CESIS

Electronic Working Paper Series

Paper No. 03

How does Accessibility to Knowledge Sources affect the Innovativeness of Corporations? - Evidence from Sweden[1]

Martin Andersson and Olof Ejermo

(JIBS, CESIS)

May 2004

The Royal Institute of technology
Centre of Excellence for studies in Science and Innovation
www.infra.kth.se/cesis/research/workpap.htm
Corresponding author: olof.ejermo@jibs.hj.se

[1] Status of the paper: The paper will be submitted for a special issue of the *Annals of Regional Science* under the management of COST action A17.

How does Accessibility to Knowledge Sources affect the Innovativeness of Corporations? - Evidence from Sweden

Martin Andersson and Olof Ejermo*
martin.andersson@jibs.hj.se, olof.ejermo@jibs.hj.se

May 7, 2004

Abstract

The paper studies innovative performance of 130 Swedish corporations for 1993-94, using number of patents per corporation as a function of internal and external knowledge sources to the corporation.

A coherent way of handling accessibility measures, within and between corporations located across regions is introduced. We examine the relative importance of intra- and interregional knowledge sources from i) the own corporation, ii) other corporations, and iii) universities. The results show that there is a positive relationship between the innovativeness of a corporation and its accessibility to university researchers within regions where they have research. Having good accessibility between the corporation's research units does not have any significant effects on the production of patents. Instead the size of the R&D staff of the corporation seem to be the most internal factor. There is no visible indication that accessibility to other corporations' research is important for innovativeness. This suggests that knowledge flows, between firms belonging to different corporations are limited.

*Jönköping International Business School, P.O. Box 1026, SE-551 11 Jönköping, Sweden

1 Introduction

One of the most important and challenging questions in economics concerns the determinants of firm innovation. A study of the literature reveals that knowledge is maintained to be the most important, as well as the most generic, input in innovation processes (see inter alia Lundvall, 1995). Consequently, much research has focused on how firms gain and generate new knowledge and how such processes relate to innovation performance. The lack of confidence in the linear model of innovation (Kline and Rosenberg, 1986; Fischer et al., 1999; Fischer, 1999) has indeed made this a complex task. It is increasingly being recognized that firms should not be studied in isolation, but interdependent relations and the surrounding environment are also important factors to be incorporated (see e.g. Cohen and Levinthal, 1990). Accordingly, a firm's knowledge is not only dependent on its internal learning activities, but also on the learning activities of actors around that firm.

A mixture of externalities based upon localization economies can be used to explain how and why the performance of an individual firm is affected by factors external to the firm. From the seminal works of Marshall (1920), Arrow (1962) and Romer (1986), the idea of so-called MAR-externalities has been advanced. In principle, it tells us that the size and the intensity of (positive) industry-specific externalities increase with the size of the industry. MAR-externalities are sometimes referred to as static externalities (see e.g. Echeverri-Carroll and Brennan, 1999). The reason is that it is the current scale/size of the industry that generates the externalities. Despite the recognition of the MAR-externalities, some authors claim that dynamic externalities play a greater role than static ones. For example, Krugman and Obstfeld (2000) maintain that externalities stemming from the accumulation of knowledge are probably more important for innovation performance. Notwithstanding the distinction between types of externalities, it is clear that the economic milieu in which a firm performs has an effect on its performance. The impact of external knowledge on the innovation performance of the firm is most often explained by recalling a particular type of externality among the MAR-externalities, namely knowledge spillovers.

What are then knowledge spillovers? In the literature, Griliches (1992) made the distinction between pure knowledge spillovers or idea spillovers and rent spillovers.[1] Pure knowledge spillovers are pure externalities, in the sense that they are uncharged, unintended and as a consequence not mediated by the market mechanism. Rent spillovers are those externalities at least partially paid for, for instance embedded in goods or explicit transactions of patent rights.

Such a precise line between the two is difficult to draw in practical examples, especially as spillovers become more complex and there is a 'club element' to knowledge. Suppose that a 'membership fee' into a network of skilled knowledge workers involves sharing of useful information with other members of the network. If you expect some information in return in the future, is this a pure knowledge spillover or a rent spillover? Clearly there is some important middle ground for which the literature has yet to come up with precise definitions. Johansson (2004) fills this gap by *parsing the menagerie of agglomeration and network externalities.*

Much attention in the literature has been given spatial aspects of knowledge flows. Such flows, are seen as being most effectively mediated through face-to-face (FTF) contacts. Thus, proximity between knowledge exchangers is deemed critical. Recalling the well-established axiom in regional economics, that is "interaction decreases with distance", (Beckmann, 2000, p. 129), it is clear that proximity has a role to play. Some confusion can easily emerge around such a reasoning. On the one hand, flows of knowledge need not be bounded by space. For instance (Geroski, 1995) refers to knowledge is the classic example of a public good, i.e. it is non-rival and non-excludable. On the other hand, all kinds of knowledge are not distance-insensitive. Different forms of knowledge certainly requires different amounts of efforts to be transmitted. The concept of "tacit" knowledge is repeatedly employed by many authors to explain why FTF-contacts are

[1]The latter seems equivalent to what some call pecuniary externalities (Scitovsky, 1954).

necessary for efficient transmission of knowledge. In fact, it seems to be a consensus among researchers that much relevant knowledge is tacit in nature (see e.g. Maillat and Kebir, 2001; Lorenzen, 1996). In contrast to knowledge that easily can be transformed into information and, hence, is possible to transmit via telecommunications (such as the internet), tacit knowledge has been defined as semi- and unconscious knowledge that does not exist in printed explicit forms (Leonard and Sensiper, 1998).

