countries. The authors were not able to separate intra- and interfirm citations. Instead, they excluded citations within regions, assuming that most intrafirm citations were removed. Verspagen & Schoenmakers (2000) extend this work by standardizing company names, including subsidiaries, of

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[4] In Acs *et al* (1991, 1994) and Feldman and Florida (1994) the equation is used similarly, but with the dependent variable replaced by innovation counts from the 1982 US Small Business Administration innovation count.

[5] The authors also exclude self-citation, i.e. those of own origin, which naturally removes some of the localization effect.

27 European multinationals. They also remove intrafirm citations explicitly. Again, the effect of geographic proximity was validated.

Advances in spatial econometrics (cf. Anselin, 1988 and Anselin & Florax, 1995) have also influenced the work on knowledge production functions. Anselin, Varga & Acs (1997) argue that the earlier lack of consistency in finding evidence of spillovers stems from Jaffe's geographic coincidence index. They maintain that this inconsistency can be removed with the help of four other measures. The authors also test and correct for accruing spatial autocorrelation. Furthermore, they replace the regional unit of states with 125 American metropolitan statistical areas (MSAs) in one specification and manage to increase the amount of states to 44, due to the use of data on professional employment in high technology research laboratories[6] and use the 1982 innovation database of the US Small Business Administration (SBA). The authors interpret the results to indicate geographic *spillovers* from university research to innovations and indirectly to industry research. Spillovers from university research extended beyond a 50-mile radius, but not private R&D.

Acs, Anselin & Varga (2002) extend their earlier work above by using the number of patents as their dependent variable. Interestingly, there is a high correlation between patenting and the SBA innovation count. The results are similar to the ones obtained earlier, but differ in how the effects extend across geographical units. It is found that university research effects dominated across Metropolitan Statistical Area (MSA) borders in the innovation count specification, whereas private R&D dominates in the patent count specification.

Fischer & Varga (2002) investigate, in similar fashion, the effect of university research (1991) on counts of patents (1993) in 72 Austrian political districts, assuming a two-year lag[7]. Applying a spatial econometric approach, the results are interpreted to show evidence of mediated knowledge spillovers from university research to regional knowledge production. Spillovers transcend political districts and follow a clear distance decay pattern.

Andersson & Ejermo (2003) study how proximity to university and knowledge handlers affects patenting activity of Swedish corporations. In the study, accessibility based on time distances is used to account for proximity. It employs a cross-sectional dataset for 1993-94. The authors find that there is a strong statistical relationship with the concentration of R&D man-years and the production of granted patents. Such strength is also found regarding the closeness to knowledge handlers at universities. However, this relationship is not important for the production of granted patents when it comes to knowledge handlers of other corporations. In short, being close to them does not (statistically) improve patenting productivity.

2.3 Critique Against the Localized Knowledge Spillover Literature

More often than not, authors who claim to test the effects of localized knowledge spillovers do not test for these explicitly. They start out by assuming the possibility of their existence and then verify them on the ground that they have obtained significant effects from their regression analyses. In fact, a lot of the results could pertain to

[6] Correlation between previously used R&D expenditure was very high.

[7] The authors prefer patents to innovation counts because "it is conceptually more closely related to invention activities" . It could be added though, that innovations should on the other hand be more related to commercial applicability.

many of the effects related to agglomeration economies and externalities. Breschi & Lissoni (2001a,b) are important proponents of this criticism. In their opinion, authors consistently allow for logical ambiguities when they outline their underlying theory. A three-step logical chain is often employed. Breschi & Lissoni (2001a, p. 980 and repeated in 2001b, p. 258) write:

1) knowledge generated within innovative firms and/or universities is somehow transmitted to other firms;

2) knowledge that spills over is a (pure) public good, i.e. it is freely available to those wishing to invest in searching for it (non-excludability), and may be exploited by more than a few users at the same time (non-rivalry);

3) despite this, knowledge that spills over is mainly "tacit", i.e. highly contextual and difficult to codify, and is therefore more easily transmitted through face-to-face contacts and personal relationships, which require spatial proximity; in other words, it is a public good, but a local one.

Breschi & Lissoni (2001a,b) maintain that what may be portrayed as localized knowledge spillovers may in fact be pecuniary externalities. They also emphasize that tacitness may not induce spillovers, but instead contribute to *natural excludability*. Scientists working in groups may therefore be able to protect their ideas more easily since they develop a common language. Furthermore, it is emphasized that tacit knowledge embodied in people, who move from one firm to another as they change jobs, can only be characterized as contributing to a general pool of knowledge if all previous employers enjoy the same benefits of knowledge sharing, something that seems counterintuitive if natural excludability is important. A specific case of labor mobility consists of university scientists appropriating supra-normal returns from their participation in start-ups located in the vicinity of their home university. Of course, this is a pecuniary externality.

2.4 Knowledge Spillovers – pure externalities or mediated by market mechanisms?

What does then the recent empirical evidence show about the importance of labor markets for knowledge transfer? Zucker, Darby & Armstrong (1998) discover that market mechanisms are the most important facilitator of knowledge transfer in the Californian biotechnology sector. All parties involved, universities, star scientists and firms can be connected through a contractual system[8]. Universities can be awarded patent rights, while scientists keep the right of commercially exploiting intellectual human capital resulting from their work. The authors use a database of firms and star scientists and check whether stars' affiliation with firms improve their productivity in

[8] A biotechnology scientist is defined as a star primarily if: a) he/she discovered 40 or more genetic sequences or b) he/she wrote 20 or more articles reporting a genetic sequence discovery. In total, 327 star scientists were identified (Armstrong, Darby and Brewer 1998, p. 292).

terms of their number of products on the market and their increase in employment and find a very strong connection. Such star-to-firm affiliation must be accompanied by a contractual agreement and is thus associated with pecuniary externalities, not spillovers. In an accompanying paper, Zucker, Darby & Brewer (1998) find that the localization of biotechnology star scientists across the US are important factors in determining both location and timing of the entry of new biotechnology firms.

Almeida & Kogut (1999) start off by noting that Jaffe *et al* (1993) are not able to answer whether localization of citations occur due to regional or technological disparity. Focusing on the semiconductor industry, they first examine whether citations of patents originating from specific regions tend to be localized. Localization is found for patents from the Silicon Valley, the New York triangle and Southern California. They are also able to confirm that mobility of engineers has an effect on the pattern of citation. The starting-point for Møen (2000) is the idea that within perfect market equilibrium, R&D-intensive work should be associated with lower wages in the beginning of the career, because workers pay a premium for their on-the-job training. As experience is accumulated, a reward is given later in the career as compared to other workers, which reflects not only higher productivity but also a higher labor market value of the working force. The ideas are tested on a large and informative dataset on technicians, using wages and mobility and R&D-intensity of firms, in the Norwegian machinery and equipment industry. It is found that R&D-investment is at least partially incorporated into the labor market through the mechanism outlined above.

In sum, these recent contributions indicate that market mechanisms seem to be able to explain part of the knowledge flows.

