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Working with Distant Researchers

– distance and content in university-industry interaction

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Abstract

This paper studies the role of geographic proximity for interaction on R&D, by exploring the special case of university-industry contacts. While numerous studies find that geographic proximity facilitates spillover effects between university and industry by utilising evidence from e.g. patenting and publishing activities, the geographical dimension is largely understudied in studies that report evidence from direct interaction. To explore when geographical proximity matters for university-industry interaction, a series of interviews with R&D managers in Swedish engineering firms is conducted. These interviews suggest that linkages in geographical proximity are more likely to generate impulses to innovation and create significant learning effects at the firm. Similarly, geographic proximate interaction is more likely to successfully contribute to R&D projects with short time to market. For long-term R&D projects, geographic proximity is generally seen as a less critical factor. A survey to 425 R&D managers in Swedish engineering firms provides evidence that supports these hypotheses.

1. Introduction

The observation that knowledge flows tend to cluster in space has made geographical patterns a central issue in the literature on knowledge creation and innovation at least since a series of contributions emerging in the 1990s (Jaffe et al., 1993; Audretsch & Feldman, 1996; Audretsch & Stephan, 1996; Maskell & Malmberg, 1999), but is typically traced back to Alfred Marshall (1919, 1920). But in spite of being a well-researched area, the role of geographic distance continues to puzzle researchers of the economics of innovation. In particular, there are persistent ambiguities in our understanding of *when* and *why* geographic proximity between actors would be crucial for successful interaction on innovation. The search for determinants has long been characterised by a dichotomous distinction between tacit and codified knowledge (Polanyi, 1966; von Hippel, 1987), the diffusion of the former being seen as dependent on localised knowledge flows. However, this view has been shown too simplified to satisfactory explain the spatial patterns of knowledge flows (Gertler 2003; Bathelt et al., 2004). In search of more appropriate models, scholars of the geography of innovation have tried to capture the key determinants for when geography matters by elaborating on different kinds of tacit knowledge (Balconi et al., 2007), different kinds of knowledge bases (Asheim & Coenen, 2005) or the possible substitution between geographical proximity and other types of proximity (Boschma, 2005).

The general explanations for beneficial effects on innovation activities from geographical proximity in both the literature on economic geography (Maskell & Malmberg, 1999) and on geographical economics (Fujita & Thiesse, 2002) focuses on the value of direct, inter-personal contacts. Codification, it is suggested, cannot fully supplement for such contacts, since knowledge generally is embedded in a variety of specific and localized contexts of application (Antonelli, 2000). Person-embedded knowledge is particularly important in dynamic, specialised activities such as those of R&D personnel (Storper & Venables, 2004). Recent research tends to recognise that the benefits from geographical proximity may be as greatest for those firms which match local and non-local relations to avoid lock-in and access a broader set of knowledge bases (Bathelt et al., 2004).

Interestingly, the empirical evidence supporting this discussion on knowledge flows from the perspective of the firm is strongly based on data aggregated over industries and firms. Convincing evidence that industry-level (Steinle & Schiele, 2002; Asheim & Gertler, 2005) and firm-level (Lemarié et al., 2001; Monjon & Waelbroeck, 2003) determinants affect the role of geography for knowledge flows has been offered. However, the general discussion on how different types of knowledge are differently difficult to transfer without the type of close, personal contacts that are facilitated by spatial proximity seem to suggest a role also for sub-firm level determinants. The role of geography may be hypothesised to differ significantly between different R&D projects of a firm, and for different functions of a firm's R&D and innovation activities (Torre & Rallet, 2005). The main thrust of this paper is to examine the role of sub-firm level determinants to the importance of geographical proximity in innovation, while controlling for the kind of firm-level determinants outlined to be important by previous studies. We chose to explore the case of interaction on R&D between private and public research organisations as this is a particularly interesting setting in which to study geographical patterns of knowledge flows, both theoretically and for its relevance to public policy. As a consequence of this choice, we are able to keep complementary dimensions of proximity (organisational, social, institutional) more or less constant, allowing us to isolate analytically the effects of geographical proximity (Boschma, 2005). In selecting this case, we also contribute to an un-finished discussion on to what extent public science provides local, as opposed to global, public goods of a type that may be appropriated by private firms. In essence, the research question of this paper is to what extent a firm is able to utilise public research institutions as interaction partners depending on the geographic distance between the two.

