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The Location of Industry R&D and the Location of University R&D – How Are They Related?[1]

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The Location of Industry R&D and the Location of University R&D
– How Are They Related?

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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 the 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. Our results indicate that the location of industrial R&D is quite sensitive to the location of university R&D, and that the location of university R&D is sensitive to the location of industrial R&D. However, the latter result is achieved only when we take away one outlier in the data.

Key words: R&D, Industry, University, Accessibility, Location
JEL Codes: C30, H50, I23, L10, O30, R10

1. Introduction

At the same time as we can observe strong tendencies of a globalisation of R&D (Florida, 1997; Cantwell, 1998), we also observe strong spatial clustering of R&D and related innovation activities (Audretsch & Feldman, 1996). The standard explanation in the literature of the clustering phenomenon is that clustering brings about external knowledge economies, typically in the form of knowledge flows[2], which tend to be spatially bounded (Jaffe, Trajtenberg & Hendersson, 1993).

R&D is a typical innovation activity; irrespective of whether it is focused on new products or new processes. Industry - i.e. private firms - and universities are the major performers of R&D. It is well established in the literature that both university and industry R&D have a positive effect on innovation output (often measured by patent applications), but that the effect diminishes with distance. As stated above, this is interpreted as that knowledge flows are spatially bounded and that clustering is consequently an effective spatial configuration.

Despite a vast literature on how university and industry R&D affect innovation output, the literature on how university and industry R&D are related to each other is rather limited. This paper focuses on possible spatial interdependencies between the location of university and the location of industry R&D.

It seems rather straightforward 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.

Does industrial R&D function as an attractor for university R&D? There are actually 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. This means 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.

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

Against the background above, the purpose of this paper is to analyse interdependencies between industry R&D and university R&D in Sweden as regards location using a simultaneous equation approach[3].

However, it has of course to be recognized that all decisions on where to start universities are taken by politicians and that many universities in Sweden were founded several hundred years ago. For this reason the paper does not focus on location decisions in terms of establishments of new industrial and university R&D departments or units. Instead, the research question is posed in the following manner: does industrial R&D tend to expand in locations with high accessibility to university R&D and vice versa?

An underlying conjecture in the paper is that the extent of links between industry R&D units and university research departments is a function of the physical proximity between the two and that many types of knowledge flows are mediated via links. It is further argued that links, in turn, may give rise to interdependencies between industry and university R&D. Of course, the extent to which link formation is determined by spatial proximity depends on the transaction's contact intensity, but transactions involving knowledge – such as when a firm purchases R&D services from universities – are highly contact intensive.

Most contributions use very crude measures of physical proximity. However, by focusing on physical accessibility and relying on actual travel time distances in the accessibility calculations, we believe that proximity is measured in a coherent fashion, (see also Karlsson & Manduchi, 2001; Andersson & Karlsson, 2004).

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. The relationship between researcher network formation, knowledge flows and physical accessibility is discussed in Section 4. Section 5 contains a presentation of the data and the variables used in the empirical analysis as well as our empirical analysis. Our conclusions and suggestions for future research can be found in Section 6.

2. Knowledge and knowledge flows

In this paper, knowledge is defined as organised or structured information that is difficult to codify and interpret, generally due to its intrinsic indivisibility.[4] As a consequence, knowledge is

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[3] 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. However, although a distinction between different science areas would be interesting, the present paper focuses on the aggregate pattern.

[4] Von Hippel (1994) 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

difficult to exchange[5] 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.[6] Since knowledge exchange requires face-to-face contacts, it requires an extensive amount of somewhat diffused movements throughout various transportation networks.[7] 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.[8] 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). Bottazzi & 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).

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

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cannot be codified easily in the form of a blueprint or a contract (Mowery & Ziedonis, 2001), or a published article (Audretsch & Feldman, 1996).

[5] 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.

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

[7] 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).

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

(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.[9] 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

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[9] 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).

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, Johansson (2005) suggests a separation into two groups of knowledge flows: (i) transaction based knowledge flows, (ii) pure knowledge spillover. Transaction based flows include pure market transactions and link transactions whereas knowledge spillovers include both spillovers due to spatial proximity and spillovers through links.

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.

3.1 The location of university R&D

The first universities[10] 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.

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[10] 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.

It is in this connection important to recognise that modern (research) universities are multi-product organisations. The set of functions and outputs include (see e.g. 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. Co-production (with other R&D organisations) of a regional knowledge infrastructure;

In this context it should be recognized 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). 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, private and 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.