The purpose of the present paper is to study the role of accessibility to knowledge sources for the production of new knowledge within Swedish corporations. In this process we check for effects arising from being close to other knowledge handlers, including those within the corporation.We use corporations as our unit of analysis, because many of the research-intensive firms are part of large corporations (multinationals) in Sweden (see Braunerhjelm, 1998) that are connected via ”mother” and ”daughter” relationships. For instance, Fors and Svensson (1994) report that 83 per cent of aggregate Swedish industrial R&D is conducted in multinational enterprises. In addition, the effects of (mainly product) R&D in Swedish multinational enterprises seem to have a causal bidirectional relationship to foreign sales, indicating that the benefits of Swedish R&D mainly occurs abroad (Fors and Svensson, 2002). Defined in this way, no previous analyses have to the authors knowledge, been done using corporations as the unit of analysis.

A corporation is here defined as a group of firms belonging to the same observational unit. A company is a parent company to another (subsidiary company) if it owns more than 50 per cent of the latter's total number of stocks.[2] It has long been recognized that R&D may be put in special departments. For example, Whitehead (1925, p. 98) wrote that "The greatest invention of the nineteenth century was the invention of the method of invention.". Mowery and Rosenberg (1998) describe the importance of the development of formalized R&D institutions in the U.S. in the 20th century. This gives credit to the use of the whole corporation as the observational unit for studying R&D. Knowledge flows between research departments

[2]Details about the requirements for being defined as a corporation can be found in the Swedish joint-stock company law (Svensk Författningssamling, 1975)

within the same corporation can be expected to be higher than knowledge flows emanating from other corporation's R&D departments. The analysis is therefore conducted by investigating the relationship between a corporation's innovativeness and (i) total stock of R&D personnel (man-years), (ii) average accessibility between the corporation's R&D staff, (iii) the average accessibility to other corporations' R&D staff and (iv) average accessibility to university R&D. Inspired by the work by Johansson and Klaesson (2001), a distinction is made between intra- and extraregional accessibility. The logic for including a firm's accessibility to its own R&D comes from the fact that the total R&D personnel of a corporation is often spread over different locations. Innovativeness is measured as the number of patents granted to a corporation. The patent data used in the analysis comes from the European Patent Office (EPO). It should be mentioned that patents are not the only way to indicate innovations. In addition, R&D, innovation expenditures, sales of imitative and innovative products and new product announcements have been used. See (Kleinknecht et al., 2002) for a recent discussion of them. (Griliches, 1990) and (Desrochers, 1998) provide discussions of patents as innovation indicators. We note that no indicator can match patents in terms of the availability of data on fine geographical levels, and over longer time periods. Another potential problem of using EPO-patent data is that they are more costly to apply for than national patents only. These costs are higher because the search for earlier priority (technical knowledge) becomes more pronounced and because more monetary value can be extracted from the monopoly right awarded the patentee. Thus, smaller firms with less far-reaching ambitions with regard to their patenting are likely to be excluded from the material. We believe this is not a serious problem for the present paper because the R&D material mainly springs from large firms anyway.

The paper proceeds as follows. In Section 2, a review of a selection of the studies on "knowledge spillovers" is presented. In Section 3, the dataset and the construction of variables are explained (part of the algebra has been put in an appendix). Thereafter, in Section 4, the model used for empirical estimation is presented, followed by empirical results and comments. Section 5 concludes the paper and outlines some directions for future research.

2 The Role of Space in Knowledge Flows

2.1 Studies of "Knowledge Spillovers" in the Geography

Using the analytical distinction of Feldman (1999), it is possible to characterize the studies of knowledge effects in regions from one of four tracks: (i) geographic knowledge production functions, (ii) paper trails, (iii) ideas in people or (iv) ideas in goods.

Geographic knowledge production functions (KPF) are used extensively in the literature. The aim of KPF's are to study the relationship between inputs, presumed to affect knowledge production of a unit, and output. The origin of this literature and setup of the main estimated equation, comes from Griliches (1979). Jaffe (1989) examined the *geographical coincidence* of university research with that of research labs within 29 US states for 1972-77, 1979 and 1984 respectively. A strong relationship between corporate lab patenting and university research in the areas drugs, chemicals and electronics was found. Furthermore, it seemed that industrial R&D was induced by presence of university research. Similar studies applying the KPF approach include Acs et al. (1992, 1994), Anselin et al. (1997, 2000), and Autant-Bernard (2001). Acs et al. (1992) examine how different industries respond to the R&D-innovation relationship using the U.S. small business administration innovation database for 1982, compared to Jaffe's (1989) patent exercise. Using the same database, Acs et al. (1994) find that small businesses seem to be better able to assimilate the knowledge from research institutions than large ones. Anselin et al. (1997) study the degree of spatial spillovers between university research and high technology innovations, by applying the KPF approach at both the state and the metropolitan statistical areas (MSA) in the U.S. They find evidence of local externalities between university reserach and high technology innovations. The same group of authors, Anselin et al. (2000), extend their work in Anselin et al. (1997) by means of a sectoral disaggregation. Their main conclusion is that local university spillovers seem to be specific to certain industries. 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[3] used to explain the results of such studies would imply that knowledge that diffuses is a pure externality. The authors go on and conclude that at 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.