University-industry interaction has received quite a lot of scholarly attention. Seemingly confirming the prediction of theoretical contributions, a large number of studies have established a link between collaboration with a university and a firm's ability to innovate (Pavitt, 2003; Laursen & Salter, 2006). There is also strong consent that collaboration patterns as well as measurable benefits from university-industry linkages are related to firm characteristics such as size, R&D-intensity, sector and innovation search profiles (Mohnen & Hoareau, 2003; Bercovitz & Feldman, 2007; Lööf & Broström, 2008). Beyond these firm-level investigations, a number of studies have emphasised that a single firm may benefit from interaction with universities in many different ways, depending on the scope and the rationale of a particular relationship (Broström, 2008). In the path-breaking contributions of Klevorick et al. (1995), Cohen et al. (2002) and Fontana et al. (2006), academic research is found to contribute to two types of basic objectives – generation of new ideas or for innovation completion – to similar extent. It has thus been well established that university-industry interaction has important roles to play throughout the cycle of industrial R&D.[i]

In the literature on direct interaction between firms and universities, the geographic dimension is almost totally neglected. For the firm-specific factors discussed above, contributions from economic geography suggesting that sectors (Asheim & Gertler, 2005), size and innovation search profiles affect the importance of geographic proximity for direct interaction in knowledge-intensive activities can be carried over to the specific case of university-industry interaction. In this paper, we suggest that beyond these factors, the role of geography is closely linked to the scope of a particular university-industry relationship. In particular, we recognise that different relationships may be focused on different parts of the R&D cycle, and stipulate that the focus of a particular relationship is linked to the geographical distance between interaction partners. The main contribution of this paper is thus to bring in a new dimension into the study of spatial patterns of R&D interaction. It should be noted that while our distinction between three phases of an innovation cycle is related to the traditional view of (academic) research as either basic or applied and to the traditional view of private R&D as either exploratory or exploitative, it represents a novel approach to studying R&D interaction. We report findings from a sample of Swedish firms supporting the notions that geographically out-stretched linkages are less likely to be focused on the early or late phases of the R&D cycle.

The remainder of this paper is organised as follows: Section 2 reviews the role of geography for R&D interaction as studied in economics, innovation studies and new economic geography. Section 3 reports results from a series of interviews, which are used to generate testable hypotheses. In Section 4, new survey data generated to test these hypotheses is described. Results from analysis of this data are reported in Section 5. Section 6 summarises the findings of the paper.

2. Local and global firm-university relationships

When studying the interfaces between science and technology, an overwhelming part of the empirical literature supports a view of public knowledge as a free good whose value decreases over distance. Some authors consequently speak about a « local public good ». Convincing evidence of spatial limitations on knowledge flows from public science is provided by Jaffe (1989), Jaffe et al. (1993) and Audretsch & Feldman (1996). However, in the few existing studies that are able to empirically investigate the relationship between geographical distance and direct university-industry interaction, the evidence remains ambiguous. Arundel & Geuna (2004) and Levy et al. (2009) are able to confirm the expectation that geographic proximity facilitates interaction. But a number of studies that survey firms directly about their interaction with universities report results that seem to contradict this view. Using detailed data on collaborations between star scientists and firms in Japanese biotechnology, Zucker and Darby (2001) find little evidence of geographically localised use of academic knowledge. Reports from Germany (Beise & Stahl, 1999) and Austria (Schartinger et al., 2002) also find at best mixed support for the view of university-industry direct interaction as strongly bound by geographical distances.

The seemingly contradictory findings on the role of geographic proximity seem to suggest that while firms ceteris paribus may *prefer* to work with local university researchers (Mansfield & Lee, 1996), firms may offset the need for physical proximity by establishing direct linkages to distant university researchers. Thus, some firms – in particular those with advanced research activities of their own – are able to successfully establish global research networks. Monjon & Waelbroeck (2003) find that only firms that are involved in incremental innovation benefit from local spillovers from universities. On the other hand, highly innovative firms appear to derive most benefit from collaborative research with foreign universities. The authors interpret this finding so that highly innovative firms are at the frontier of the academic knowledge in their industry, and therefore need to seek out academic excellence worldwide for collaboration.

