Industry R&D and University R&D – How Are They Related?

By

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Abstract

During the years, a large number of formal studies have presented evidences of a positive impact of university R&D on firm performance in general and on the location of industrial R&D, in particular. The question is does it also work the other way around? Does industrial R&D function as an attractor for university R&D? What are behavioural relationships between industrial R&D and university R&D and vice versa? The fact that knowledge flows seem to be spatially bounded implies that proximity matters for the relationships between industrial and university R&D. We argue that spatial proximity should be measured using accessibility measures. Furthermore, accessibility measures can be used to model interaction opportunities at different spatial scales: local, intra-regional and inter-regional. Against this background, the purpose of this paper is to analyse the locational relationship between industry R&D and university R&D in Sweden using a simultaneous equation approach and to analyse existing differences between different science areas and different industry sectors. Our results indicate that the location of industrial R&D is quite sensitive to the location of university R&D, while the location of university R&D is insensitive to the location of industrial R&D.

Key words: R&D, Industry, University, Accessibility, Location

JEL Codes: C300, H500, I230, L100, O300, R100

1. Introduction

At the same time as we can observe strong tendencies of a globalisation of R&D (Florida, 1997; Cantwell, 1998), we also can observe a strong spatial clustering of R&D and related innovative activities (Audretsch & Feldman, 1996). The standard explanation in the literature of the clustering of innovative activities is that such clusters offer external knowledge economies to innovative companies, since they are dependent upon knowledge flows[1] and that knowledge flows are spatially bounded (Jaffe, Trajtenberg & Hendersson, 1993). Obviously, location is crucial in under-

[1] For reasons given in Section 2 we use the general term "knowledge flows" instead of the term "knowledge spillovers" commonly used in the literature.

standing knowledge flows and knowledge production, since knowledge sources have been found to be geographically concentrated.

There are two major performers of R&D: industry and universities. It seems rather straight-forward to assume that industrial R&D might be attracted to locate near research universities doing R&D in fields relevant to industry. Already as far back as in the 1960s a number of case studies confirmed the important roles played by Stanford University and MIT for commercial innovation and entrepreneurship (Teplitz, 1965; Wainer, 1965; Shimshoni, 1966; se also Dorfman, 1983). Starting with Nelson (1986) a large number of formal studies have presented evidences of a positive impact of university R&D on firm performance.

The question is, does it also work the other way around? Does industrial R&D function as an attractor for university R&D? We may actually think of several reasons why university R&D may grow close to concentrations of industrial R&D. First of all political decision-makers may decide to start or expand university R&D at locations where industry already is doing R&D. Secondly, we can imagine that industry doing R&D in a region might use part of their R&D funds to finance university R&D. Thirdly, universities in regions with industrial R&D might find it easier to attract R&D funds from national and international sources due to co-operation with industry.

Obviously, not all types of university R&D attract industrial R&D. There are reasons to believe that, in particular, university R&D in natural, technical and medical sciences attracts industrial R&D but that there are also strong reasons to believe that there are variations between different sectors of industry regarding how dependent their R&D is to be located close to university R&D.

The above implies that there are behavioural relationships between industrial R&D and university R&D and vice versa. This was observed by Jaffe (1989), who modelled these relationships as a simultaneous system. However, we have found few other studies dealing with this problem. The study by Anselin, Varga & Acs (1997) is an exception. Most studies have concentrated on the one-directional effect from university R&D to industrial R&D and the outputs of industrial R&D in most cases measured in terms of the number of patents and neglected the possible mutual interaction. However, if there is a mutual interaction between university and industry R&D, and if there are knowledge externalities involved, then we can develop a dynamic explanation to the clustering of innovative activities based on positive feedback loops. This would imply strong tendencies to path dependency and that policy initiatives to transfer non-innovative regions to innovative regions would have small chances to succeed.

The fact that knowledge flows seem to be spatially bounded implies that proximity matters. Most contributions analysing spatial knowledge flows have used very crude measures of proximity. However, there are some authors that have argued that proximity could be measured using accessibility measures (Karlsson & Manduchi, 2001; Andersson & Karlsson, 2004). As showed in Andersson & Karlsson (2004) accessibility measures can be used to model interaction opportunities at different spatial scales: local, intra-regional and inter-regional.

The purpose of this paper is to analyse the locational relationship between industry R&D and university R&D in Sweden using a simultaneous equation approach and to analyse existing differences between different science areas and different industry sectors.

The outline of this paper is as follows: In Section 2 we discuss the knowledge concept and the conditions for knowledge flows. In Sections 3 we review some of the literature on the location of university R&D and industrial R&D, respectively. Our hypotheses and our empirical model is presented in Section 6. Section 7 contains a presentation of the data and the variables used in the empirical analysis. The empirical analysis is presented in Section 8 and our conclusions and suggestions for future research can be found in Section 9.

2. Knowledge and knowledge flows

We here define knowledge as consisting of organised or structured information that is difficult to codify and interpret, generally due to its intrinsic indivisibility.[2] As a consequence, knowledge is difficult to exchange[3] without direct face-to-face interaction, since human capital is the major knowledge carrier. Loosely speaking, when knowledge is exchanged between two persons they both have to calibrate their explanation and interpretation activities, i.e. the exchange of knowledge needs oral communication and reciprocity.[4] Since knowledge exchange requires face-to-face contacts, it requires an extensive amount of somewhat diffused movements throughout various transportation networks.[5] Hence, while the costs of transmitting information may be close to invariant with respect to distance, the cost of exchanging knowledge increases together with the distance.[6] As Teece (1981) remarked, knowledge is neither shared ubiquitously nor passed around at zero cost. This implies that geographical proximity matters and that knowledge has the properties of a public good only within a short distance from the source (Harhoff, 1997). Bottazi & Peri (2003) show, that the costs of accessing and absorbing knowledge are not invariant to geographic location. Several studies show that the capacity to absorb flows of new knowledge is facilitated by geographical proximity (Jaffe, Trajtenberg & Henderson, 1993; Baptista & Swann, 1998).

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[2] Von Hippel (1995) persuasively demonstrates that highly contextual and uncertain knowledge, i.e. what he refers to as “sticky knowledge,” is best transmitted via (preferably frequent) face-to-face interactions. This is in line with the claim by Teece (1998) that knowledge assets are often inherently difficult to copy. Von Hippel’s sticky knowledge is also referred to as tacit knowledge in many studies from the last decade (Kogut & Zander, 1992). Tacit knowledge cannot be codified easily in the form of a blueprint or a contract (Mowery & Ziedonis, 2001), or a published article (Audretsch & Feldman, 1996).