Paper trail studies start off by noting that knowledge does sometimes leave a paper trail in the form of patents (Jaffe et al., 1993). Thus, by studying citations it is reasoned that we may get information on the direction of knowledge flows. Most authors conclude that citations are in fact constrained geographically. Furthermore, citations spread over larger distances as time goes by. A potential pitfall of patent citations is that self-citations, i.e. citation to own work, should be disregarded if we want to study the networks of inventors. Jaffe et al. (1993) examined localization of citation patterns by constructing a *control sample* with similar properties as the original patents. It was found that patents were more likely to be domestic to the US if the cited patents were from within the country. Furthermore, citations were more likely to come from the same state or Standard Metropolitan Statistical Area as the original patent. Some evidence was also found that geographic localization fades over time. Also, citations in specific technology areas were found to be less geographically localized. The Jaffe et al. (1993) spurred several research efforts. In a study across European regions, Maurseth and Verspagen (2002) also found compelling evidence of a localization pattern of patent citations. However, national barriers were important so that patent citations occurred more often between regions belonging to the same country. Fischer and Varga (2003), examined

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

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. Employing a spatial econometric approach, the authors find evidence of spillovers across regions, which is linked to a spatial decay effect. The Jaffe et al. (1993) method has recently been challenged in two working papers. Thompson and Fox-Kean (2003) redo the control sample exercise of Jaffe et al. (1993), on a higher level of disaggregation, but were unable to replicate their exercise. Breschi and Lissoni (2003) construct a database of all patenting inventors 1987-1989 of the Italian innovation system, to see how *social networks* and measurement of their strength influence the result of Jaffe et al. (1993). Their results suggest that the strength of these networks alone are able to explain all the localization effects of citations, thus casting doubt on the pure knowledge spillover hypothesis.

The third tradition of studying knowledge flows is more recent and builds on the idea that knowledge is mainly embedded in people. Therefore, mobility of labour, and in particular scientists is studied. In this manner, Zucker et al. (1998) study the California biotechnology sector. They find that market mechanisms, facilitated by contracting of star scientists, induce transfer of knowledge from star scientists retaining their connections to universities while being affiliated to biotechnology firms. In an accompanying paper, Zucker et al. (1998) find that the localization of biotechnology star scientists over the US are important factors in determining both the location and timing of entry of new biotechnology firms. Similarly, Almeida and Kogut (1999) study how the mobility of engineers in the semiconductor industry affects the pattern of citation of patents. Indeed, they find that there are strong effects of relocation of people on these, suggesting that movement of core individuals shape the evolution of industry. If knowledge is embedded in labour markets, Møen (2000) suggests that we should be able to observe how wages reflect the accumulation of knowledge. He tests this with a large and informative dataset on technicians, using wages, mobility and the R&D-intensity of firms of the Norwegian machinery and equipment industry. It is found that R&D-investment is at least partially incorporated into the labour market through the mechanism outlined above.

Flow of goods mainly refers to the literature on inter-industry spillovers. This literature has emphasized the role of linkages between firms and industries formed by customer-supplier relationships. For an overview of this literature we refer to Ejermo (2004).

In sum, there is a vast amount of empirical literature using different approaches examining the nature of knowledge spillovers. Many of the later contributions, cast doubt on whether spillovers really are pure knowledge spillovers, i.e. spillovers for which no compensations is given. Whether, working through the labour market or through explicit knowledge-transfer contracts, knowledge flows seem more often to be pecuniary. Our paper clearly belongs to the KPF-tradition. In the next subsection, we present a simple framework, showing the role of proximity for knowledge flows.

2.2 A framework for spillovers within and across regions

This paper builds on the assumption that knowledge flows are more intense the higher the accessibility between two parties. Using a slightly modified version of a set-up introduced by Beckmann (2000, p. 134), the importance of distance for the potential of assimilating knowledge flows can be illustrated relatively simple. As a start, we assume that the innovative activity of a corporation k, is dependent on two sources, university research $U \equiv \sum U_i$ and research from the own and other corporations' research, $R_k \equiv \sum R_l$.[4] Thus, we can write:

$$Y_k = f\left(\sum U_i, \sum_{l \neq k} R_l\right) \tag{1}$$

where Y_k denotes innovation of corporation k. Furthermore, we assume that the potential of a research unit of corporation k to receive knowledge is negatively related to the distance to those sources. With a Cobb-Douglas

[4] Of course, this is a stylized simplification because it implies that all research is treated equally for all corporations. In the applied empirical analysis we distinguish between own and other corporate research, as well as make a distinction between intra- and interregional accessibility to knowledge.

setting it can quite easily be shown that distance affects the expected size of knowledge flows. Following Beckmann (2000), the formulation presented in Equation (2) is used. Each research unit of a corporation k is assumed to maximize the benefits of innovations, which is assumed to be dependent on the amounts of university and corporate research. The function should not be interpreted literally, i.e. the corporation cannot choose the research levels of other corporations', but it should be interpreted as the efforts laid down to access research. So we write:

$$\max P_k Y_k = \max_{U,R_k} U^\alpha R_k^\beta - \tau_u U - \tau_R R_k \tag{2}$$

which is an unconstrained optimization problem. P_k is the price of corporation k:s innovations. $\tau_u$denotes the average time-distance cost of accessing university research, τ_R is the average time-distance cost of accessing corporation research. Hence, τ_u and τ_R are the opportunity costs of accessing knowledge. Without loss of generality, (2) can reformulated as in (3), where $P_k = 1$.

$$\max Y_k = \max_{U,R_k} U^\alpha R_k^\beta - \tau_u U - \tau_R R_k \tag{3}$$

From the first order conditions we can compare the relative use of knowledge of universities and corporations:

$$\frac{\partial Y_k}{\partial U} = \alpha U^{\alpha-1} R_k^\beta - \tau_u = 0 \tag{4}$$

$$\frac{\partial Y_k}{\partial R_k} = U^\alpha \beta R_k^{\beta-1} - \tau_R = 0 \tag{5}$$

Dividing (4) with (5) leaves us with,

$$\frac{\alpha U^{\alpha-1} R_k^\beta}{U^\alpha \beta R_k^{\beta-1}} = \frac{\tau_u}{\tau_R} \Leftrightarrow \frac{R_k}{U} = \frac{\beta}{\alpha}\frac{\tau_u}{\tau_R} \tag{6}$$

which shows that the optimal efforts of assimilating university relative to corporation research (whether from the own corporation or to that of other corporations) is dependent on the ratio of average time-distance costs to access these resources multiplied by the relative elasticities, i.e. the effect on innovations. Thus, if the time distance to university researchers is significantly lower than the time distance to private research institutions, then we may expect that the exchange and collaboration with university researchers is larger.