3.2 The location of industrial R&D

There are plenty of evidences in the literature that industrial R&D is substantially more concentrated spatially than industrial production.[11] For example, Kelly & Hageman (1999) show

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[11] 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,

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, Audretsch & Feldman (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.

Theoretical arguments concerning localised knowledge flows suggest 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 companies, 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, 2002; Agrawal & Henderson, 2002; Colyvas, 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

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et al., 2003). In her study of Japanese investments in Europe Mariani (2002) found that R&D tends to locate close to production activities.

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 & Nerlinger 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 (Griliches, 1979). 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, & 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):

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

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[12]. 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[13]:

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

(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 $c_{ij} = \gamma t_{ij}$. 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:

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

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

$$A_i^U = \sum\nolimits_{j \in M} U_j e^{\{-\lambda t_{ij}\}} \qquad (4.3)$$

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.

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:

$$A_i^I = \sum\nolimits_{j \in M} I_j e^{\{-\lambda t_{ij}\}} \qquad (4.4)$$

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, Klaesson & Olsson (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:

$$A_i^U = A_i^{UM} + A_i^{UR} + A_i^{UE} \qquad (4.5)$$

where $A_i^{UM} = U_i e^{\{-\lambda t_{ii}\}}$ is intra-municipal accessibility, $A_i^{UR} = \sum\nolimits_{j \in R, i \neq j} U_j e^{\{-\lambda t_{ij}\}}$ is intra-regional accessibility and $A_i^{UE} = \sum\nolimits_{j \notin R} U_j e^{\{-\lambda t_{ij}\}}$ 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 assessment 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 between 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, a pre-specified value of the time distance sensitivity parameter, λ, has to be used in order to calculate each accessibility value. In this paper we set λ to 0.017, which is the estimated time distance sensitivity for business trips between regions in Sweden (Hugosson and Johansson, 2001).

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.

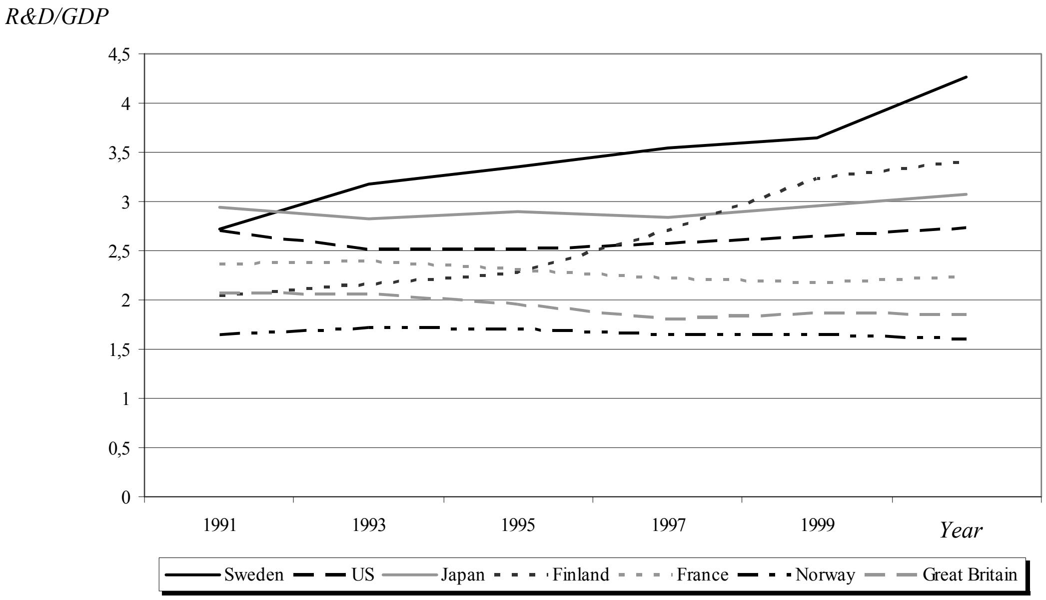

Figure 5.1. *R&D expenditure as a share of GDP in selected countries 1995-2001.*

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.