[3] Knowledge exchange is defined here as any face-to-face interaction that can contribute to the process of the disclosure, dissemination, transmission, and/or communication of knowledge.

[4] In this way face-to-face contacts become a necessary or facilitating condition, though not a sufficient condition, for knowledge transfer.

[5] Historically, the transfer/communication of rich information has required proximity and specialised channels to customers, suppliers, and distributors. However, we must acknowledge the possibility that the new developments are undermining the traditional chains and business models, and that new structures – generally less dependent on physical communication channels – might become more and more often an economically viable option (cf. Teece, 1998).

[6] Interestingly, some authors assume that geography play no role for the costs of accessing knowledge (Spence, 1984; Cohen & Levinthal, 1990).

Obviously, there are costs and fundamental difficulties in exchanging knowledge. It explains why markets for exchange of knowledge are rare. Potential buyers may question the value of the knowledge, and sellers cannot easily assuage their concern without revealing their valuable asset – the specific knowledge. The buyer's and the seller's transaction information is intrinsically asymmetric. It also explains why companies prefer – in principle – to carry out R&D in-house rather than having it contracted out or licensed (Soete, 2001).

In view of the above exposition, it seems useful for our purposes to distinguish two knowledge concepts:

1. Scientific knowledge in the form of basic scientific principles that can form a basis for the development of technological knowledge.
2. Technological knowledge – implicit and explicit blueprints – in the form of inventions (or technical solutions) that either materialise in new products or can be readily used in the production of goods and services.

In concordance with Schumpeter's analysis, scientific knowledge functions as a background to or platform for technological knowledge in the innovation process (Schumpeter, 1934). As suggested by Nelson & Winter (1982), a company's innovation can be a change in the routines (technique, organisation, etc.) of the company and/or a new product (e.g. a change in attributes of a good or a service).

In dealing with the different concepts of knowledge it is essential to characterise them according to the degree to which they are *rivalrous* and *excludable* (cf., Cornes & Sandler, 1986). A purely rivalrous good has the property that its use by one company or person precludes its use by another, whereas a purely non-rivalrous good has the property that its use by one agent in no way limits its use by another. Excludability relates to both technology and legal systems (Kobayashi & Andersson, 1994). A good is excludable if the owner can prevent others from using it. While conventional goods are rivalrous and excludable, pure public goods are both non-rivalrous and non-excludable.

Scientific knowledge has the character of a pure public good, although it is generally only available to those with the relevant scientific training. Hence, access to scientific knowledge can differ between companies and between regions, due to an unequal supply of scientifically trained labour but also due to the general costs of transferring knowledge over space.

Technological knowledge may be perceived and even deliberately created as a non-rivalrous, partially excludable good (Romer, 1990). Its non-rivalrous character stems from the fact that technological knowledge is inherently different from other economic goods. Once the costs of creating new "technological knowledge" have been incurred, this knowledge may be used over and over again at no additional cost. It is in this sense that technological knowledge is non-rivalrous. The partially excludable character of technological knowledge stems from the fact that companies generally protect new inventions by having patents issued on them. However, patent applications – and therefore patents - must be quite detailed. This opens up opportunities for the competitors to imitate or to "invent around" patents, so that as a matter of fact technological knowledge *may* be accessible for intellectual purposes. At the same time, investigation and imitation activities consume resources. This implies that there is a cost or friction element in the process of imitating.

The processes by which the different types of knowledge may flow from their creators to other individuals or companies take place in spatial networks, i.e. "knowledge networks" (Batten, Kobayashi & Andersson, 1989; Kobayashi, 1995) consisting of a set of nodes and a set of links connecting them. At a coarse spatial resolution these nodes are represented by human settlements such as towns, cities and metropolitan regions, providing different instances of functional regions.[7] At a finer geographical scale we can observe network links between companies and even individuals. The nodes can be characterised by their endowment of knowledge production capacities and related activities, including knowledge infrastructure such as universities, meeting infrastructure, stocks of knowledge and human capital, local knowledge networks, and so on. The links include transportation as well as communication channels. The spatial perspective adds a further dimension to knowledge transfers. Partial excludability of the new knowledge is not only a result of patents, business secrets, and so on but also a consequence of limited physical accessibility.

Much of the discussion and analysis of knowledge flows has become contaminated because of unclear and fuzzy definitions of pertinent flows. In particular, many scholars have employed the concept of "knowledge spillovers" in an unfortunate way (Echeverri-Carrol 2001; Gordon & McCann, 2000). As a step towards more clarity and precision in the analysis, Karlsson & Johansson (2005) suggest a separation into the three groups of knowledge flows: (i) transaction based knowledge flows, (ii) transaction related knowledge flows, and (iii) pure knowledge spillover flows.

The distinctions made are important for several reasons. First, when the flows are transaction-based the participating economic agents have – in their own hands – market-like instruments to influence the resource allocation. Second, the mechanisms that generate the flows are different for the three categories which have implications for policy formation. Third, the externalities that can arise in the cases vary in nature (e.g. pecuniary and non-pecuniary) and should not be confused with each other. Knowledge flows generate knowledge externalities towards R&D performing companies when the source (a research university or another company) is not fully compensated for the value of the knowledge flow (Harris, 2001).

3. The Spatial Distribution of R&D – interdependencies between university and industrial R&D

As mentioned previously, there are two major performers of R&D: industry and universities. The subsequent subsections discuss the location of each type of R&D respectively. The discussion focuses on the interdependencies between university and industrial R&D.

[7] Functional regions are delimited based upon the spatial interaction patterns of the economic agents in a country. A functional region is fundamentally characterised by its size, by its density of economic activities, social opportunities and interaction options, and by the frequency of spatial interaction between the actors within the region (Johansson, 1997).

3.1 The location of university R&D

The first universities[8] were founded already in medieval times (Karlsson, 1994). A second wave of founding of universities came in the late 19th and early 20th century and a third wave in the post-war period culminating during the 1960s. This implies that the decisions of where to locate university R&D were taken a long time ago and long before the rapid increase of total R&D expenditures in recent decades.

However, important decisions concerning the location of university R&D have also been taken in recent decades in terms of governmental allocations and private grants to university R&D. In many countries institutions of higher education have been upgraded to university status and here and there new universities have been started. The motivations for these decisions have certainly varied but it is quite natural to assume that some of them have been taken as a response to or as an indirect support to industrial R&D.