3 Data description and computations of variables

This section describes the model and the variables used in the empirical analysis. Further, the model presented in section 3 will be extended by incorporating accessibility. A coherent way of handling accessibility measures within and between corporations located across space is also introduced.

3.1 Data

Our two main indicators of inventive activity are R&D data and granted patents. The geographic distribution of these have been shown to be highly concentrated to the three metropolitan regions Stockholm (mid-east Sweden), Gothenburg (west-south-west) and Malmö (south). This concentration is a lot higher than is motivated by population size. For a more detailed description including maps see Andersson and Ejermo (2004).

Data for patents were taken from the European Patent Office database of granted patents. Data on number of man-years in research are from the primary material of "Research and Development in the Business Enterprise Sector 1993" (BERD), a data collection effort done biyearly by Statistics Sweden, which is the basis for the statistics on research and development compiled for the OECD. Time distances between Swedish local labour market regions, used to calculate accessibilities, were computed from the Swedish National Road Administration's database in Sweden. It was calculated as the average of time distances between functional regions (LA-regions) in 1990 and 1998. The definition of local labour market regions follows the one given by NUTEK (1998). In essence, regions are identified

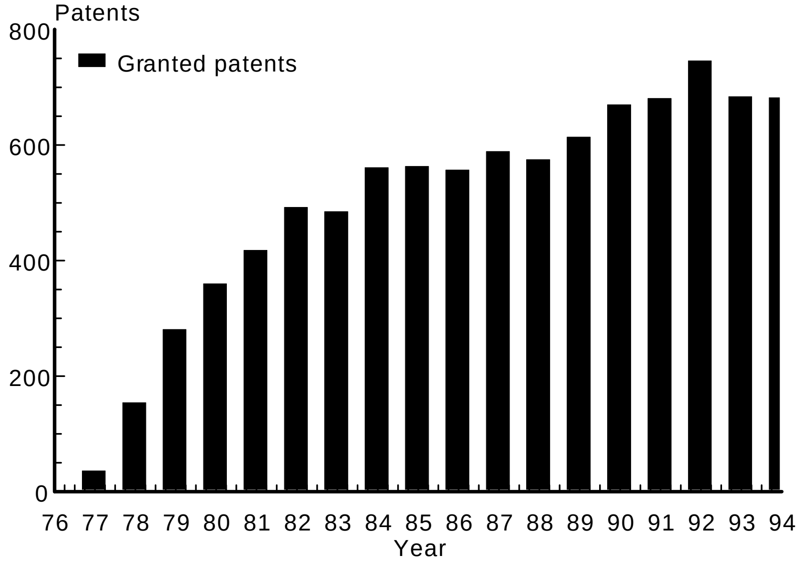

Figure 1: Number of granted patents to the EPO with a Swedish inventor. Year shows the year of priority.

by the intensity of commuting flows between Swedish municipalities.[5]

The latest year for which we could be reasonably sure that most applications had been processed and granted, were patents applied for in 1994. This date was determined by looking at the priority date. Swedish patents from this year were taken from the database, on a company-to-company basis (the names of the companies were also available). For each company the number of patents were added together.

The second dataset consists of amount of man-years in research & development from 1993 on the county level, which is the closest year for which such data are available. Usually it takes time for company research to result in innovation, hence the fact that one year separates application from actual conducted research did we not consider to be a problem. R&D data is taken from BERD. Furthermore, firms were aggregated into corporations as described in the introduction, both for the patent and BERD datasets. Sources for this work were among others the yellow pages of the Swedish

[5]NUTEK aggregated Swedish municipalities into 81 local labour market regions.

phonebook. The county data information from BERD was used to manually distribute R&D to local labour market regions.

A third dataset consisted of man-years in university and higher education R&D. This data was provided by Statistics Sweden.

3.2 Computation of variables

As mentioned earlier, the analysis considers three knowledge sources available for a corporation. These are (1) own R&D, (2) other corporations' R&D and (3) university research. As stated in the introduction, accessibility is used to operationalize geographical proximity. Measuring accessibility is an appropriate method to handle proximity since it is related to concepts such as ease of spatial interaction and potential of opportunities of interaction, etc (see inter alia Weibull, 1980). This implies that accessibility is by definition strongly connected to the potential of FTF-interactions and thus knowledge exchange as discussed in Andersson and Karlsson (2004). The measure of accessibility used here is employed to represent potential of opportunities and takes the following form with an exponential distance decay (see e.g. Johansson et al., 2002)

$$ACC_r = \sum_{s=1}^{n} D_s e^{-\lambda t_{rs}} \tag{7}$$

In the formulation above, ACC_r denotes accessibility for region r to some relevant opportunity D of region s discounted by $e^{-\lambda t_{rs}}$ where λ is a sensitivity parameter with respect to t. This variable can either represent geographical distance or time distance. The time distance of travelling between two regions is denoted by t_{rs}. The internal time distances are calculated as the mean time distances between the municipalities within the local labour market regions.[6] The use of time distances brings many advantages (see e.g. **?**). Clearly, what is relevant in the context of interaction

[6] If a local labour market region only consists of one municipality the internal time distance is calculated as the mean time distances between the SAMS-areas of that municipality.