3. PRESENTATION OF DATA & CONSTRUCTION OF VARIABLES

Because technological opportunity differs across sectors, (cf. Breschi *et al,* 2000), it is fruitful to account for sectors in knowledge production analyses. We intend to model (see the next section) the patent applications of regions in a given sector as a function of (i) company research, (ii) university research, (iii) past innovative activities and (iv) regional industry structure. In this section, we describe the data used to construct these variables as well as how we account for spatial proximity. We also present the spatial distribution of the patent and R&D data.

3.1 Patent, R&D and Employment Statistics

A patent is classified as Swedish if at least one inventor is Swedish. The address(es) of Swedish inventor(s) was used to allocate a patent to a specific region[9]. The original data from the EPO database on patent applications consists of data published in the European Patent Bulletin, which comprises patents with priority number from the year 2000, at the latest. Since applications arrive with different lags we have limited the study to the period 1993 to 1999. Figure 3.1 presents the total number of patent

[9] Using the inventor's residence is the most common approach in the literature, but also the applicant's (usually company) address could be used. The data was examined to see if such a classification would be different. It was found that in 80 per cent of the cases, the regional classifications were the same. A formal χ^2 -test did not reveal significant differences over the 81 regions.

applications with Swedish origin 1977-2000. Patents were regionally classified with the use of the postal code of inventors, and then coded to 81 functional regions based on the classification made by NUTEK (1998).

The patent applications being allocated to Swedish functional regions were then assigned to industrial sectors using the Yale concordance table. The Canadian patent office has been unique in assigning, for each patent, an industry of manufacture and a sector of use[10]. A problem with this definition for economic researchers has been that the available correspondence table maps the international patent classification into Canadian SIC (1980) sectors. Therefore, we first investigated another option, the so-called MERIT concordance table documented in Verspagen *et al* (1994). But, this table has the limitation that it only maps manufacturing sectors. However, OECD has a project to concord the patent classification to ISIC-3 classes, which matches very well with the Swedish industrial classification system (SNI92). From documentation of this project, we could find a concordance table between the Canadian SIC-E (1980) classification and the ISIC3, which was used for classifying the patents to sectors[11]. The patents were first classified in accordance with the Canadian SIC-E (1980) system via the Yale concordance table and then converted to each of our "Swedish" sectors by use of the documentation in the project.

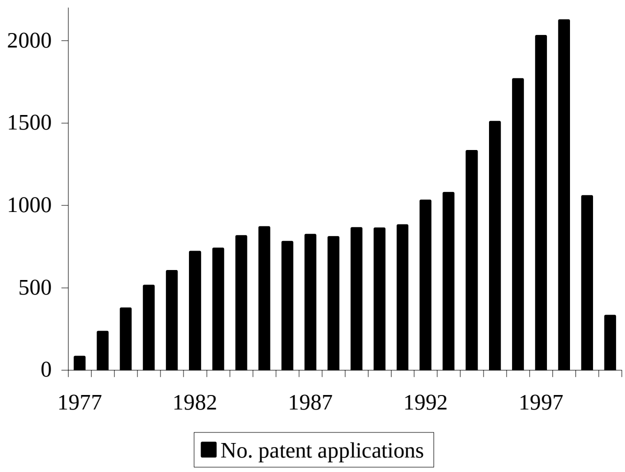

Figure 3.1. *Number of patent applications filed to the EPO with Swedish origin and priority number from the 1977-2000 period.*

Primary material provided by Statistics Sweden on R&D man-years of Swedish firms is used to establish the amount of company research in each region. This data is used for OECD's statistical indicators. The dataset is censored to the "left" because regionally distributed R&D-data starts in 1993. The names of the firms are removed due to confidentiality reasons, but the judicial municipality of each firm is given. Moreover, there is information about the research distribution across counties in the database. This data was distributed to functional regions in one of three ways, based on its properties. In a subset of cases the assignment to regions had to be carried out on the basis of specific assumptions. The most important was that when firms have

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[10] Originally, it was used by Putnam & Evenson (1994).

[11] Extensive information about the OECD-project, along with useful files containing the Yale concordance table, is found at http://www.wellesley.edu/economics/johnson/oecd.html.

research activities in several counties in which they do not have their judicial location, the research was allocated to the largest functional region of the county. In the data, each firm is coupled to the Swedish industrial classification system (SNI92) at the 5-digit level, which allows for a straightforward aggregation of the firms' R&D man-years into sectors.

Data on university research is also based on primary material from Statistics Sweden. Statistics Sweden's data on R&D in the higher education sector reports each university's R&D man-years. The distribution of this data over functional regions is revealed by the names of the universities and the location of the universities is known. The data on university research allowed us to discriminate between different subject fields. To obtain total university R&D, we aggregated the R&D within (i) natural sciences, (ii) technical sciences, (iv) medical sciences and (iv) social sciences. Information on employment in regions and number of establishments (plants) in municipalities is taken from a database provided by Statistics Sweden. This data was aggregated to functional regions. The variable reflecting the regional industry structure was then simply constructed by taking the total amount of establishments divided by the total number of employees in the functional regions. This variable was calculated for each sector using the SNI92 industrial classification system. The purpose of including this variable is to reveal if there are differences between regions characterized by small- and large-scale establishments in the respective sectors. The so-called *Schumpeterian* hypothesis, for instance, states that large firms have an advantage over small firms (cf. Scherer, 1983)[12].

3.2 Sectoral Classification

The sectoral classification used is based on the Swedish industrial classification system (SNI92) at the 2-digit level. As mentioned previously, each firm is coupled to the Swedish industrial classification system (SNI92) at the 5-digit level in the R&D data for Swedish firms described above.

To construct sufficiently large sectors in terms of number of firms representing the sector, we aggregated the observations to the 2-digit level. The lower limit of the number of firms representing a sector was set to 10 different firms between 1993 and 1997. Hence, a sector made up of less than 10 firms in any year between 1993 and 1997 was excluded from the analysis. In this manner, we were able to identify 19 sectors, see Table 3.1 for a description.

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[12] Also, EPO patents are costly and smaller firms may not be able to raise the required funding.

Table 3.1. *Description of the 19 sectors in the analysis.*

Sector	Description	SNI-codes at the 2-digit level
1	*Manufacture of food and tobacco products*	*15, 16*
2	*Manufacture of textile, clothing and leather products*	*17, 18, 19*
3	*Manufacture of timber and wood products*	*20*
4	*Manufacture of pulp, paper and publishing*	*21, 22*
5	*Manufacture of coal, petroleum and chemicals*	*23, 24*
6	*Manufacture of rubber and plastic products*	*25*
7	*Manufacture of non-metallic mineral products*	*26*
8	*Steel and metal preparation*	*27*
9	*Manufacture of metal goods except machines and apparatus*	*28*
10	*Manufacture of machines*	*29*
11	*Manufacture of electric and optical products*	*30, 31, 32*
12	*Manufacture of precision instruments, medical and optical instruments*	*33*
13	*Manufacture of motor vehicles and other means of transportation*	*34, 35*
14	*Manufacture of furniture*	*36*
15	*Wholesale and retail sale*	*50, 51, 52*
16	*Data processing activities*	*72*
17	*Research and Development*	*73*
18	*Other producer and business services*	*74*
19	*Social and personal services*	*90, 91, 92, 93*

Source: Construction by the authors based on primary material from Statistics Sweden on R&D man- years of Swedish firms.