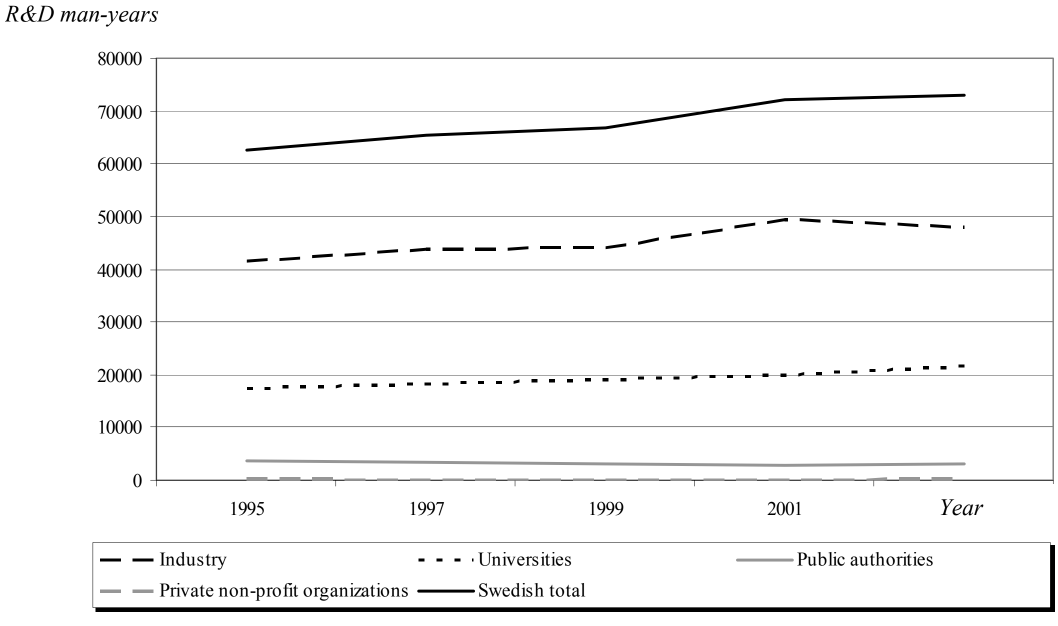

Figure 5.2. *R&D man-years 1995-2003 in Sweden by performer.*

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 have 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 from the figure, both industrial and university R&D are much more concentrated than population.

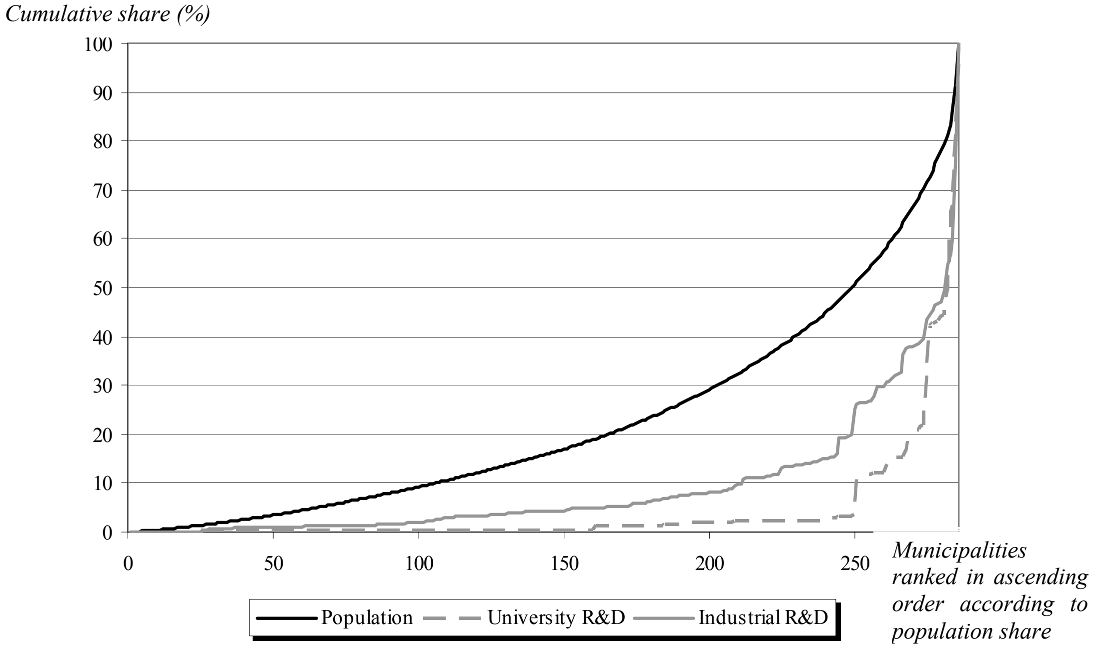

Figure 5.3. *R&D man-years 1995-2003 in Sweden by performer.*

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.

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[14] municipalities hosted approximately 90 % of the total university R&D. The corresponding figures for industrial R&D are 17[15] 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. 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.

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[14] These municipalities are Stockholm, Uppsala, Göteborg, Lund, Umeå, Solna Linköping, Huddinge, Malmö and Luleå.