is not so much the geographical distance. It is rather the time needed in order to overcome a certain distance. Moreover, geographical distances do not reveal important difference across regions. Two regions may have the same geographical distance to some relevant opportunity but unequal time distance due to, say, differences in the quality of the regional infrastructure. Such differences are important to take into account when dealing with the potential for FTF-interactions. Furthermore, since time distances at least in one aspect reflects regional infrastructure capacity, they provide a first-rate base for policy-analysis incorporating infrastructure investments. The value of the time sensitivity parameter, λ, is set to 0.1 for intraregional time distances which is the value found by Åberg (2000) for daily commuting. For interregional time distances λ is set to 0.017. This is the time distance sensitivity estimated by Hugosson (2001) based on data on Swedish interregional business trips. Formulating accessibility as in equation 8 provides an easy way of separating intra- and interregional accessibility. If we let $W = \{1, ..., n\}$ 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:

$$ACC_r = D_r e^{-\lambda_{ir} t_{rr}} + \sum_s D_s e^{-\lambda_{er} t_{rs}}, \qquad r \in W \text{ and } s \in W_{-r} \tag{8}$$

Hence, the total accessibility to an opportunity for a region is a weighted sum of accessibility to opportunities within the region and accessibility opportunities in other regions. In Appendix B we have put the algebraic details of how our variables were constructed.

The method described above should be an effective way of assessing the role of closeness to knowledge resources. Since the distinction between intra- and interregional accessibility provides two parameters to be studied, it allows for a clear-cut evaluation of the relative importance of resources within and outside regions. Concurrently, it may also give a hint of the nature of the knowledge externalities that are important. Of course, our approach will not be able to reveal the exact mechanisms through which

Variable	Denotes
pat_k	Number of patents
R_k	Number of research personnel employed by the own corporation
$A_{int,k}$	Average total accessibility to own research
$A_{ext1,k}$	Average intraregional accessibility to other corporations' research
$A_{ext2,k}$	Average interregional accessibility to other corporations' research
$AU_{1,k}$	Average intraregional accessibility to university research
$AU_{2,k}$	Average extraregional accessibility to university research

Table 1: Variables, their meaning and importance with respect to intra- and interregional accessibility.

knowledge is transferred. However, if we believe that FTF-contacts are required for fruitful knowledge exchange and interregional accessibility turns out to be important we can at least rule out that the process of knowledge exchange should be characterized as a pure externality. Unplanned and involuntary FTF-contacts between researchers in different regions are most unlikely since the time distances are sufficiently large to demand planning in advance. In this case one would expect that knowledge spillovers would occur through, for example, business meetings and networks across regions. On the other hand, if it is intraregional accessibility that is important we can at least conclude that the processes that generate knowledge exchange do indeed have a local character. However, it is not possible to rule out the role of both pure and pecuniary externalities in either case.

4 Empirical Analysis

4.1 Estimation Issues

The number of patents pat_k of a corporation k is modelled as dependent on the variables as indicated by Table 1.

Since the number of patents is a discrete variable, count data techniques are appropriate. Normally, this type of regressions are handled by a Poisson type of model. However, only 39 of 130 corporations (30 per cent) in our dataset have patents granted and registered at the EPO. In the econometrics literature, another type of model, the Zero-Inflated Poisson (ZIP) model, has been advanced to take into account that decision units may be subject to one of two types of regimes: (1) whether to engage in patenting at all, (2) how many patents to "produce" (where 0 patents is still an option). Another problem with the Poisson-model is the implicit assumption that variance and mean are equal (Greene, 2003). The other way that the literature copes with the problem is to use a Negative-Binomial, which generalizes this assumption to allow for the variance to differ. Finally, the Zero-Inflated Negative Binomial (ZINB) model is a mixture of the two approaches. We briefly review the stated models below.[7]

In the Poisson model, the probability that the number of patents takes a certain value is a function of the underlying observations. The above list of right-hand side parameters for $R_k, A_{int,k}, A_{ext1,k}, A_{ext2,k}, AU_{1,k}, AU_{2,k}$ can be generalized as a column vector $\boldsymbol{\beta}$ and the values themselves as a column vector $\mathbf{x}_k$. The Poisson model is written

$$\Pr[PAT_k = pat_k] = \frac{e^{-\lambda_k}\lambda^{pat_k}}{pat_k!}, \qquad pat_k = 0, 1, 2, 3, ... \tag{9}$$

where λ_k is in turn related to the set of regressors $\mathbf{x}_k$:

$$\ln \lambda_k = \boldsymbol{\beta}'\mathbf{x}_k \tag{10}$$

As stated, a disadvantage of the Poisson model is that variance and expected value are assumed to be the same:

$$E[pat_k \mid \mathbf{x}_k] = \mathrm{Var}[pat_k \mid \mathbf{x}_k] = \lambda_k = e^{\boldsymbol{\beta}'\mathbf{x}_k} \tag{11}$$

A more general form is given by the negative binomial regression model.

[7]The following text draws on Cameron and Trivedi (1998) and Greene (2003).

λ_k is respecified as

$$\ln \lambda_k = \boldsymbol{\beta}'\mathbf{x}_k + \varepsilon$$

where e^{ε} has a gamma distribution with mean 1 and variance α. In what follows we test for *overdispersion*, i.e. difference between mean and variance, using a likelihood-ratio test. The resulting probability distribution is

$$\Pr[PAT_k = pat_k \mid \varepsilon] = \frac{e^{-\boldsymbol{\beta}'\mathbf{x}_k e^{\varepsilon}} (\boldsymbol{\beta}'\mathbf{x}_k)^{pat_k!}}{pat_k!}, \qquad pat_k = 0, 1, 2, 3, ... \tag{12}$$

In the *ZIP-model*, we have two regimes at work. The probability of a zero outcome, is the probability of regime 1 - no patents, + the probability of a zero patents, given regime 2 - patenting activity.