Since each firm is allocated to one or several functional regions according to the method described earlier and each firm is coupled to an SNI-code, the distribution of company research in each sector over functional regions follows automatically. The patent applications were coupled to the sectors following the method just described. The vast majority of the sectors are within the manufacturing industry. Also, some of the sectors consist of more than one SNI-code at the 2-digit level because of the similarity between the codes and through the construction of the mapping tables.

3.3 Construction of Accessibility Variables

As mentioned in the introduction, accessibility is used to control for the role of proximity in the production of knowledge. We believe that this is a sound way of handling proximity (cf. Andersson & Karlsson, 2004) since it can be interpreted as a measure of the ease of spatial interaction and potential of opportunities of interaction, (see e.g. Weibull 1980). The accessibility of a region r to some opportunity D is defined as:

(2) $$A_D^r = \sum_{s=1}^{n} D_s e^{-\lambda t_{rs}}$$

which is a standard measure of accessibility with exponential distance decay, (cf. Klaesson 2001). In the expression above, λ is a time distance sensitivity parameter and t_{rs} is the time-distance between region r and s. In our calculations, we use the travel-time between functional regions by car as time distance[13]. Following Johansson *et al* (2002), we separate between intra- and extraregional accessibility. If we let $W=\{1,\ldots,n\}$ be a set of all regions in the economy and let $W_{-r} = W \backslash r$ denote a set of all regions in the economy except region r, the separation can be made in the following manner:

$$(3) \qquad A_D^r = D_r e^{-\lambda_{ir} t_{rr}} + \sum_{s \in W_{-r}} D_s e^{-\lambda_{er} t_{rs}}$$

where $D_r e^{-\lambda_{ir} t_{rr}}$ is the intraregional and $\sum_{s \in W_{-r}} D_s e^{-\lambda_{er} t_{rs}}$ is the extraregional accessibility. $s \in W_{-r}$ refers to a region other than r. Hence, the total accessibility of a region is the sum of the two accessibilities. Note that in the above equation, the two types of accessibilities have different time distance sensitivity parameters, λ_{ir} and λ_{er}. This is because they empirically have been found to be different. In a study of Swedish interregional business interactions, Hugosson & Johansson (2001) estimate a time distance sensitivity of 0.017. Moreover, studies of commuting patterns reveal that the time distance sensitivity within functional regions is approximately 0.1, (see e.g. Åberg 2000). Therefore, we set λ_{ir} equal to 0.1 and λ_{er} equal to 0.017. The rationale for doing so is that trips between functional regions in Sweden are related to planned and pre-arranged meetings. This circumstance reduces the time sensitivity.

The method outlined above is applied to two variables in our model, company research and university research. For example, intra- and extra-regional accessibility to company research in sector k for region r at time t, $R(t)_{r,k}^I$ and $R(t)_{r,k}^E$ respectively, are defined as follows:

$$R(t)_{r,k}^I = R(t)_{r,k} e^{-\lambda_{ir} t(t)_{rr}}$$

$$R(t)_{r,k}^E = \sum_{s \in W_{-r}} R(t)_{s,k} e^{-\lambda_{er} t(t)_{rs}}$$

Intra- and extraregional accessibility to university research is treated in exactly the same way. In the interpretation of accessibility given above, for individuals (e.g. workers and researchers etc.) living in a region, we calculate the opportunity of FTF-interaction with company and university researchers within and outside the region. The major advantage with the distinction between intra-regional and extra-regional accessibility is not the specification of two distinct time-sensitivity coefficients. Instead, by having two different accessibility variables for each type of R&D, the subsequent regression exercises will reveal the importance of each accessibility measure.

[13] This data was provided by the Swedish National Road Office.

3.4 The Spatial Distribution of Patents & R&D in Sweden

The Swedish economy must be regarded as heterogeneous in the sense that the economic activities are geographically distributed in a very uneven manner. In 1999, for example, the three largest functional regions in Sweden (Stockholm, Göteborg and Malmö)[14] accounted for approximately 38 % of the total Swedish population. In the same year, these three regions accounted for 43 % of the total private employment and 43 % of the total number of plants in the private sector[15]. This shows that the economic activities in Sweden are concentrated to a few regions. It is against this background that the following figures should be consulted.

Figure 3.2 shows the cumulative distribution of patent applications, population, business and university R&D in the 81 Swedish labor market regions ranked by population as a sum across all 19 investigated sectors (patent applications and business R&D).

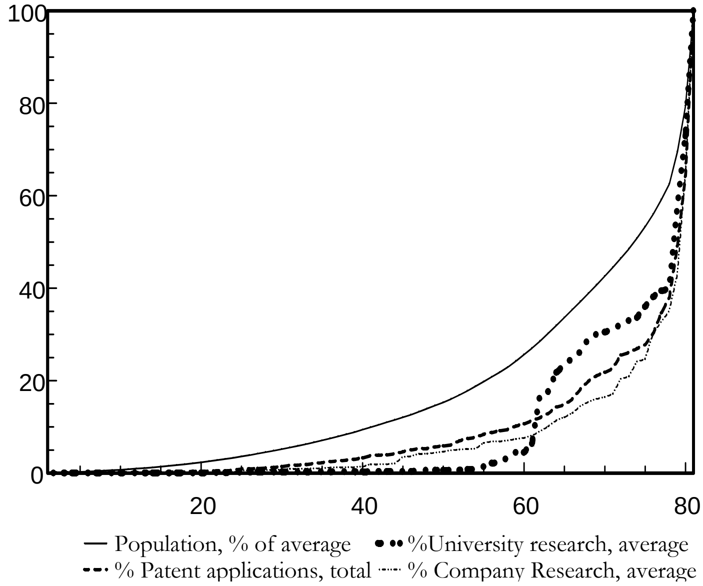

Figure 3.2. *Cumulative distribution of patent applications, population, business and university R&D in 81 Swedish labor market regions ranked by population, sum across all 19 sectors.*

Stockholm, Göteborg and Malmö are at the right end of the figure. While the cumulative distribution of population rises steadily, patent applications (dotted and bold line) increase very rapidly towards the end. A similar line is drawn by the cumulative distribution of company research. An interesting feature is shown by university research: this line does not follow a smooth pattern, but seems rather to follow discrete shifts, clearly showing the influence of political decisions. All in all, the figure shows that innovative activity, whether measured by patent applications or by university or business R&D is even more concentrated to the three largest regions than population.

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[14] Henceforth we will refer to these three regions as the metropolitan regions.

[15] These figures can easily be obtained from employment and population statistics provided by Statistics Sweden.