It is in this connection important to recognise that modern (research) universities are multi-product organisations. The set of functions and outputs include (Luger & Goldstein ,1997):

1. The creation of new basic knowledge though research;
2. The creation of human capital through teaching (i.e., knowledge transfer from faculty to students);
3. The transfer of existing know-how (technology) to businesses, governmental agencies, and other organisations;
4. The application of knowledge to the creation and commercialisation of new products and processes, or the improvement of existing ones (i.e., technological innovation);
5. Capital investments in the built form, and in equity in private businesses;
6. Leadership in addressing critical local problems;
7. Co-production (with other R&D organisations) of a regional knowledge infrastructure;
8. The creation of a certain kind of regional milieu favourable to innovation.

We have to acknowledge, that universities might pursue both reactive and proactive policies with regard to industrial R&D. Significant industrial R&D as well as lack of such R&D in a region might stimulate the local university to hire more research faculty, to be more active in acquiring R&D funds, to set up new campuses, to start business incubators, to start science and technology parks, etc.

Even if lists of functions and outputs of (research) universities, such as the list above, can be helpful in understanding the scope of the activities of a university, they do not provide a basis for an analytical understanding of universities and their behaviour. It is obvious that there is a lack of theoretical understanding of the role of the (research) university as an actor in technological change, the innovation process, organisational transformation and (regional) economic development (cf., Florida & Cohen, 1999).

[8] There is no generally accepted definition of a university. We use the term university here as a collective term for institutions of higher education, whether they are major R&D performers or not. Major R&D performing universities we term research universities.

Without such theoretical understanding, we have great difficulties in understanding the factors driving the localisation of university R&D.

A (research) university might be defined as an institution that in competition with other similar institutions generate and disseminate knowledge with the objective to achieve eminence, reputation and prestige. These objectives are defined in an objective function that each university tries to maximise under a budget constraint. To achieve its objectives each university competes for highly reputed faculty. Highly reputed faculty is a strategic production factor for a university for several reasons. Firstly, they attract outstanding graduate and undergraduate students. Secondly, they reduce the budget constraint by attracting R&D funds.

However, we must acknowledge that private, independent universities only make up a limited share of the "university market". Most universities are public and in various ways controlled by the public sector at the national or the regional level. This implies that we have a kind of principal-agent relationship where the principle in various ways (laws, regulations, budget allocations, etc.) tries to control the behaviour of the agent. As the institutional framework for universities differs between different countries it is difficult to suggest a general model of university behaviour. However, this is beyond the scope of this paper.

3.2 The location of industrial R&D

R&D-intensive companies face high R&D expenditures combined with high technological risks and uncertainties as well as substantial market risks and uncertainties concerning customers demand and willingness to pay as well as the behaviour of competitors. To reduce their R&D expenditures, R&D-intensive companies have an incentive to choose locations for R&D-activities, which offer rich opportunities to benefit from knowledge externalities due to knowledge flows from research universities, R&D institutes and other R&D- and innovation-intensive companies. The major reason is of course that there are strong evidences that knowledge externalities are spatially restricted (Jaffe, 1989; Schrader, 1991; Harhoff, 1997). Locating R&D-activities close to those of competing companies is also a way to reduce uncertainty about the behaviour of competitors. On the other hand, it involves the risk that competitors might learn from your own R&D-activities. This implies that opposed to the potential benefits of knowledge externalities in agglomerations of R&D-performing companies there is the potential costs of sharing private knowledge with other (rival) companies. Thus, there exist incentives both to cluster to separate R&D-activities (Alsleben, 2004).

In developing innovations several trade-offs exist between the benefits of locating R&D close to production, the benefits of locating R&D close to markets, and the advantages of concentrating R&D in locations that offer opportunities for external knowledge externalities. Actually, Rosenberg (1982) points out that innovation depends on systemic relationships with markets or manufacturing operations. This indicates that innovative activities, including R&D-activities, ought to be located near the customers and/or close to production facilities, and therefore tend to be spread to different locations. However, R&D and innovation activities also benefit substantially from external knowledge economies and other supply side factors for knowledge generation, which generally are geographically concentrated. By locating according to these factors, R&D-activities would tend to concentrate in a limited number of regions.

It is also probable that successful innovation partly depends on the ability of companies to acquire scientific and technological knowledge from external sources and to integrate effectively this knowledge in their innovation activities (Kline & Rosenberg, 1986; Freeman, 1987). This implies that companies have two major instruments to achieve successful innovation: (i) the choice of location for their innovative activities, and (ii) the investment in internal innovative skills with capacity both to absorb knowledge from outside and to develop original inventions. The choice of location and the type and volume of investment will be influenced by company specific characteristics, such as their internal competencies not least at the managerial level and the industry to which the company belongs, but also by the characteristics of the national, sectoral and regional innovation systems of the regions where it is located (Lundvall, 1992 ed.; Nelson, 1993, ed.). The latter includes the availability and the quality produced by other companies and by the 'public science' infrastructure, consisting of universities and public research institutes (Arundel & Geuna, 2004).

There are plenty of evidences in the literature that industrial R&D is substantially more concentrated spatially than industrial production.[9] For example, Kelly & Hageman (1999) show that innovation exhibits strong geographical clustering, independently of the distribution of employment. Sectors locate their R&D not where they are producing but near to where other sectors do their R&D. However, Feldman & Audretsch (1996) found that there are substantial sectoral differences in spatial clustering with some industries like computers and pharmaceuticals displaying a higher degree of concentration compared to all manufacturing. Similar conclusions were drawn by Breschi (1999) after an examination of patent data for the period 1978-1991 from the European Patent Office.

We may assume that the location of industrial R&D is a strategic decision within companies that is based on several considerations. As R&D is a strategic function within companies there seems to be a general tendency to locate R&D close to company headquarters. On the other hand there is also a need to access and absorb knowledge flows to increase the efficiency of the own R&D. The literature in the field establishes that knowledge not only spills over from universities and other R&D performing companies but that it is also spatially bounded, which implies that the prospects for industrial R&D are greater in locations conducive to assessing and absorbing those knowledge flows. Thus, the major premise of the location argument is that companies would like to reduce their knowledge acquisition costs by locating close to knowledge sources, i.e. research universities and other R&D performing companies. However, those benefits must bear the possibly higher costs of locational proximity to a university and/or other R&D performing companies.