$$\Pr[pat_k = 0] = \Pr[\text{regime 1}] + \Pr[pat_k = 0 \mid \text{regime 2}] \tag{13}$$

$$\Pr[pat_k = n] = \Pr[pat_k = n \mid \text{regime 2}] \Pr[\text{regime 2}], \qquad n > 0 \tag{14}$$

An underlying variable, z, is a dummy, taking the value 1 if regime 2 is in action and 0 under regime 1. Compared to the models above, the probability of attaining a zero value has been increased. The process determining z_k is $z_k^* = \gamma'\mathbf{x}_k + \eta_k$, where η_k is i.i.d. with cumulative density function $\Phi(.)$. If $z_k^* > 0$ then $z_k = 1$ and $z_k^* \leq 0$ if $z_k = 0$.Then

$$\Pr[pat_k = 0] = 1 - \Phi(\gamma'\mathbf{x}_k) + \Phi(\gamma'\mathbf{x}_k) \cdot \Psi(0 \mid \boldsymbol{\beta}'\mathbf{x}_k) \tag{15}$$

$$\Pr[pat_k = n] = \Phi(\gamma'\mathbf{x}_k) \cdot \Psi(n \mid \boldsymbol{\beta}'\mathbf{x}_k), \qquad n > 0 \tag{16}$$

The distribution of $\Psi(n \mid \boldsymbol{\beta}'\mathbf{x}_k)$ can be estimated either with a Poisson or a negative binomial distribution. The next section reports on the estimations based on the Poisson, the negative binomial, the ZIP-model and the ZINB-model.

4.2 Empirical results

4.2.1 Model specification issues

Table 3, presents the results from the Poisson, ZIP, neg. bin. and ZINB models. The results are sensitive to model specification, i.e. coefficients and significance levels change which makes it important to test for specification. This makes it important to evaluate the models preferably by formal test procedures. Greene (2003) and the software Stata's website (STATA Webpages, 2003) emphasize that the processes are very different. "Either unobserved heterogeneity or a process that has separate mechanisms for generating zero and nonzero counts can produce both over-dispersion and 'excess zeros' in the raw data." (STATA Webpages, 2003). Thus, if we start out with a Poisson model, if a test of overdispersion rejects the Poisson model, we must still test for Zero-inflation. The overdispersion test is done using a Likelihood-Ratio test. This test rejects the Poisson model in favour of the Negative binomial model ($\chi^2 = 722.77$). In addition, a nonnested test due to Vuong (1989) is used to test ZINB vs. Neg. bin. and ZIP vs. Poisson. We find that Neg. bin. is strongly rejected (1 per cent level) for ZINB and Poisson is rejected for ZIP (5 per cent level). These results suggest either a ZIP or a ZINB model to be appropriate. Unfortunately, there is no applicable test of ZINB vs. ZIP, but the Likelihood-ratios and the log-likelihoods, show that the ZIP-model is the better model.[8] Hence, the ZIP-model gives the most reliable estimates. The estimates of the Negative binomial and the ZINB-model are put in the Appendix.

4.2.2 Interpretation of the results

The ZIP model suggests that research in the own corporation has a highly significant effect on the likelihood to produce patents. Furthermore, internal accessibility is positive but not significant. This means that it is the size

[8] We also looked for the prediction accuracy of the models. In an Appendix, Figures 2 and 3 show the predictions pat_k compared to actual values for the poisson, zip and zinb models (Figure 2) and the neg. bin. model (Figure 2). As can be seen, the negative binomial model performed remarkably poorly, with three extreme outliers (see the Appendix for details).

Variable	Poisson		ZIP	
constant	.4262 (.1569)	***	2.0615 (.1703)	***
R_k	.0004 (.0000)	***	.0002 (.0000)	***
$A_{int,k}$	.0020 (.0006)	***	.0007 (.0006)	
$A_{ext1,k}$	.0000 (.0011)		.0014 (.0012)	
$A_{ext2,k}$	-.0001 (.0001)		-.0004 (.0001)	***
$AU_{1,k}$	.0046 (.0010)	***	.0042 (.0011)	***
$AU_{2,k}$	.0009 (.0004)	**	.0005 (.0005)	
LR-test	296.48		127.83	
$no.obs$	130		130	

Table 2: Estimates of the Poisson and the Zero Inflated Probability Model. Standard errors are in parenthesis. *, ** and *** denote significance at the 10, 5 and 1 per cent level respectively.

of the R&D-staff that is important, while the accessibility to FTF-contacts between the research units is of minor importance. No significant intra-regional effects are found between corporations. Thus Swedish corporations formally engaged in R&D activities do not benefit from the accessibility obtained by having high accesibility to other corporations' research units in the same region. Patenting is also found to be somewhat less likely when there is higher accessibility to other corporations research in regions outside where the own corporation has R&D.

We find that it is much more likely that there is patenting when the corporation has high intra-regional accessibility to university research, which is even stronger than the likelihood effects obtained from conducting own research. This may be the result of established local networks to the university. Interestingly, it seems as if university contacts should be maintained close to where universities are located, since their effect is highly local in scope. Our results are consistent with those of Ejermo (2004) who found little sign of spillovers across Swedish industries and firms.

5 Conclusions

R&D-effects on patenting in Swedish corporations have been examined in a framework of accessibility. R&D-activities of our sample of corporations have not been found to affect the likelihood of patent production of other corporations intra-regionally (although higher accessibility improves the likelihood across regions). Thus, although Swedish corporations are R&D-intensive by international standards, they do not benefit much from localizing their activities near one another. It must be stressed however, that not all learning in firms take place through R&D. That is, small firms without formal R&D-units are not captured by our sample. Thus, it would be wrong to conjecture that no knowledge effects take place across firms. A future research issue is therefore to analyze local effects investigating firms not in the sample, perhaps through community innovation survey indicators. It should in this context also be of particular importance to divide between large and small Swedish innovators, to see whether there are differences in the ability to assimilate university or other corporate research that is related to size. The presence of high accessibility to university research in the same region seem to spur the likelihood for patenting in corporations.