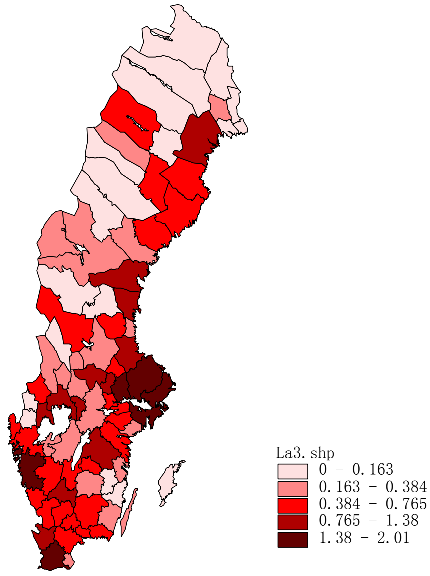

Figure 3.3. *Total number of patent applications per capita in the 19 sectors in Swedish functional regions 1993-1999.*

The uneven geographical distribution described above is clearly visible when we look at a map (see Figure 3.3) of the number of patent applications per capita 1993-99, summed over all 19 sectors. As can be seen, even though patent applications are divided by population, Stockholm Göteborg and Malmö stand out as especially dense with respect to the number of applications per capita. Most of the regions in the northwest have zero or very few patent applications, which reflect their sparse population and low intensity of economic activities. However, only 5 out of the 81 functional regions had zero patent applications 1993-1999. Clearly, the three metropolitan regions deviate to a large extent from the average region, and we will therefore take them into special consideration in our KPF model.

4. EMPIRICAL MODEL & RESULTS

4.1 Our KPF Model

The KPF model used in this paper differs from the types of production functions usually employed. We cannot apply a Cobb-Douglas type of knowledge production function, because many of the observations are zero[16]. Our work will therefore be limited to model the knowledge production of regions in an additive setting.

As mentioned in Section 3, we intend to model the patent applications of regions in a given sector as a function of (i) company research, (ii) university research, (iii) and (iv) regional industry structure. The equation to be estimated is presented in Equation (4):

$$P_{r,k} = \alpha + \beta U_r^I + \delta U_r^E + \phi R_{r,k}^I + \gamma R_{r,k}^E$$

[16] We believe that replacing zero with a value close to zero and then taking the log is not proper for two reasons. Firstly, the choice of a value "close" to zero is arbitrary and secondly, taking the log of values "close" to zero only creates extreme outliers. The size of these outliers is also very sensitive to the choice of the value "close" to zero.

(4)

$$+\theta\ C_{r,k} + \varphi\ P_{r,k}^{past} + \xi\ D_{r}^{metro} + \varepsilon_{r,k}$$

Table 4.1 lists the variables of interest as well as their definition. The calculation of the accessibilities follows the method outlined in Section 3.3.

Table 4.1. *Description of variables in the KPF model.*

Variable	*Parameter*	*Definition*
$P_{rt,k}$	(dependent variable)	Mean number of patent applications per capita of region *r* in sector *k* (1993-1999).
U_{r}^{I}	β	Mean intra-regional accessibility to university R&D per capita of region *r* (1993-1997).
U_{r}^{E}	δ	Mean extra-regional accessibility to university R&D per capita of region *r* (1993-1997).
$R_{r,k}^{I}$	ϕ	Mean intra-regional accessibility to company R&D per capita in sector *k* of region *r* (1993-1997).
$R_{r,k}^{E}$	γ	Mean extra-regional accessibility to company R&D per capita in sector *k* of region *r* (1993-1997).
$C_{r,k}$	θ	Mean number of establishments per employee in sector *k* in region *r* (1993-1997).
$P_{r,k}^{past}$	φ	Mean number of patent applications per capita region *r* in sector *k* (1982-1992)
D_{r}^{metro}	ξ	A dummy for metropolitan regions (=1 for Stockholm, Göteborg and Malmö).

As seen, we explain the mean number of patent applications per capita 1993-1999 in a given sector by seven explanatory variables. For university R&D and company R&D the mean is based on 1993-1997[17]. The same applies for the regional industry structure variable. The mean number of patents per capita 1982-1992 is used as a proxy for past innovative activity. This variable is used to capture path-dependence effects. Another interpretation is that it is a "catch-all" variable for all things that have an influence from the past. To the authors' knowledge, this variable has not been included before in similar setups. Also, we account for the three metropolitan regions (Stockholm, Göteborg and Malmö) with a dummy variable. Finally, it should be mentioned that the intention was to account for different fields of subject as regard the university research. However, this was not possible due to problems of multicollinearity. The model above will be applied to all the 19 sectors listed in Table 3.1, as well as to the total number of patents per capita in the 19 sectors. In the latter case, we exclude the regional industry structure variable since it cannot properly be defined across different sectors.

4.2 Estimation Results

The results from the estimation of Equation (4) for the 19 sectors are listed in Table 4.2. It is evident that past innovative activity is the most important determinant for current patenting activity. Path-dependence effects seem to be strong and influential. The mean number of patents per capita (1982-1992) is only insignificant for three sectors: *Manufacture of motor vehicles and other means of transportation*; *Wholesale and retail sale* and *Social and personal services*. For the latter two industries the

[17] For university R&D and company R&D we did not have any observations for 1994 and 1996. When possible, we made use of interpolation. Otherwise, we took the mean of the year after and the year before.

adjusted R^2 is comparatively low, implying that our model does not explain much of their patenting across regions. In terms of the ability to explain the variation in patent applications per capita across the Swedish functional regions, the fit of the model is highest for the following sectors (in descending order): *Manufacture of coal, petroleum and chemicals; Manufacture of electric and optical products* and *Manufacture of precision instruments*, *medical and optical instruments*. The adjusted R^2 for these industries exceeds 0.70. The coefficient estimate for the regional industry structure is significantly negative on seven occasions. Hence, regions with relatively many establishments per employee, i.e. are characterized by small-scale establishments in the sectors, produce fewer patents per capita in the respective sectors. Given the structure of the data presented in Section 3.4, a positive metropolitan dummy should be expected for most of the sectors. As it turns out, the dummy is only significantly positive for five sectors. Hence, when disaggregating the total number of patent applications per capita into sectors, much of the structural difference between the metropolitan regions and the other regions shown in Section 3.4 seems to disappear. Intra-regional accessibility to company research and university R&D is insignificant for the majority of the sectors. Only for two sectors, *Manufacture of metal goods except machines and apparatus* and *Manufacture of motor vehicles and other means of transportation*, intra-regional accessibility to company R&D turns out as a positive statistically significant variable. Likewise, *Manufacture of coal, petroleum and chemicals* and *Manufacture of electric and optical products* are the only sectors for which intra-regional accessibility to university R&D is a positive and statistically significant explanatory variable. Moreover, there is no clear pattern in the sign of the estimates. To a certain extent the mean number of patents per capita (1982-1992) may capture the effect. Yet, the effect of past innovative activity is much stronger, indicating that past innovation output is more important than current R&D input. This can be interpreted as that the knowledge gained in the past by producing patents is very important for current patenting. Moreover, good accessibility to knowledge sources outside the region does not seem to play any role. Hence, no “spillover-effects” between the Swedish functional regions can be found.