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

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.

Table 5.3. Top 5 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)

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, $U_i^{R\&D}$, (and vice versa) 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):

$$I_i^{R\&D} = \underset{(1.38)}{47.81} + \underset{(20.06)}{1.8}\, U_i^{R\&D} + \varepsilon_i \quad ; \quad U_i^{R\&D} = \underset{(0.87)}{12.89} + \underset{(20.06)}{0.33}\, I_i^{R\&D} + \varepsilon_i \qquad (5.1)$$

where it is apparent that the coefficient for the independent is significant and positive in both equations. The R^2 of both equations amounts to 0.59. 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 formulation of the simultaneous two-equation model follows the work by Johansson & Strömqvist (2003), which in turn is a variation of the model in Carlino-Mills (1989). The Equations that are estimated simultaneously are presented in Equation (5.2a) and (5.2b):

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

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

where $t+\tau$ refers to 2001 and t refers to 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
$I_{i,t}^{R\&D}$	Industrial R&D in year *t* in municipality *i.*
$U_{i,t}^{R\&D}$	University R&D in year *t* in municipality *i.*
$A_{i,t}^{M}$	Intra-municipal accessibility of municipality *I* in time *t.*
$A_{i,t}^{R}$	Intra-regional accessibility of municipality *I* in time *t.*
$A_{i,t}^{E}$	Extra-regional accessibility of municipality *i* in time *t.*
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
Superscripts	
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[16]. 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	$I^{R\&D}_{i,t+\tau}$	$U^{R\&D}_{i,t+\tau}$	$I^{R\&D}_{i,t+\tau}$ **	$U^{R\&D}_{i,t+\tau}$ **
α	-12.90 (-0.95)	-	-14.68 (-1.09)	-
μ	-	-0.31 (-0.04)	-	0.40 (0.05)
$A^{UM}_{i,t+\tau}$	0.19* (7.44)	-	0.21* (7.69)	-
$A^{UR}_{i,t+\tau}$	-0.007 (-1.39)	-	-0.004 (-0.94)	-
$A^{UE}_{i,t+\tau}$	0.009 (1.26)	-	0.01 (1.47)	-
$I^{R\&D}_{i,t}$	1.09* (99.84)	-	1.09* (98.15)	-
$A^{IM}_{i,t+\tau}$	-	0.01 (1.53)	-	0.02* (2.89)
$A^{IR}_{i,t+\tau}$	-	0.001 (0.02)	-	-0.0005 (-0.49)
$A^{IE}_{i,t+\tau}$	-	-0.001 (-0.1)	-	-0.0003 (-0.21)
$U^{R\&D}_{i,t}$	-	0.95* (69.29)	-	0.93* (77.07)
D^{L}_{i}	15.84 (1.01)	15.31 (1.56)	15.29 (0.99)	16.38* (1.96)
D^{SL}_{i}	7.52 (0.50)	1.89 (0.19)	6.62 (0.44)	4.36 (0.53)
R^2	0.98	0.97	0.99	0.98
N	286	286	285	285

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

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

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[16] Lagged values are used as instruments.

6. Conclusions and suggestions for future research

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 in this paper 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 has been to analyse the locational relationship between industry R&D and university R&D in Sweden using a simultaneous equation approach. First of all, our empirical results show that there is a strong persistence or path-dependence in the location of both industrial and university R&D. Concerning the interdependencies between the location of the two types of R&D, our results indicate that the location of industrial R&D is quite sensitive to the location of university R&D, and that the location of university R&D is sensitive to the location of industrial R&D. However, the latter result is achieved only when we take away one outlier in the data – the municipality of Solna that is the location for the largest medical university in Sweden.

Having established the general and overall interdependencies between industrial and university R&D, it is of course important to continue to investigate this kind of interdependencies between industrial R&D in different sectors and university R&D in different faculties and disciplines. We expect to find quite different interdependencies in the different cases. We believe that analyses of this kind have strong policy relevance since they will show to what extent that the public university funding is allocated in an optimal way given the location of industrial R&D. They will also show to what extent that public investments in R&D changes the location of industrial R&D and then show to what extent that the Swedish university policy also functions as a regional industrial policy.

Another avenue for future R&D is of course to more in detail to analyse the flows of R&D funds between industry and universities and to see how these flows change over time. Similarly, would it be interesting to study to what extent that trained researchers move from universities to industry. How important is this mobility and to what extent is it local and interregional, respectively. It would also be useful to explore to what extent new innovations are transferred from universities to industry and to what extent that this transfer is dependent upon spatial proximity.

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