The paper has stressed that any spillover effects involved may be of both pecuniary and pure externality type, i.e. it is not possible to separate between rent vs. idea spillovers, hence both market and non-market effects are estimated jointly. Thus, this research could be complemented along a number of lines. As mentioned, future studies should separate the effect of firm size on appropriability and dissipation of research. The age of the corporation could also play an important role. It could be that only established corporations have access to university research. It would also be illuminating to investigate which are the spillover channels through which results are spread. One such opportunity is to study the role for labour markets. For instance, inventors role in forming new companies and their mobility across employers.

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Appendix A Details on construction of accessibility variables

These sections describe the construction of the accessibility variables used in the empirical estimations.

Appendix A.1 Within-corporation knowledge accessibility

Internal accessibility to R&D plants within each corporation can be calculated by matrix algebra in the following way. First, we define an 81 x 81 symmetrical matrix, T, displaying mean time distance between 1990 and 1998 from one local labour market region to another.

$$\mathbf{T} = \begin{bmatrix} \tau_{1,1} & \cdots & \tau_{1,81} \\ \vdots & \ddots & \vdots \\ \tau_{81,1} & \cdots & \tau_{81,81} \end{bmatrix}, \text{ where } \tau_{i,j} = e^{-\lambda t_{i,j}} \tag{17}$$

We define a matrix $\mathbf{R}$ describing the distribution of each corporation's R&D personnel across space. This matrix is 81 x 130 so that:

$$\mathbf{R} = \begin{bmatrix} R_{1,1} & \cdots & R_{1,130} \\ \vdots & \ddots & \vdots \\ R_{81,1} & \cdots & R_{81,130} \end{bmatrix} \tag{18}$$

where for example $R_{39,53}$ denotes the research activity of corporation 53 in region 39. $\mathbf{R}$ denotes the number of research personnel. Also, a dummy matrix is defined so that

$$\mathbf{D} = \begin{bmatrix} D_{1,1} & \cdots & D_{1,130} \\ \vdots & \ddots & \vdots \\ D_{81,1} & \cdots & D_{81,130} \end{bmatrix} \tag{19}$$

Each value $D_{r,k}$ has a value of 1 if corporation k has research activity in region r and 0 otherwise. This matrix is constructed to ensure that if a corporation is not present in a region, it will not have access to other research within the corporation from that region. Then we define

$$\mathbf{TRD} = (\mathbf{TR}). * \mathbf{D} \tag{20}$$

where $.*$ denotes the Hadamard (elementwise) matrix multiplication (. / will later denote Hadamard, elementwise, matrix division). To sum over the columns in the matrix $\mathbf{TRD}$ and account for the number of regions in which a corporation is present in we form an 1x81 row vector i_{81} of ones and premultiply $\mathbf{TRD}$ with this. The result is a 1x130 row vector, showing the sum of a corporation's accessibility of all locations in which it is present.

$$\mathbf{TRD}_{sum} = i_{81}\mathbf{TRD} \tag{21}$$

Next, we premultiply the $\mathbf{D}$ matrix with the same row vector i. The resulting 1 x 130 row vector, N, shows for each element the number of locations in which a corporation has research activities.

$$\mathbf{N} = i_{81}\mathbf{D} \tag{22}$$

Finally, we divide each element of $\mathbf{TRD}_{sum}$ by the corresponding element of $\mathbf{N}$ and take the transpose, so that internal accessibility shows up as a 130x1 column vector:

$$\mathbf{A}_{int} = (\mathbf{TRD}_{sum} \; ./ \; \mathbf{N})' \tag{23}$$

Appendix A.2 Between-corporation knowledge accessibility

We are interested in dividing external accessibility to other corporations' knowledge into two knowledge sources: those that are accessed within a region where the corporation has own research and accessibility to research outside such regions. First, we sum a region's research amount by multiplying $\mathbf{R}$ with an identity column vector i_{130}. The result is an $81x1$ column vector where each element shows the total amount of research in region r. Then we multiply the result with i'_{130}. The end result is a $81x130$ matrix, $\widetilde{\mathbf{R}}$, where an element from row r shows the sum of research within region r so that $\widetilde{R}_{r,1} = \widetilde{R}_{r,k}$. Then we deduct research from the own company so that only external research is left.

$$\mathbf{R}^e = \widetilde{\mathbf{R}} - \mathbf{R} = \begin{bmatrix} R^e_{1,1} & \cdots & R^e_{1,130} \\ \vdots & \ddots & \vdots \\ R^e_{81,1} & \cdots & R^e_{81,130} \end{bmatrix}$$

An element $R^e_{r,k}$ shows the potential amount of external knowledge available for corporation k coming from region r. Finally, we have to adjust for time distance to external knowledge and if a company has research in the region, in a fashion similar to the above.

$$\mathbf{TRD}^e = (\mathbf{TR}^e). * \mathbf{D} \tag{24}$$

We use the same procedure as outlined above to arrive at the column vector A_{ext} :

$$\mathbf{A}_{ext} = (i_{81}\mathbf{TRD}^{e}\ ./\ \mathbf{N})' \tag{25}$$

This leaves us with a $130x1$ column vector of external accessibilities to other corporations' research available for each corporation. Now we divide this effect into intra- and interregional accessibilities to external knowledge. First, we calculate only those effects which are internal to the region and subtract this from (25). We construct a matrix $\widetilde{\mathbf{T}}$ with dimensions $81x130$, on row 1 consisting only of the internal time distances within region 1 for each element so that:

$$\widetilde{\mathbf{T}} = \begin{bmatrix} \tau_{1,1} & \tau_{1,1} & \cdots & \cdots & \tau_{1,1} \\ \tau_{2,2} & \tau_{2,2} & \cdots & \cdots & \tau_{2,2} \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ \tau_{81,81} & \tau_{81,81} & \cdots & \cdots & \tau_{81,81} \end{bmatrix}$$