Table 4.2. *Estimation results of Equation (4) for the 19 sectors.(N=81)*

	α	U_r^I	U_r^E	$R_{r,k}^I$	$R_{r,k}^E$	$C_{r,k}$	$P_{r,k}^{past}$	D_r^{metro}	*adj.*R^2
1	1.2e-7 *1.24*	0.004 *1.52*	5.9e-6 *-0.89*	0.001 *1.47*	0.0001 *0.46*	-1.0e-6 *-1.50*	1.35* *3.36*	-1.5e-7 *-0.50*	0.69
2	2.7e-7 *1.45*	2.2e-3 *-0.68*	-8.5e-6 *1.62*	-5.4e-3* *-3.26*	9.6e-4 *1.37*	1.9e-7 *0.72*	0.73* *4.40*	1.7e-6* *2.33*	0.46
3	2.7e-7 *1.45*	-8.5e-6 -1.63	-4.9e-6 *-1.26*	-3.6e-3 *-1.73*	-1.1e-3 *-1.55*	-4.4e-7* *-2.01*	0.81* *2.88*	-4.0e-9 *-0.03*	0.36
4	5.6e-7* *3.18*	-0.003 *-0.78*	-1.5e-5 *-1.46*	-0.04 *-1.46*	-2.1e-5 *-0.36*	-6.5e-7* *-1.99*	1.40* *6.71*	-1.6e-7 *-0.18*	0.60
5	2.4e-6* *2.07*	0.08* *2.06*	-4.7e-5 *-0.76*	-0.10 *-1.14*	6.4e-5 *0.44*	-2.9e-6* *-2.0*	0.79* *2.84*	1.75e-5* *2.33*	0.77
6	1.7e-6* *3.04*	-3.3e-3 *-0.35*	-2.5e-5 *-1.19*	-7.0e-4 *-0.03*	1.1e-3 *1.51*	-6.1e-6* *-2.41*	0.96* *3.59*	1.6e-6 *1.33*	0.49
7	5.4e-7* *2.74*	-4.5e-3 *-1.21*	-9.3e-6 *-0.82*	3.1e-4 *0.06*	9.5e-4 *1.33*	-8.6e-7* *-1.91*	0.65* *4.43*	1.1e-6 *1.60*	0.32
8	4.4e-7 *1.62*	-0.004 *-1.30*	-8.2e-6 *-0.43*	0.009 *0.52*	0.0003 *0.72*	-0.6e-7 *-0.49*	1.13* *5.27*	3.9e-7 *0.79*	0.69
9	1.4e-6 *1.22*	-0.004 *-0.53*	-3.8e-5 *-1.33*	0.02* *2.58*	-0.0001 *-0.49*	-1.2e-6 *-0.23*	1.07* *4.52*	6.5e-7 *0.50*	0.55
10	7.0e-6 *1.46*	0.07 *1.23*	0.0004 *1.13*	-0.002 *-0.28*	-0.0009 *-1.36*	-3.3e-5 *-1.40*	1.16* *6.56*	1.1e-5 *1.21*	0.55
11	5.4e-7 *0.37*	0.15* *2.56*	-3.3e-5 *-0.39*	0.03 0.68	-4.0e-5 *-0.40*	5.0e-6 *0.79*	2.01* *5.97*	8.4e-6 *0.64*	0.75
12	1.9e-7 *0.16*	-0.01 *-0.60*	6.1e-5 *0.48*	-0.11 *-1.25*	-0.0003 *-0.49*	1.5e-6 *0.66*	1.45* *4.36*	1.1e-5* *2.56*	0.74
13	5.2e-6* *5.15*	-0.02 *-0.72*	-7.4e-5 *-1.87*	0.04* *1.99*	8.1e-5 *1.51*	-4.5e-6 *-1.76*	0.11 *0.82*	8.9e-6 *1.57*	0.20
14	2.2e-6* *3.15*	-0.02* *-1.98*	-2.3e-5 *-0.64*	0.05 *0.59*	1.6e-4 *0.04*	-2.1e-6 *-1.57*	0.87* *4.32*	7.2e-6* *2.48*	0.41
15	4.1e-8* *3.08*	-1.0e-4 *-1.40*	4.9e-7 *1.19*	-4.9e-4* *-2.37*	-3.6e-6 *0.45*	-1.6e-7* *-2.44*	0.09 *0.37*	4.6e-8* *2.28*	0.06
16	2.9e-10* *2.07*	8.3e-6 *1.57*	6.6e-9 *0.88*	2.1e-5 *0.33*	-7.3e-8 *-0.91*	-5.4e-10* *-2.35*	0.98* *2.65*	1.4e-9 *1.27*	0.46
17	5.7e-11 *1.88*	1.2e-6 *1.75*	-2.7e-9 *1.46.*	-1.9e-7 *-0.25*	3.8e-9 *0.59*	1.8e-11 *0.34*	3.15* *2.24*	-4.7e-10 *-1.64*	0.38
18	-5.6e-9 *-1.48*	-3.0e-7 *-0.007*	3.9e-8 *0.60*	-1.6e-4 *-1.39*	-2.4e-6* *2.02*	2.9e-8 *1.81*	1.46* *3.86*	-9.0e-10 *-0.14*	0.59
19	*1.8e-8** *3.49*	-7.2e-6 *-0.23*	-7.9e-8 *-1.34*	-4.2e-4 *-0.87*	-7.4e-6 *-0.76*	-3.9e-8* *-2.9*	8.4e-4 *0.04*	5.0e-10 *0.09*	0.05

* Denotes statistical significance at the 5 per cent level. t-values are written in italics.
**All standard errors are calculated using White's (1980) heteroscedasticity consistent covariance matrix.

Since it is likely that those regions with high levels of past innovative activities also have a tradition in either company R&D or university R&D (or both), we also test the model in Equation 4 *without* past innovative activity. In this manner, we can determine to what extent the mean patent per capita in the past "steals" the effect of company and university R&D. The result of this undertaking is presented in Table 4.3. When excluding past innovative activity from the model, the explanatory power decreases sharply for a majority of the sectors[18]. This confirms that it is very important to incorporate past innovative activity in order to explain and predict current innovative activities. As in Table 4.2, the fit of the model is highest for *Manufacture of coal, petroleum and chemicals*; *Manufacture of electric and optical products* and *Manufacture of precision instruments, medical and optical instruments*. Also, compared to previously, we can see that intra-regional accessibility to company R&D becomes significant for three new sectors when the patent stock is excluded. These are: *Manufacture of pulp, paper and publishing*; *Manufacture of electric and optical products* and *Manufacture of precision instruments, medical and optical instruments*. In this setting intra-regional accessibility to company R&D has a statistically significant positive effect on patenting for five sectors.

[18] Observe that the reported R^2's are adjusted so that they are comparable with models with different number of independent variables.