Theoretical arguments concerning localised knowledge flows suggests that knowledge production and innovative activities within a company will tend to be more efficient in agglomerations containing research universities and other R&D performing com-

[9] However, there are authors that claim that R&D-intensive and high-tech industries do not necessarily agglomerate (Devereux, Griffith & Simpson, 1999; Shaver & Flyer (2000), Kalnins & Chung, 2001, Barrios, et al., 2003; Alecke, et al., 2003). In her study of Japanese investments in Europe Mariani (2002) found that R&D tends to locate close to production activities.

panies, since the access to knowledge flows and thus potential knowledge externalities is greater. The knowledge production and the innovative activities will be more productive and more cost-efficient because in such agglomerations there is a high probability that companies can access potentially useful external knowledge at a cost that is lower than producing this knowledge internally or of trying to acquire it externally from a geographic distance (Harhoff, 2000). The cost of transferring such knowledge is a function of geographic time distance and this is why R&D agglomerations give rise to localised knowledge externalities (Siegel, Westhead & Wright, 2003). Thus, given the character of knowledge flows, it seems natural to assume that the spatial dimension is a key factor explaining the location of R&D activities of companies. Obviously, the location of R&D activities of companies is influenced by the potential knowledge externalities from knowledge flows from university R&D and R&D in other companies.

There is a rich literature regarding various aspects of the relationship between university R&D and industrial R&D and innovation. Some studies focus on the ability of companies to utilise knowledge flows from universities (Cohen & Levinthal, 1989 & 1990; Cockburn & Henderson,1998; Ziedonis, 1999; Lim, 2000). Another strand of literature studies the characteristics of universities that generate knowledge flows of interest for industrial R&D and innovation (Henderson, Jaffe & Trajtenberg, 1998; Thursby & Thursby, 2002; Feldman, et al., 2002; Jensen & Thursby, 1998; Di Gregorio & Shane, 2000). A third set of studies analyse the channels through which knowledge flow from universities to industry (Cohen, et al., 1998; Cohen, Nelson & Walsh, 1998; Agrawal & Henderson, 2002; Colywas, et al., 2002; Shane, 2002). These channels include:

- Personal networks of academic and industrial researchers (Liebeskind, et al., 1996; MacPerson, 1998)
- Spin-offs of new firms from universities (Stuart & Shane, 2002)
- Participation in conferences and presentations
- Flows of fresh graduates to industry (Varga, 2000).

However, there seems to be fewer studies that explicitly study the influences of university R&D on companies in general and on company R&D, in particular. Zucker, Darby and Brewer (1998) examine the location decisions of companies relative too the location of star university scientists. Mariani (2002) in a study of Japanese investments in Europe showed that geographical proximity to the local science base is an important factor for locating only R&D laboratories compared to R&D and production and production only. Agrawal & Cockburn (2002) use data on scientific publications and patents as indicators of university R&D and industrial R&D and find strong evidences of geographic concentration in both activities at the level of metropolitan statistical areas (MSAs) in the US. They also find strong evidences of co-location of upstream and downstream R&D activities. Agrawal & Cockburn (2003) report that high levels of university publishing in metropolitan areas in the United States and Canada tend to be matched by high levels of company patenting in the same technology field and metropolitan area, suggesting co-location of research activities. Other empirical studies suggest a strong correlation between the specialisation of the regional R&D infrastructure and the innovative activities conducted by industry (Feldman, 1994 a; Felder, Fier & Nerlingar 1997 a & b; Harhoff, 1997; Nerlinger, 1998). These results can be interpreted as indicating that knowledge externalities from

R&D infrastructure can be best used in innovation activities in companies in the same or closely related scientific and technological field(s). The correlation tends to increase with the complexity of the R&D and innovation activities and the more specific the demand for technological know-how (Feldman, 1994 a; Feldman & Florida, 1994). Results presented by Bade & Nerlinger (2000) indicate strong correlations between the occurrence of new technology-based firms and the proximity to R&D-facilities comprising universities, technical colleges and non-university R&D-institutes as well as private R&D.

Griliches' 'knowledge production function approach' introduced above did not acknowledge that knowledgeable persons and knowledge production activities are spread out in geography and at the same time to a high degree concentrated to agglomerations. However, the original 'knowledge production function approach' has later been modified to also accommodate the spatial dimension (Jaffe, 1989; Audretsch & Feldman, 1994 & 1996; Feldman, 1994a & 1994b). The inputs and outputs considered in these studies vary from study to study and so does the geographic unit of analysis. With a few exceptions (Henderson, Jaffe & Trajtenberg, 1994; Beise & Stahl, 1999), empirical research suggests that knowledge flows from public science to companies decline with geographical distance.

The input 'federal research funding' is related to the output 'new patents issued' at the state level in the US by Jaffe (1989). Acs, Audretsch & Feldman (1992) correlate the input 'university research spending' with the output 'new product announcements'. Jaffe, Trajtenberg & Henderson (1993) use the input 'original patents' to explain the output 'patents that cite the original patents' at the city level in the US. They as well as several other studies (Narin, Hamilton & Olivastro, 1997; Verspagen, 1999; Malo & Geuna, 2000) find that academic papers and university patents are more frequently cited than their equivalents from private companies suggesting that public science outputs are an important knowledge source for inventions in companies. However, this method is not entirely accurate because the cited papers and patents may not have contributed to the invention, since the citation may be included only to build the patent claim. This method also underestimates the value of public science since many inventions are not patented (Arundel & Kabla, 1998). Audretsch & Feldman (1996) connect the input 'local university research funding' in the US to the output 'local industry value-added' at the state level. The input 'number of local research stars' is associated to the output 'number of new local biotech firms' at the level of the economic region in the US by Zucker, Darby & Armstrong (1998). Branstetter (2000) links the input 'scientific publications from the University of California' to the output 'patents that cite those papers' at the state level. The input 'hours of interaction with the MIT professor associated with a particular patented invention' is used by Agrawal (2002) to estimate the effect on the output 'likelihood or degree of success of commercialising that invention' and he also evaluates the impact of distance on this effect.

Irrespectively of whether these studies use the production function approach or patent citations they find that knowledge flows from academic research to private companies are highly localised at the regional or state level in the US.

Summarising the theoretical arguments and empirical results presented above there seems to be clear evidences that the location of industrial R&D is attracted to locations offering good opportunities to take advantage of knowledge flows from universities (and public research institutes). There seems to be less evidences concerning whether concentrations of industrial R&D is an attractor for industrial R&D. Obviously there are both costs and benefits from locating company R&D and other innovative activities close to similar activities of other companies competing in the same market. Adams (2001) surveyed 208 private R&D laboratories in the US and found that distance is a greater barrier to take advantage from knowledge flows from public science than from companies.