In summary, evidence from previous studies does not allow us to disregard geographic proximity as irrelevant, but is neither able to confirm its role as an important factor for direct university-industry interaction. From a research perspective, this conclusion seems somewhat unsatisfactory. A more systematic understanding of in what contexts geographic proximity significantly enhances a firm's ability to appropriate the returns of university-industry interaction is called upon. In the remainder of this section, we briefly describe the two main approaches through which previous studies have sought to advance our understanding of this problem: by analysing (1) differences between different kinds of knowledge and (2) differences between different kinds of interaction mechanisms.

The first of these two approaches is sprung from the discussion of tacit vs codified knowledge, which is associated with Polanyi (1966). This discussion of how different kinds of knowledge flows have different spatial characteristics was further developed by von Hippel (1994), who coined the term "sticky knowledge", defined as the cost to transfer knowledge between two places. Another take on the problem is that "complex" knowledge is associated with greater spatial friction (Beckmann, 1994). Relating to such arguments, a number of studies on the geography of university-industry linkages suggest that the most recent, and as such the most valuable type of knowledge, tends to have such a complex, uncertain and non-codified form that it can not be fully articulated and may only be transferred through personal interactions (Dosi, 1988). As pointed out by Feldman (2000), existing empirical evidence on interaction between university researchers and biotech firms can be interpreted as supporting this line of argument. Adding further evidence, Mariani (2004) found that when controlling for firm characteristics, the characteristics of the region in which the firm resided does not help explain the firm's ability to generate breakthrough patents in the traditional chemical sector. In the quickly developing biotech-sector, however, regional characteristics were found to have significant impact, suggesting an important role of localised knowledge flows. Feldman & Lichtenberg (1998) attempt to construct several indicators of tacitness for the R&D projects that they examine. Their results indicate that the more tacit the outcomes of the project, the more clustered in space is R&D collaboration and project administration. Monjon & Waelbroeck (2003) and Mariani & Giuri (2007) both find that interactions tend to be local when the research project has a low scientific content.

A second line of analysis relates the need for physical proximity to the form of interaction. Mowery & Ziedonis (2001) and Zucker et al. (1998) report evidence that knowledge flows from universities through market transactions are more geographically localized than those operating through non-market "spillovers". These findings seem to suggest that firms that are able to interact informally with universities are better positioned to bridge physical distances than firms that depend on formal contacts only, even though informal contacts traditionally has been associated with 'tacit', localised knowledge. Survey evidence supporting this interpretation is presented by Schartinger et al. (2002) and, for the case of Europe's largest firms, by Arundel &

Geuna (2004). The latter study compares four kinds of interaction forms, and concludes that in the Austrian setting, interaction between firms and universities is not hindered by distance. Only in the case of contract research – the form of interaction best characterised as an arms-length relationship – is distance identified as a possible barrier to interaction.

The approaches described above suffer from different problems. Attempts to discriminate between different kinds of knowledge have been criticized as conceptually vague; a critique that in particular applies to the identification of 'tacit' knowledge (Cowan et al., 2000). Operationalisation of abstract concepts such as 'tacit knowledge' is also very problematic. The second line of analysis described above is more straightforward from an empirical point of view, but is less clearly connected to economic theory. Neither of the two approaches is able to connect university-industry interaction to the underlying drivers for interaction.

In this paper, we explore the role of geography in knowledge flows related to innovation activities by examining the special case of direct interaction between academic researchers and firms. We seek to contribute to the scarce literature that exists on this subject by going beyond it in two respects. First, by going beyond the firm and industry levels of abstraction to explore under what circumstances (sub-firm level factors) that geographical proximity is truly an important determinant for direct knowledge exchange. Second, we achieve this through an approach that represents a departure from previous emphasis on the nature of the knowledge involved or the mode of interaction. In choosing to explore the relationship between the geographical distance between interaction partners and the benefits of the interaction from the point of view of the firm, this study connects the geography of innovation to the economic fundamentals of innovation management.