Table 4.3. *Estimation results of Equation 4 for the 19 sectors, past innovative activity excluded (N=81)*

	α	U_r^I	U_r^E	$R_{r,k}^I$	$R_{r,k}^E$	$C_{r,k}$	$P_{r,k}^{past}$	D_r^{metro}	adj.R^2
1	6.9e-7 *1.54*	5.7e-3 *1.15*	-2.5e-5 *-1.82*	2.7e-3 *1.51*	8.9e-4* *2.08*	-2.8e-6 *-1.73*	-	5.4e-7 *1.07*	0.08
2	8.7e-7* *4.30*	-4.1e-3 -0.98	1.5e-5* *-2.19*	-6.2e-3 *-1.84*	1.7e-3 *1.43*	-4.8e-7 *-1.37*	-	2.5e-6* *2.47*	0.21
3	6.1e-7* *6.56*	-1.0e-3 *-0.76*	-2.6e-6 *-0.61*	-8.3e-3* *-4.1*	-7.4e-4 *-1.12*	-7.9e-7* -2.93	-	2.7e-7 *1.47*	-0.01
4	1.4e-6* *4.59*	3.0e-3 *0.75*	-5.1e-6 *-0.49*	6.6e-3* *3.71*	-7.9e-5 *-1.39*	-2.0e-6* *-2.88*	-	1.9e-6* *2.12*	0.21
5	6.7e-6* *2.48*	0.11 *1.58*	-2.9e-4* *-1.98*	0.08 *0.80*	7.9e-4* *2.42*	--9.3e-6 *-1.95*	-	2.0e-5 *1.70*	0.38
6	2.9e-6* *5.66*	0.01 *1.45*	-3.13 *-1.17*	0.03 *0.73*	2.0e-3 *1.90*	-3.6e-6 *-1.41*	-	2.9e-6* *2.11*	0.15
7	1.1e-6* *6.04*	-3.7e-3 *-1.61*	-4.9e-6 *-0.39*	-4.8e-3 *-0.68*	4.9e-4 *0.57*	-1.3e-6* *-2.24*	-	1.6e-6* *3.14*	0.04
8	1.6e-6* *2.49*	-7.2e-3 *-1.62*	-4.4e-5 *-0.94*	0.07 *1.13*	9.2e-4 *0.99*	-2.8e-6 *-1.48*	-	1.3e-6 *1.34*	0.21
9	5.8e-6* *5.81*	-3.3e-3 *-0.41*	1.4e-5 *0.33*	0.04* *4.57*	-3.6e-4 *-1.11*	-8.8e-6* *-2.14*	-	4.3e-6* *4.18*	0.23
10	3.5e-5* *5.97*	0.08 *0.88*	3.3e-4 *0.84*	0.01 *1.55*	-5.6e-4 *-0.89*	-7.9e-5* *-3.29*	-	3.5e-5* *2.55*	0.15
11	6.7e-6* *4.1*	0.14 *1.15*	-1.2e-4 *-1.24*	0.16* *2.09*	-2.9e-5 *-0.26*	1.4e-6 *0.25*	-	2.3e-5 *1.12*	0.54
12	5.1e-6* *3.22*	0.05 *1.33*	-6.9e-5 *-0.51*	0.16* *4.57*	2.3e-4 *0.36*	-1.7e-6 *-0.46*	-	1.9e-5* *3.51*	0.44
13	5.7e-6* *6.18*	-0.02 *-0.81*	-7.9e-5* *-1.97*	0.04* *2.00*	8.9e-5 *1.51*	-4.7e-6 *-1.67*	-	9.6e-6 *1.63*	0.19
14	4.2e-6* *5.79*	-0.02 *-1.12*	-2.9e-5 *-0.90*	0.13 *1.65*	2.9e-3 *0.72*	-1.9e-6 *-1.16*	-	1.13* *2.86*	0.19
15	4.5e-8* *2.83*	-1.1e-4 *-1.40*	5.0e-7 *1.24*	-5.3e-4* *-2.8*	-3.6e-6 *-0.45*	-1.8e-7* *-2.45*	-	4.8e-8* *2.41*	0.07
16	3.7e-10* *2.80*	7.5e-6 *1.02*	5.6e-9 *0.75*	5.6e-5 *0.87*	-8.8e-8 *-1.10*	-5.7e-10* *-2.54*	-	1.8e-9 *1.18*	0.41
17	1.2e-10* *2.12*	8.6e-7 *0.56*	-4.1e-9 *-1.31*	1.1e-6 *0.87*	2.7e-9 *0.28*	-2.7e-12 *-0.04*	-	2.9e-11 *0.09*	0.006
18	4.4e-9 *1.54*	1.4e-4 *1.71*	9.3e-8 *1.30*	-1.9e-4 *-0.86*	-4.2e-6* *-2.24*	1.15e-8 *0.68*	-	-4.2e-9 *-0.33*	0.05
19	1.8e-8* *3.50*	-7.2e-6 *-0.23*	-7.9e-8 *-1.32*	-4.2e-4 *-0.89*	-7.5e-6 *-0.75*	-4.0e-8* *-2.92*	-	5.1e-10 *0.09*	0.06

* Denotes statistical significance at the 5 per cent level. t-values are written in italics.
**All standard errors are calculated using White's (1980) heteroscedasticity consistent covariance matrix.

The estimate is significantly negative for two sectors. This indicates that company R&D and patenting activity in some sectors do not coincide in space. Tin other words, patenting activity does not necessitate any company research internal to the region. The same applies to both intra-regional and external accessibility to university R&D. As before, the coefficient estimate for the regional industry structure variable is negative whenever it is significant.

Having estimated the model for the individual sectors, the next step is to turn to the results at the aggregated level. The selected model has the following form:

$$(5) \qquad P_{r,tot} = \alpha + \beta\, U_r^I + \delta\, U_r^E + \phi\, R_{r,tot}^I + \gamma\, R_{r,tot}^E + \varphi\, P_{r,tot}^{past} + \xi\, D_r^{metro} + \varepsilon_{r,tot}$$

Note that the regional industry structure is left out from this model. The reason is that it cannot properly be defined over the 19 different sectors. Table 4.4 provides the estimation results of Equation 5, both with and without past innovative activities on the right hand side (RHS).

Table 4.4. *Estimation results of Equation 5 with and without past innovative activity on the RHS.*

	Past innovative activity included	Past innovative activity excluded
α	1.8e-5* *2.16*	6.4e-5* *6.96*
U_r^I	0.25 *1.42*	0.39 *1.53*
U_r^E	0.0002 *0.36*	-7.8e-4 *-1.28*
R_r^I	0.008 *0.43*	0.07* *2.73*
R_r^E	-0.0001 *-0.71*	2.1e-4 *0.96*
P_r^{past}	1.02* *5.44*	-
D^{metro}	7.4e-5* *2.78*	1.4e-4* *4.00*
adj.R^2	0.67	0.40
N	81	81

*)Denotes statistical significance at the 5 per cent level. t-values are written in italics. All standard errors are calculated using White's (1980) heteroscedasticity consistent covariance matrix.

When past innovative activity is included in the model, it is the only significant determinant for the number of patent applications per capita in the 19 sectors. Also, the dummy for metropolitan regions is significantly positive, which confirms their special performance when it comes to patenting. In this specification, neither company R&D nor university R&D seems to have any distinct effect on the aggregate number of patent applications of the functional regions in Sweden. Of course, it is unlikely that past innovative activities are all that matters. Rather, it indicates that, at the aggregated level, the past innovative activity of a region contains the information needed in order to explain current patenting activity and its effect dominates. When past innovative activity is excluded from the model, intra-regional accessibility to company R&D becomes significant. Actually, besides the dummy for the three metropolitan regions, this is the only significant variable. This specification suggests that for the aggregate performance it is intra-regional accessibility to company R&D that matters, with regard to patent applications per capita. Intra-regional accessibility to university R&D does not play any statistically significant role, although it is positive.

In summary, the empirical results of this paper suggest that past innovative activity together with intra-regional accessibility to company research of a region are by far the most important factor for regional patenting (or innovative) activities. Past innovative activity alone is able to explain most of the variations across regions, which indicates strong effects of path-dependence. Moreover, it has been shown that the fit of the model differs substantially across sectors.