4. Network Formation, Knowledge Flows and Physical Accessibility

The preceding sections suggest interdependencies between industrial and university R&D as regards the location across space. This section illustrates the importance of accessibility between these actors for the establishment of contacts and durable links between them. Durable links constitute important means by which knowledge is transmitted.

The probability that durable links will be established between actors depends on the conditions for personal interaction. Therefore, economic networks and networks for transportation and infrastructure are complementary, (Fischer and Johansson, 1994). A link between two economic actors can be established via transactions, e.g. when a supplier and customer specify a delivery contract. In general, the extent to which such a link formation is determined by spatial proximity depends on the transaction's contact intensity.

Transactions involving knowledge – such as when a firm purchases R&D services from universities – are highly contact intensive. The outcomes of R&D projects are often uncertain and the transmission of complex and tacit knowledge often requires face-to-face communication. Because of this, durable links between industrial R&D units and university researchers are likely to be particularly dependent on the physical accessibility between the two. Moreover, many types of knowledge flows are transmitted via durable links.

Against the background above, we now consider an industrial R&D unit k located in municipality i and follow the basic set-up in Johansson, Klaesson & Olsson (2002). When it comes to establish contacts (links) with university researchers, we assume that a typical R&D unit k faces a set of M alternatives. The set $M = \{1,\ldots,i,\ldots,j,\ldots,n\}$ contains all municipalities in the economy. Thus, each alternative pertains to university researchers in a specific municipality. We might now ask: what determines the preference value of R&D unit k regarding contacts with university researchers in location j? It is assumed that this preference value, denoted by $\pi_{ij,k}$, is a function of (i) the size of the R&D resources in the university, (ii) the overall quality of the university R&D, (iii) the price differential of university R&D services in location j and i, (iv) the travel costs between i and j and (iv) random influence from non-observed factors. This is specified in Equation (4.1):

$$\pi_{ij,k} = \theta_j u_j - \alpha(p_j - p_i) - \sigma c_{ij} - \gamma t_{ij} + \varepsilon_{ij} \qquad (4.1)$$

where θ_j denotes the overall quality of the university R&D in municipality *i*, $p_{i,j}$ denotes the price of R&D services in the respective municipality, c_{ij} is the monetary cost of travelling between municipality *i* and *j*, t_{ij} denotes the travel-time distance between municipality *i* and *j* and γ represents the value of time[10]. ε_{ij} represents the random influence from non-observed factors. In Equation (4.1), $\theta_j u_j$ can be interpreted as the attraction factor in municipality *j* whereas c_{ij}, t_{ij} and the price differential can be interpreted as factors that pertains to the link between municipality *i* and *j*.

Letting $\Pi_{ij}^k = \pi_{ij}^k - \varepsilon_{ij}$ and assuming that ε_{ij} is distributed independently, identically in accordance with the extreme value distribution, the probability that an R&D-unit located in municipality *i* will choose to establish contacts with university researchers in municipality *j*, P_{ij}^k, is given by[11]:

$$P_{ij}^k = \frac{e^{\{\Pi_{ij}^k\}}}{\sum_{j \in M} e^{\{\Pi_{ij}^k\}}} \tag{4.2}$$

In Equation (4.2), the numerator is the preference value for contacts with university R&D in municipality *j* whereas the denominator is the sum of such preference values, (c.f. Johansson Klaesson & Olsson, 2002). This means that, *ceteris paribus*, the probability of choosing contacts with university researchers in municipality *j* increases with the size of the attraction factor (the size of the R&D resources in *j*) and decreases with the time distance to municipality *j*.

We now consider the denominator in (4.2) and assume that (i) the quality of university R&D is equal in all regions, (ii) the price differential is equal to zero, $\alpha(p_j - p_i)=0$ and that (iii) the monetary travel costs are proportional to the time distance such that $c_{ij} = \gamma t_{ij}$ [12]. Moreover, we assume that $u_j = \ln U_j$ where U_j is the size of university R&D resources in municipality *j*. Using these assumptions, the denominator in (4.2) can be expressed as:

$$A_i^U = \sum_{j \in M} U_j e^{\{-\lambda t_{ij}\}} \tag{4.3}$$

where $\lambda = (\sigma\gamma + \gamma)$. A_i^U in Equation (4.3) is a standard measure of accessibility with exponential distance decay. Obviously, an industrial R&D unit with high accessibility to university R&D is likely to have more frequent contacts and durable links with university researchers. Both the size of the attractor and time distances in (4.3) are arguments in the preference function in (4.1). Moreover, since durable links are important means by which knowledge is transmitted, knowledge flows between industrial R&D units and university researcher can be expected to be larger the higher the accessibility between the two.

[10] Since *p* and *c* are monetary values, α and σ translates these values to a common preference base, (c.f. Johansson, Klaesson and Olsson, 2002).

[11] This condition is derived in several texts, see *inter alia* Train (1993).

[12] These assumptions are equivalent to the ones in Johansson, Klaesson & Olsson (2002).

A similar set-up can be specified for university researchers which wish to establish contacts with industrial R&D units. In this case, the accessibility to industrial R&D for university researchers in municipality *i* becomes:

$$A_i^I = \sum_{j \in M} I_j e^{\{-\lambda t_{ij}\}} \tag{4.4}$$

where I_j denotes the size of industrial R&D resources in municipality *j*.

In Equation (4.3) and (4.4), the accessibility measures represent the total accessibility. However, a national economy can be divided into functional regions that consist of one or several municipalities. Functional regions are connected to other functional regions by means of economic and infrastructure networks. The same prevails for the different municipalities within a functional region. Moreover, each municipality can also be looked upon as a number of nodes connected by the same type of networks. With reference to such a structure, it is possible to define three different spatial levels with different characteristics in terms of mobility and interaction opportunities. Because of this, it is also possible to construct three different categories of accessibility. Johansson, Olsson & Klaesson (2002) separates between: (i) intra-municipal accessibility, (ii) intra-regional accessibility and (iii) extra-regional accessibility. Letting *R* denote the set of municipalities belonging to functional region *R*, the total accessibility to university R&D of municipality *i* can be expressed as:

$$A_i^U = A_i^{UM} + A_i^{UR} + A_i^{UE} \tag{4.5}$$

where $A_i^{UM} = U_i e^{\{-\lambda_{im} t_{ii}\}}$ is intra-municipal accessibility, $A_i^{UR} = \sum_{j \in R, i \neq j} U_j e^{\{-\lambda_{ir} t_{ij}\}}$ is intra-regional accessibility and $A_i^{UE} = \sum_{j \notin R} U_j e^{\{-\lambda_{er} t_{ij}\}}$ is extra-regional accessibility. The subscript of the time-distance sensitivity parameter λ is different for each type of accessibility.