3. Investigating the role of proximity throughout the innovation cycle

Given the lack of theoretical evidence on a possible relationship between different phases of the innovation cycle and different needs for geographical proximity in collaboration, an exploratory study was conducted, where 18 research and development (R&D) executives in the Swedish engineering industry were interviewed. Particular care was taken to include respondents representing several different engineering sectors. Using open-ended questions, respondents were asked to reflect upon the following three themes and their interrelationships: 1) the benefits of interaction with public research organisations (PROs), 2) the degree of affinity between the firm and the public research organisation and 3) the geographical dimension of interaction. From our interviews, we produce the following categorisation of effects of collaboration with public research institutions. This is not a fully exhaustive list of potential benefits from interaction (see Broström, 2008), but a categorisation found to relate to differing degrees of affinity and geographical distances in interviews.

Contacts with public research can *create learning and impulses for new R&D projects*. It is thus not necessarily any type of research results that emerge from the collaborative effort itself that create value for the firm. Interactions between the firm's employees and the researchers may also provide widened perspectives and have the effect of increasing general levels of competence. By providing opportunities for such learning and impulses to innovation, contacts may help firms perform the very first steps of an innovation process.

The firm can also be *assisted with the execution of long-term R&D projects that it has initiated*. The classification of R&D projects as "long term" is often related to the nature of the product or process at the firm. The technological platform may also be of a nature that makes development times necessarily long. In this category, we find R&D efforts intended to pave the way for future product or process development through the development of technological "platforms". Another typical objective of work in this category is to apply existing technology to new problems in order to either create new products or radically improve products.

The third type of effect is characterized by the firm being *assisted with the execution of short-term R&D projects that it has initiated*. The firm defines a problem that is expected to make the creation of new or improved products or processes possible within a limited period of time. Typical examples are the need to verify the performance of a certain product, to carry through limited changes to an existing product or process, or to develop a new product in a context where short lead-times are customary, for example, in the development of services.

A fourth possible effect is that firms can commercialize the research results of public research institutions through collaboration with the universities and university colleges – in effect shortcutting the commercial innovation process. This is the type of effect that is closest to the "linear" model of how public research creates industrial value. Since our interviewees revealed these types of effects only at the margin, we have not paid further attention to such effects in this paper.

The three types of identified effects can be interpreted as relating to three different phases of a stylised innovation process that starts in open-ended exploration and goes over managed, oriented exploration activities to focused development activities close to commercial application. From our interviews, we deduce a hypothesis that the 'tacitness' and complexity of the knowledge involved in interactions differs systematically between the three phases. Both the earliest and the latest phases of an innovation process - impulses for innovation and R&D closely related to products or processes, respectively - are associated with such high levels of non-codified, complex knowledge that effective collaboration demands relatively high degrees of affinity between the firm and the public research institution. For effects in short-term projects, the need for affinity is strengthened by the fact that the work is often of an integrative character, or by special needs for trust. An example of the latter case is where the collaboration concerns R&D related to a particular product or process, information about which is highly sensitive to the firm involved. Application oriented R&D interaction may be characterised by a high degree of complexity if the involved products or processes are highly complex. For more generic long-term R&D it is often easier to formulate clear commissions for public partners, where deliverables can be formulated in terms of codified knowledge. Thus, complexity can be reduced, and hence, the need for affinity is generally less acute for interaction related to long-term project objectives. In our interviews, we note voices echoing the message of von Hippel (1994); "When the information transfer costs […] are high, innovation-related problem-solving activities that require access to multiple loci of sticky information will sometimes be 'task partitioned' into subproblems that each draw on only one such locus of sticky information."