Surprisingly, our results suggest that university R&D plays a minor role for the number of patent applications. Do these results then mean, for instance, that university research is without clear benefits for regional innovative performance? We are confident that university research may have benefits in some regions and little in others, because networks between public research policy and commercial actors may be less developed at certain locations, hence our results show up as not significant. Similarly, the other results may be due to how each regional innovation system functions. Also, the results indicate that the relevant factors for patenting are to be found *within* the region. The separation between external and intra-regional accessibility shows that it is intra-regional accessibility that matters. To the extent that the results are due to externalities, the latter are to be found within the borders of a functional region. This means that studies using a finer spatial resolution than functional regions can provide deeper understanding of the knowledge production process. Moreover, a striking result is that the relationship between company R&D and patent applications is very weak for the majority of the sectors analyzed in this paper. How can this be explained? At a general level, the propensity to patent differs across sectors. Sherer (1983, p.107), for example, maintains that "the quantity and quality of industrial patenting may depend upon chance, how readily a technology lends itself to patent protection and business decision-maker's varying perceptions of how much advantage they will derive from patent rights". This implies that the output from R&D cannot always be patented as well as that some firms choose not to patent even if they can. An example of the former effect is implicitly given by Hunt (2001). According to the author, it was not until the 1990s that the patentability of computer software was clearly established in the U.S. Yet, firms in the software industry "… were innovating rapidly long before it was thought possible to patent their innovations", (Hunt, 2001 p.11). Why would firms choose not to patent even if they can? In a survey in 1994 of 1478 R&D labs in the U.S manufacturing sector, Cohen *et al* (2000) put particular focus on the relative importance of different appropriability mechanisms[19] as well as on why firms choose not to patent (different reasons to patent were also investigated). Relative to the other appropriability mechanisms, patents were not considered effective. For both product and process innovations, only *other legal mechanisms* were considered to be less effective. *Secrecy* and *lead time* were considered to be the most effective appropriability mechanisms. The main reason why patents provide limited protection was found to be the ease of inventing around and disclosure of critical information[20], (cf. Teece, 1986). Moreover, the R&D labs reported that the most important reasons not to patent were (in descending order): (1) *the difficulty in demonstrating the novelty of an invention*, (2) *the ease of legally inventing around a patent* and (3) *the amount of information disclosed in a patent application*.

The above implies that the lack of a significant relationship between company R&D and patent applications found for many sectors in this paper does not necessarily mean that their R&D is unsuccessful. Firms may simply choose not to patent their inventions. Also, it may not be possible to patent their R&D output. Of course, the insignificance may also simply be a result of that firms without (or with little amount of) R&D apply for patents. Because of this, an obvious avenue for further research is to investigate in detail the reasons for the insignificant relationship between both company and university R&D and patent applications.

5. CONCLUSIONS & SUGGESTIONS FOR FURTHER RESEARCH

Our endeavor in this paper has been to explain knowledge production across regions. In order to account for technological opportunity (Breschi *et al*, 2000), we performed a sectoral analysis, although we also looked at the aggregate level. The results of our efforts are mainly that patenting activity, both in the aggregate and at the sectoral level, is highly dependent on past successful innovation activities as reflected by past

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[19] Six appropriability mechanisms were considered: (i) patents, (ii) other legal, (iii) secrecy, (iv) lead time, (v) complementary sale/service and (vi) complementary manufacturing.

[20] Five reasons for not to patent were considered: (i) difficulty in demonstrating the novelty of an invention, (ii) the amount of information disclosed in a patent application, (iii) the cost of applying, (iv) the cost of defending a patent in court and (v) the ease of legally inventing around a patent.

patent applications. This variable dominates over most of the other variables in the analysis. When removing past innovative activity completely, intra-regional company research displays a statistically more clear impact on patenting activity. Surprisingly, our results suggest that university R&D plays a minor role for the number of patent applications. Some regions may be working very well in terms of the output of patents and the interplay with public actors (universities) may work smoothly. However, for other regions this interplay works less efficiently and there may be very little cooperation. This can explain insignificant results in our regressions. A next step in this analysis would be to find out which regions perform better and which do not. Such decomposition may be used to identify other explanatory variables.

REFERENCES

Acs, Z., L. Anselin, and A. Varga (2002), "Patents and Innovation Counts as Measures of Regional Production of New Knowledge," *Research Policy*, 31, 1069–1085.

Acs, Z., D. Audretsch, and M. Feldman (1991), "Real Effects of Academic Research: Comment," *American Economic Review*, 81, 363–367.

Acs, Z., D. Audretsch, and M. Feldman (1994), "R&D Spillovers and Innovative Activity," *Managerial and Decision Economics*, 15, 131–138.

Aghion, P., and P. Howitt (1998), *Endogenous Growth Theory*, The MIT Press, Cambridge Massachusetts.

Almeida, P., and B. Kogut (1999), "Localization of Knowledge and the Mobility of Engineers in Regional Networks," *Management Science*, 45(7), 905–917.

Andersson, M., and O. Ejermo (2003), "Does Closeness to Knowledge Handlers Spur Firms' Innovativeness?," JIBS Working Paper 2003-1.

Andersson, M., and C. Karlsson (2004), "The Role of Accessibility for Regional Innovation Systems," in Karlsson, C., Flensburg, P. & Hörte, S.-Å. (eds) (2004), *Knowledge Spillovers and Knowledge Management*, Edward Elgar, Cheltenham (Forthcoming)

Anselin, L. (1988), *Spatial Econometrics, Methods and Models*. Dordrecht, Kluwer Academic Publishers.

Anselin, L., and R. Florax (eds.) (1995), *Advances in Spatial Econometrics*. Berlin, Springer-Verlag.

Anselin, L., A. Varga, and Z., Acs (1997), "Local Geographic Spillovers between University Research and High Technology Innovations", *Journal of Urban Economics*, 42, 422-448

Breschi, S., F. Malerba, F. and L. Orsenigo, (2000), "Technological Regimes and Schumpeterian Patterns of Innovation", *Economic Journal*, vol. 110, April, 388-410

Breschi, S., and F. Lissoni (2001a), "Knowledge Spillovers and Local Innovation Systems, A Critical Survey," *Industrial and Corporate Change*, 10(4), 975–1005.

Breschi, S., and F. Lissoni (2001b), "Localized Knowledge Spillovers vs. Innovative Milieux - Knowledge Tacitness Reconsidered," *Papers in Regional Science*, 80, 255–273.

Cameron, G. (1998), *Innovation and Growth, A Survey of the Empirical Evidence*. paper based on 2nd chapter of D. Phil. thesis, Oxford, Nu¢eld College.

Capello, R. (2001), "Urban Innovation and Collective Learning, Theory and Evidence from Five Metropolitan Cities in Europe", in Fischer, M. and Fröhlich, J. (2001), *Knowledge, Complexity and Innovation Systems*. Berlin, Springer-Verlag.