In the sequel, the decomposition in (4.5) will be applied on both industrial and university R&D to empirically examine the interdependencies between industrial R&D and university R&D. An underlying conjecture is that high accessibility promotes contacts between the actors, which in turn encourage knowledge flows.

5. Interdependencies between university and industrial R&D – an examination using Swedish data

This section analyses the relationship between industrial and university R&D using Swedish data at the municipality level 1995-2001. The section starts by presenting the data and the variables used in the analysis and goes on to analyse the relationship industrial and university R&D across municipalities in Sweden.

5.1 Data sources and variables

The R&D data used in this paper originates from Statistics Sweden. These data are collected by SCB via questionnaires that are sent out to firms and universities. The

R&D data is measured in man-years. One man-year is the amount of work a full-time employee performs during a year. This means that a full-time employee who only spends 50 % of her work on R&D counts as 0.5 man-years. The data used in this paper cover 1995 and 2001.

To calculate the accessibilities in Equation (4.5) with respect each type of R&D, we employ data on travel time distances by car between Swedish municipalities. These data are provided by the Swedish Road Administration (SRA). The data reports the travel time distance by car between each of the municipalities in Sweden. Moreover, we apply values for the time distance sensitivity parameters – λ_{im} for intra-municipal accessibility, λ_{ir} for intra-regional accessibility and λ_{er} for extra-regional accessibility – that are found by Johansson, Klaesson & Olsson (2003). Using data on commuting flows, these authors find that the three different λ differ from each other in the following manner: λ_{ir} (0.1) > λ_{er} (0.05) > λ_{im} (0.02). Although these values are not estimated for contacts between industrial and university R&D, they represent the best information available. Thus, these values will be used in the calculation of each type of accessibility.

5.2 University and Industrial R&D - description and empirical analysis of interrelationships on Swedish data

Sweden is among the most R&D-intensive countries in the world. Figure 5.1 compares Sweden's R&D expenditure as a share of GDP with a set of advanced industrialized countries during the 20th century. As is evident from the figure, Sweden passed Japan in the early 1990's and has then shown a steadily increase in R&D expenditure as a share of GDP. In figures, R&D/GDP has increased from about 2.7 % in 1991 to well over 4 % in 2001. Moreover, relative to other countries Sweden has a very high level of R&D expenditure relative to its GDP.

Which are the major performers of R&D? In vast majority of countries, the major performers of R&D are universities and private firms. Figure 5.2 presents Sweden's R&D man-years – the data source that will be used in the empirical analysis – by four performers 1995-2003: (i) industry, (ii) universities, (iii) private non-profit organizations and (iv) public authorities.

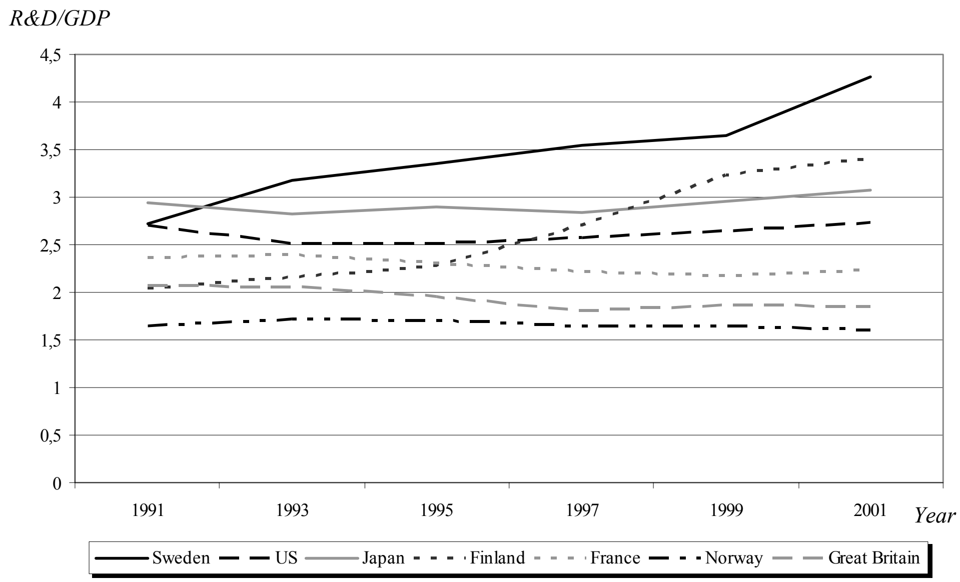

Figure 5.1. *R&D expenditure as a share of GDP in selected countries 1995-2001.*

Consulting Figure 5.2, it is evident that industry and universities are the major performers of R&D. These two performers of R&D constitute over 90 % of the Swedish total R&D. Moreover, the relative contribution of each performed tend to be stable over the period considered. Private non-profit organizations and public authorities have very limited R&D man-years. Thus, focusing on industrial and university R&D does not imply the exclusion of any significant R&D performer.

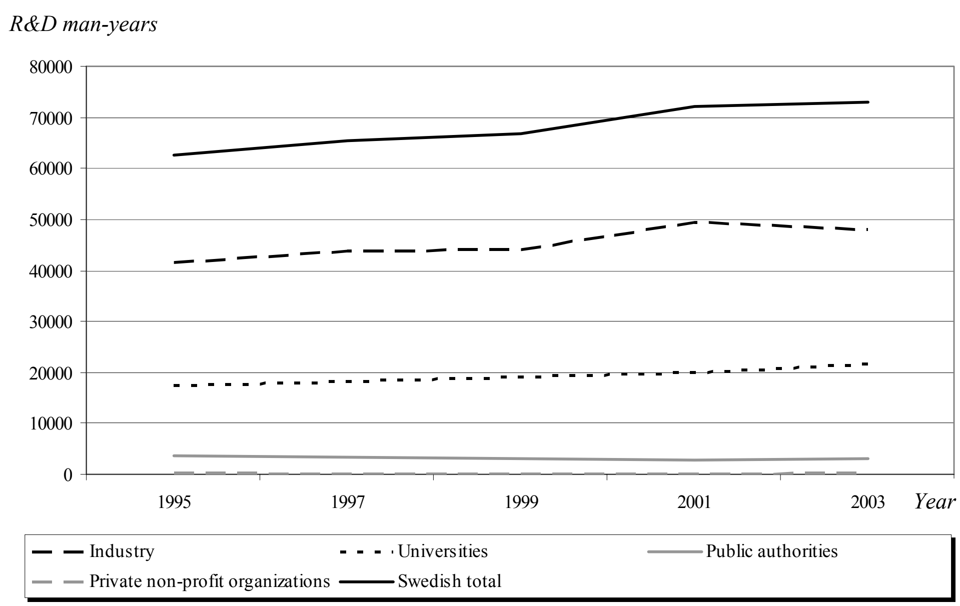

Figure 5.2. *R&D man-years 1995-2003 in Sweden by performer.*

In addition to the former figure, Table 5.1 provides descriptive statistics for the aggregate industrial and university R&D in Sweden 1995 & 2001. Industry R&D is more than twice as large as university R&D, and the distance between them has increased between 1995 and 2001. However, both industry and university R&D man years has increased during the period.