We multiply $\mathbf{R}^{e}$ elementwise with $\widetilde{\mathbf{T}}$ to form intraregional but external knowledge accessibility, $\mathbf{AR}_{ext,1}$ for each corporation.

$$\widetilde{\mathbf{TRD}}^{e} = (\widetilde{\mathbf{T}}. * \mathbf{R}^{e}). * \mathbf{D} \tag{26}$$

$$\mathbf{AR}_{ext,1} = (i_{81}\widetilde{\mathbf{TRD}}^{e}./\ \mathbf{N})' \tag{27}$$

The dummy $\mathbf{D}$ again plays the role of only taking into account effects when the corporation conducts research in the region. Then, to calculate external knowledge from other corporations from other regions, we simply subtract $\mathbf{AR}_{ext,1}$ from $\mathbf{AR}_{ext}$:

$$\mathbf{AR}_{ext,2} = \mathbf{AR}_{ext} - \mathbf{AR}_{ext,1} \tag{28}$$

Appendix A.3 Accessibility to university research

We now turn to accessibility to research of universities (or higher education).[9] We start out with an $81x1$ column vector, u, showing the amount of university research in a region. This is premultiplied with **T** to form:

$$\mathbf{Tu} = \begin{bmatrix} Tu_1 \\ \vdots \\ Tu_{81} \end{bmatrix} \tag{29}$$

where Tu_r shows region r's total accessibility research. Next, we form a matrix $\widetilde{\mathbf{Tu}}$ which we get by postmultiplying by first a column identity row-vector i_{130}. This results in an 81 x 130 matrix, $\widetilde{\mathbf{TU}}$. We then proceed with the same method as above,

$$\mathbf{AU} = (i_{81}(\widetilde{\mathbf{TU}}. * \mathbf{D})./\mathbf{N})' \tag{30}$$

which results in a 130 x 1 vector in which each element represents a corporation's average accessibility to university research. To separate between intra- and interregional accessibility, exactly the same method is applied as for between corporations knowledge accessibility. We label intraregional university research $\mathbf{AU}_1$ and interregional accessibility $\mathbf{AU}_2$.

Variable	Neg. bin.		ZINB	
constant	-.0674 (.6928)		1.8245 (.6651)	***
R_k	.0038 (.0017)	**	.0003 (.0003)	
$A_{int,k}$	-.0255 (.0195)		.0021 (.0066)	
$A_{ext1,k}$	-.0033 (.0054)		.0066 (.0057)	
$A_{ext2,k}$	-.0002 (.0005)		.0006 (.0005)	
$AU_{1,k}$	-.0029 (.0070)		.0069 (.0096)	
$AU_{2,k}$	.0011 (.0020)		-.0007 (.0019)	
LR-test	17.93		13.26	
$no.obs$	130		130	

Table 3: Estimates of the negative binomial and the Zero Inflated negative binomial models. Standard errors are in parenthesis. *, ** and *** denote significance at the 10, 5 and 1 per cent level respectively.

Appendix B Results of the Neg. bin. and the Zero-inflated neg. bin. models

Appendix C Prediction graphs of the presented models

Figures 2 and 3 show the predicted values plotted against the actual, for the Poisson, ZIP, neg. bin. and ZINB models.

[9]Swedish higher education institutions are divided into universities and university colleges.

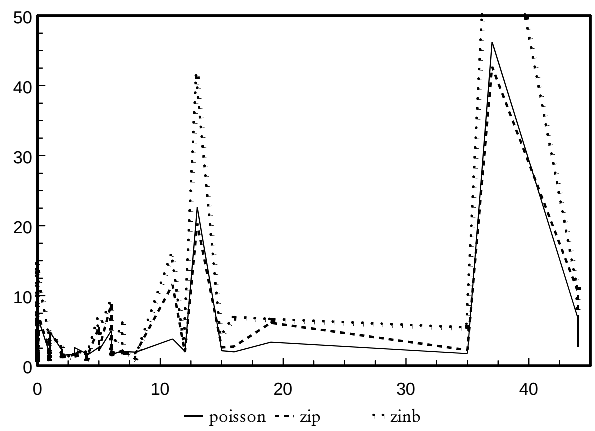

Figure 2: Prediction values for the Poisson, Zero-Inflated Poisson and the Zero-Inflated Negative Binomial Model. One outlier is not shown for the ZINB model, 75.44 corresponding to actual value 37.

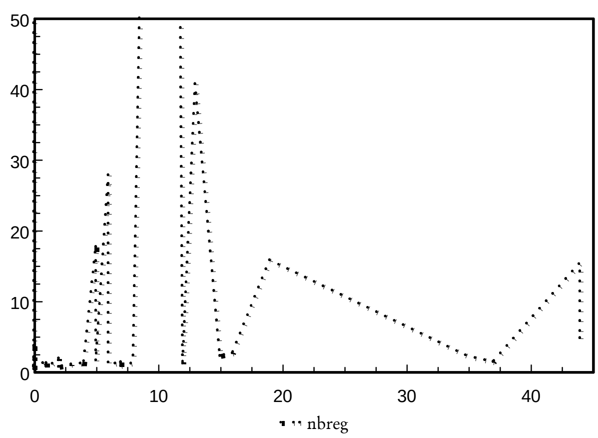

Figure 3: Prediction values for the negative binomial model, plotted against the actual values. Note: there are some extraordinary outlier-predictions outside the range shown. 139,000,000,000, 2080.196 and 280.6752 corresponding to actual patent values 37, 0 and 11.