Cohen, W.M. & Levinthal, D.A. (1990), "Absorptive Capacity – a new perspective on learning and innovation", *Administrative Science Quarterly*, 35, 128-152

Cohen, W., Nelson, R. & Walsh, J. (2000), "Protecting their Intellectual Assets: appropriability conditions and why U.S. manufacturing firms patent (or not)", *NBER Working Paper*, No. 7552

Desrochers, P. (1998), "On the Abuse of Patents as Economic Indicators," *Quarterly Journal of Austrian Economics*, 1(4), 51–74.

Desrochers, P. (2001), "Local Diversity, Human Creativity, and Technological Innovation,"*Growth and Change*, 32, 369–394.

Dosi, G. (1988), "Sources, Procedures and Microeconomic Effects of Innovation," *Journal of Economic Literature*, 26, 1120–1126.

Edquist, C. (1997a), “Systems of Innovation Approaches - their Emergence and Characteristics, in Edquist”, C. (Ed)., *Systems of Innovation, Technologies, Institutions and Organizations*. London, Pinter.

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

Ejermo, O. (2002a), “The Influence of Technological and Geographical Distance on Swedish Innovations and Knowledge Spillovers,” Dissertation plan presented at Jönköping International Business School, August 23rd 2002.

Ejermo, O. (2002b), “Productivity Spillovers of R&D in Swedish Industries and Firms,” Mimeograph.

European Patent Office (2002), European Patent Bulletin Information on DVD and CD-Rom. Vienna, EPO.

Fai, F., and N. von Tunzelmann (2001), “Industry-specific Competencies and Converging Technological Systems, Evidence from Patents,” *Structural Change and Economic Dynamics*, 12, 141–170

Feldman, M., and R. Florida (1994), “The Geographic Sources of Innovation, Technological Infrastructure and Product Innovation in the United States,” *Annals of the Association of American Geographers*, 84, 210–229.

Fischer, M. M., and A. Varga (2002), “Spatial Knowledge Spillovers and University Research, Evidence from Austria,” Forthcoming in *Annals of Regional Science*.

Fischer, M., and J.Fröhlich (2001), *Knowledge, Complexity and Innovation Systems*, Berlin, Springer-Verlag.

Glaeser, E., Kallal, H., Scheinkman, J. & Shleifer, A. (1992), ”Growth in Cities”, *Journal of Political Economy*, 6, 1126-1152

Griliches, Z. (1979), “Issues in Assessing the Contribution of R&D to Productivity Growth,” *Bell Journal of Economics*, 10, 92–116.

Griliches, Z., & Mairesse J. (1984), Productivity and R&D at the Firm Level, chap. 17, pp. 339–74. Chicago, University of Chicago Press.

Griliches, Z. (1990), “Patent Statistics as Economic Indicators, A Survey,” *Journal of Economic Literature*, XXVIII, 1661–1707

Harrison, B. (1996), “Innovative Firm Behavior and Local Milieu, Exploring the Intersection of Agglomeration, Firm Effects and Technological Change,” *Economic Geography*, 72, 233–258.

Hugosson, P. (2001), “Interregional Business Travel and the Economics of Business Interaction,” Ph.D. thesis, Jönköping International Business School.

Hugosson, P., and B. Johansson (2001), “Business Trips Between Functional Regions”, in Hugosson, P. (2001), “Interregional Business Travel and the Economics of Business Interaction,” Ph.D. thesis, Jönköping International Business School.

Hunt, R.M. (2001), “You can Patent that? Are Patents on Computer Programs and Business Methods Good for the New Economy?”, *Federal Reserve Bank of Philadelphia Business Review*, Q1, 5-15

Jaffe, A. B. (1989), “Real Effects of Academic Research,” *American Economic Review*, 79, 957–970.

Jaffe, A. B., M. Trajtenberg, and R. Henderson (1993), “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations,” *Quarterly Journal of Economics*, 108, 577–598.

Johansson, B., Klaesson, J. & Olsson, M. (2002), “Time Distance and Labour Market Integration”, *Papers in Regional Science*, 81, 305-327

Karlsson, C., Flensburg, P. & Hörte, S.-Å. (eds) (2004), *Knowledge Spillovers and Knowledge Management*, Edward Elgar, Cheltenham (Forthcoming)

Lorenzen, M. (1996), "Communicating Trust in Industrial Districts," Mimeograph.

Lundvall, B., E. (1995), *National Systems of Innovation - Towards a Theory of Innovation and Interactive Learning*. Biddles Ltd., London.

Marshall, A. (1920), *Principles of Economics*. London, MacMillan.

Maurseth, P. B., and B. Verspagen (1999), "Knowledge Spillovers in Europe and its Consequences for Systems of Innovations", chap. 7, pp. 1–20. Aldershot, Edward Elgar Publishing.

Møen, J. (2000), "Is Mobility of Technical Personnel a Source of R&D Spillovers?," NBER working paper no. 7834, Cambridge, MA, National Bureau of Economic Research.

NUTEK (1998), Små företag och regioner i Sverige 1998 - Med ett tillväxtperspektiv för hela landet, B1998,10. Stockholm, NUTEK.

Romer, P.M. (1986), "Increasing Returns and Long Run Growth," *Journal of Political Economy*, 94, 1002–1037.

Romer, P.M (1990), "Endogenous Technical Change," *Journal of Political Economy*, 98(5), 71–102.

Scherer, F.M. (1983), "The Propensity to Patent", *International Journal of Industrial Organization*, 1, 107-128

Teece, D. (1986), "Profiting from Technological Innovation: implications for integration, collaboration, licensing and public policy", *Research Policy*, 15, 285-305

van Pottelsberghe de la Potterie, B. (1997), "Issues in Assessing the Effect of Interindustry R&D Spillovers," *Economic Systems Research*, 9, 331–355.

Verspagen, B., and I. de Loo (1999), "Technology Spillovers Between Sectors and over Time," *Technological Forecasting and Social Change*, 60, 215–235.

Verspagen, B., and W. Schoenmakers (2000), "The Spatial Dimension of Knowledge Spillovers in Europe, Evidence from Firm Patenting Data", MERIT Working Paper No. 16. presented at the AEA Conference on Intellectual Property, Alicante, Spain.

Weibull, J. (1980), "On the Numerical Measurement of Accessibility," *Environmental Planning A*, 12, 53–67.

White, H. (1980), "A Heteroscedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity", *Econometrica*, 48, 817-838

Wiig, H., and M. Wood (1995), "What Comprises a Regional Innovation System? - An Empirical Study," Working Paper R-01, STEP, Oslo.

Zucker, L. G., M. R. Darby, and J. Armstrong (1998), "Geographically Localized Knowledge, Spillovers or Markets?," *Economic Inquiry*, XXXVI, 65–86. 22

Zucker, L. G., M. R. Darby, and M. B. Brewer (1998), "Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises," *American Economic Review*, 88(1), 290–306.

Åberg, P. (2000), Three Essays on Flows - Trade, Commuting and Foreign Direct Investment, Trita - IP FR 00-82.

APPENDIX A

Three procedures to distribute R&D-data to functional regions were undertaken, based on properties of the data. Data was provided with regional information in two ways: the judicial municipality of the firm, the regional distribution of R&D man-years on the county level. There are 25 counties, 81 functional regions and 289 municipalities (year 2002) in Sweden.