Table 5.1. Descriptive statistics for the aggregate industrial and university R&D in Sweden 1995 & 2001.

	1995		2001			
	Man-years	*Share of total*	*Man-years*	*Share of total*	Δ man-years 1995-2001 (%)	Δ share of total 1995-2001
Industrial R&D	41 647	66.5 %	49 192	68.6 %	18.11	2.1
University R&D	18 246	29.1 %	19 715	26.6 %	8.05	-2.5
Swedish total	**62 635**	**-**	**72 190**	**-**	**15.26**	**-**

Data source: Statistics Sweden (SCB)

Turning to the spatial distribution of university and industrial R&D it is clear that both university and industrial R&D are highly concentrated in space. Figure 5.3 compares the spatial concentration of industrial and university R&D with population in 2001. Municipalities where ranked in ascending order according to their share of the total population. Then, the cumulative percentage of population, industrial R&D and university R&D where calculated. As is evident form the figure, both industrial and university R&D are much more concentrated than population.

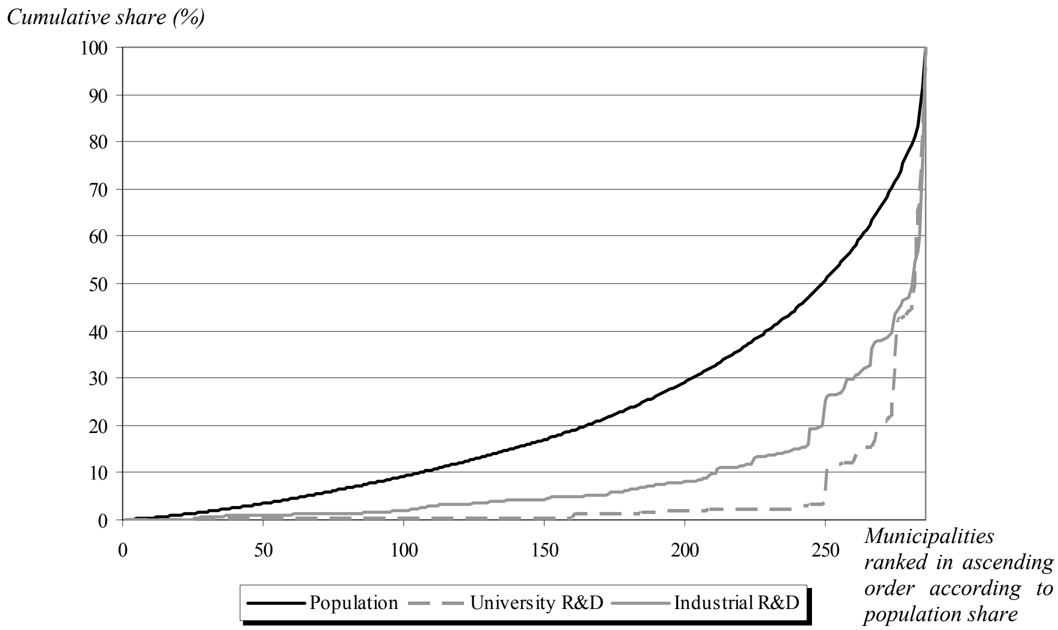

Figure 5.3. *R&D man-years 1995-2003 in Sweden by performer.*

To complement the figure above, Table 5.2 presents descriptive statistics for university and industrial R&D in 1995 and 2001. As is evident from the table, the distribution is highly skewed. The standard deviations are large compared to the means and the statistics for both skewness and kurtosis are high.

Table 5.2. Descriptive statistics for industrial and university R&D in Sweden 1995 & 2001 across 286 municipalities**.**

	University R&D		Industrial R&D	
	1995	*2001*	*1995*	*2001*
Min	0	0	0	0
Max	3 572.77	3 452.03	10 135.41	11 912.35
Mean	63.80	68.94	145.62	171.87
Std. deviation	388.20	380.57	769.45	894.58
Skewness*	7.62 (0.14)	7.08 (0.14)	10.18 (0.14)	10.45 (0.14)
Kurtosis*	60.38 (0.29)	52.31 (0.29)	117.79 (0.29)	123.27 (0.29)
No. obs.	286	286	286	286

Data source: Statistics Sweden (SCB)
*) Standard errors presented within brackets.

Both university and industrial R&D are highly concentrated to specific municipalities. As an example, only 11 municipalities individually hosted more than 1 % of the total university R&D in Sweden in 2001. Yet, these 11[13] municipalities hosted approximately 90 % of the total university R&D. The corresponding figures for industrial R&D are 17[14] municipalities with a cumulative share of industrial R&D that amounts to about 78 %. Moreover, many municipalities have zero university and industrial R&D man-years. Table 5.3 lists the top five municipalities in terms of the number of R&D man-years as regards both industry and universities in 2001.

Table 5.3. Top5 municipalities in terms of R&D man-years of university and industrial R&D 2001.

University R&D			Industrial R&D		
Top 5 municipalities	*R&D man-years 2001*	*Share of Swedish total (%)*	*Top 5 municipalities*	*R&D man-years 2001*	*Share of Swedish total (%)*
Stockholm	3 452.0	17.5	Stockholm	11 912.4	24.2
Uppsala	3 116.3	15.8	Göteborg	7 850.3	16.0
Göteborg	2 891.7	14.7	Mölndal	2 632.5	5.4
Lund	2 487.3	12.6	Linköping	2 561.3	5.2
Umeå	1 529.7	7.8	Lund	1 962.8	4.0
Sum	**13 852.6**	**68.4**	***Sum***	**26 919.2**	**54.8**

Data source: Statistics Sweden (SCB)

[13] These municipalities are Stockholm, Uppsala, Göteborg, Lund, Umeå, Solna Linköping, Huddinge,.Malmö. Luleå,
[14] These municipalities are Stockholm, Göteborg, Mölndal, Linköping, Lund, Södertälje, Trollhättan, Malmö, Västerås, Uppsala, Järfälla, Karlstad, Karlskoga, Luleå, Sandviken, Jönköping and Solna.

As is evident from the table, despite that the cumulative percentage is larger for the university R&D, industrial R&D show a larger concentration to specific municipalities. Stockholm and Göteborg alone hosts more than 40 % of Sweden's total industrial R&D.

In order to analyze the spatial interdependencies between university and industrial R&D, we start by simply regressing industrial R&D in municipality *i*, $I_i^{R\&D}$, on the university R&D in the same municipality, $U_i^{R\&D}$, in 2001. This gives an overall picture of the relationship as regards the location. The result of this undertaking is presented in Equation (5.1):

$$I_i^{R\&D} = \underset{(1.38)}{47.81} + \underset{(20.06)}{1.8}\, U_i^{R\&D} + \varepsilon_i \qquad R^2 = 0.59 \qquad (5.1)$$

where it is apparent that the coefficient for university R&D is significant and positive. Thus, university and industrial R&D tend to coincide in space.

However, in this paper the major hypothesis is that there are interdependencies between the location of university and industrial R&D. In order to test this hypothesis we analyze the aggregate pattern of the change in industrial and university R&D across Swedish municipalities 1995-2001 in a simultaneous setting. The Equations that are estimated simultaneously are presented in Equation (5.2a) and (5.2b):

$$\Delta I_i^{R\&D} = \alpha + \beta_1 A_{i,t}^{UM} + \beta_2 A_{i,t}^{UR} + \beta_3 A_{i,t}^{UE} + \beta_4 I_{i,t-n}^{R\&D} + \beta_5 D_i^{L} + \beta_6 D_i^{SL} + \varepsilon_i \quad (5.2a)$$

$$\Delta U_i^{R\&D} = \mu + \phi_1 A_{i,t}^{IM} + \phi_2 A_{i,t}^{IR} + \phi_3 A_{i,t}^{IE} + \phi_4 U_{i,t-n}^{R\&D} + \phi_5 D_i^{L} + \phi_6 D_i^{SL} + \varepsilon_i \quad (5.2b)$$

where Δ denotes the absolute change in the pertinent variable between 1995 and 2001. Moreover, *t*=2001 and *t-n*=1995. Table 5.4 explains each of the variables in the above Equations. The calculations of accessibility follow the derivation of accessibility in Section 4.

Table 5.4. Explanation of the variables in Equation (5.2a) and (5.2b).

Variable	***Explanation***
$\Delta I_i^{R\&D}$	Absolute change in industrial R&D between 1995 and 2001 in municipality *i.*
$\Delta U_i^{R\&D}$	Absolute change university R&D between 1995 and 2001 in municipality *i.*
$A_{i,t}^{M}$	Intra-municipal accessibility of municipality *i* in 2001.
$A_{i,t}^{R}$	Intra-regional accessibility of municipality *i* in 2001.
$A_{i,t}^{E}$	Extra-regional accessibility of municipality *i* in 2001.
D_i^{L}	Dummy which takes the value 1 if municipality *i* is the central municipality in the region it belongs to; 0 otherwise
D_i^{SL}	Dummy which takes the value 1 if municipality *i* is *not* the central municipality in the region it belongs to but the region is large; 0 otherwise
Supersripts	
U	University R&D (i.e. $A_{i,t}^{UM}$ means intra-municipal accessibility to university R&D)
I	Industrial R&D (i.e. $A_{i,t}^{IM}$ means intra-municipal accessibility to industrial R&D)

Observe that the accessibility variables are measured in the year 2001. This is to reflect that they are themselves determined by the change in university and industrial R&D respectively.

Table 5.5 presents the estimated coefficients of the variables in Equation (5.2a) and (5.2b) using the 2SLS estimator[15]. The table presents estimates obtained on the full sample – i.e. all municipalities in Sweden – and the estimates obtained by excluding one municipality (Solna) which comes out as an extreme outlier in the estimations.

Table 5.5. 2SLS estimation of Equation (5.2a) and (5.2b).

Variable	$\Delta I_i^{R\&D}$	$\Delta U_i^{R\&D}$	$\Delta I_i^{R\&D}$ **	$\Delta U_i^{R\&D}$ **
α	59.13 (-0.81)	-	-9.13 (-0.81)	-
μ	-	-0.34 (-1.51)	-	-0.22 (-0.04)
$A_{i,t}^{UM}$	0.19* (7.24)	-	0.20* (7.40)	-
$A_{i,t}^{UR}$	-0.05* (-2.47)	-	-0.03 (-1.68)	-
$A_{i,t}^{UE}$	0.07* (2.02)	-	0.08* (2.27)	-
$I_{i,t-n}^{R\&D}$	0.10 (8.80)*	-	0.09 (8.27)*	-
$A_{i,t}^{IM}$	-	0.01 (1.56)	-	0.02* (3.03)
$A_{i,t}^{IR}$	-	-0.002 (-0.22)	-	-0.005 (-1.26)
$A_{i,t}^{IE}$	-	-0.001 (-0.13)	-	-0.001 (-0.13)
$U_{i,t-n}^{R\&D}$	-	-0.05* (-3.71)	-	-0.07* (-5.91)
D_i^L	16.01 (1.03)	15.62 (1.62)	15.32 (0.90)	16.65* (2.01)
D_i^{SL}	7.16 (0.49)	2.46 (0.27)	5.8 (0.41)	5.43 (0.70)
R^2	0.65	0.05	0.66	0.14
N	286	286	286	286

*) t-values are presented within brackets.
*) * denotes significance at the 0.05-level.
***) ** denotes that one municipality (Solna) is excluded from the sample.

As is evident from the table, fit of the equation for university R&D increases dramatically when the outlier (Solna) is excluded. The R^2 increases from 0.05 to 0.16, which motivates the exclusion of this particular observation. The fit of the equation for industry R&D only improves slightly.

The results in Equation 5.5 suggest that university R&D tend to increase in location offering high accessibility to municipal R&D and that industrial R&D tend to increase in locations offering high accessibility to university R&D. Thus, the aggregate results of support the hypothesis set out in the paper. Interestingly, regional accessibility does not have any statistically significant effect on the change in neither university nor

[15] Lagged values are used as instruments.

industrial R&D. Hence, the effect between industrial and university R&D seems to be highly local in scope.

6. Conclusions and suggestions for future research

TO BE COMPLETED

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