Our 18 interviews indicate that close affinity in relationships often is closely associated with geographical proximity. This relationship is particularly clearly described by representatives for firms with limited or highly application-oriented R&D competences. In congruence with Monjon & Waelbroeck (2003) and Asheim & Coenen (2005), our interviews suggest that firms with an advanced R&D capacity of their own possess greater possibilities for overcoming the hindrances of geographical distance, for example through temporary relocation of R&D staff to the work places of important partners or by working with a remote public research institution through one of its affiliated offices nearby. However, we also observe that current levels of affinity between privately employed and university researchers depend on past patterns of interaction, and in this sense, a history of localised interactions pave the way for further localised interaction. We postulate that on average, the relationship between affinity and interaction effects discussed above has implications for how the geographical dimension of the public research system affects its ability to create value through direct interaction with engineering firms.

In summary, we derive the following basic hypothesis from interviews: the likelihood of a linkage delivering *learning and impulses* (benefits for the first phase of the innovation process) and/or *assistance with short-term projects* (benefits for the last phase of the innovation process) to a higher degree than *assistance with long-term projects* decreases with distance between the firm and the PRO. However, since we cannot assume that benefits in the first and the last phases of an innovation cycle behave similarly in relation to other factors than that of geography, we split this prediction into two hypotheses:

H1: The likelihood of a linkage delivering *learning and impulses for new R&D projects* to a higher degree than *assistance in long-term R&D projects* defined by the firm decreases with distance between the firm and the PRO.

H2: The likelihood of a linkage delivering *assistance with the execution of short-term R&D projects* to a higher degree than *assistance with long-term projects* decreases with distance between the firm and the PRO.

Compared to the scarce literature on the geographical aspects of university-industry interaction, these hypotheses and their motivation are in line with Levy et al. (2009), but directly conflicting with Schartinger et al. (2002), who find that proximity may only be important for interactions characterised by arms-length (strictly contracted) relationships.[ii]

4. Data

To test these hypotheses, a survey was constructed and sent to managers responsible for R&D at 425 randomly selected engineering establishments in Sweden. The choice to sample local units rather than firms does in effect allow us to partition the R&D contacts of large corporations into well-defined subsets, within each of which the geographic dimension is fixed. The selection of work-places was stratified on work place size (in terms of number of employees) and NACE-codes to oversample large work places and work places with NACE-codes indicating a major orientation towards R&D activities. The motivation for this oversampling was to emphasise working places that, according to well-established findings in the literature, are more likely to have experience from collaboration with universities (Mohnen & Hoareau, 2003).

All workplaces were contacted over phone and asked to identify the most proper respondent for our survey. In falling order of priority, the workplace was asked to identify its R&D manager in charge of external relations, general R&D manager, technology manager, production manager or site manager/CEO. The respondents were then contacted by e-mail and given the chance to respond to the survey electronically or indicate that they did not want to participate. After one week, a second e-mail was sent, reminding about the survey. In parallel, respondents who had not reacted to the survey were contacted over phone, and given the option to respond to the survey questions orally. After three weeks of intensive contact efforts, a final e-mail was sent out. In total, 68 % of the respondents completed the survey. A further 6 % gave incomplete answer.

In designing the survey, a central choice concerns the operationalisation of the term 'distance' in our two hypotheses. We choose to concentrate on three levels of distance; within the (administrative) region of the firm, within the country and outside the country. Compared to asking respondents to provide a measure of distance to her most important interaction partners, this choice reduces the complexity of the survey layout. A test of the survey also indicated that respondents may hesitate to provide distance measures.

Respondents were presented with questions regarding formal interaction with five categories of public research organisations (PROs): universities[iii] in own county, domestic universities outside own county, foreign universities, domestic public research institutes and foreign public research institutes.[iv] For each category, the respondents were asked to state whether his/her working place has had R&D collaboration with a partner in this category in the period 2004-2006. For each category, respondents have then been asked to evaluate three possible benefits from collaboration on a three-level Likert scale ('not at all' / 'to some extent' / 'to a significant extent').

A1: Interaction has helped the firm suggest and formulate new innovation projects

A2: Interaction has contributed to the execution of long-term innovation projects

A3: Interaction has contributed to the execution of short-term innovation projects

For each respondent, between 0 and 15 assessments of collaboration have thus been made. For our analysis, we use the second of these three effects as reference. We thus compare the assessment of this effect with the assessments of each of the two other effects, and construct the following two variables:

focus on learning = 1 if A1 > A2

focus on short term effects = 1 if A3 > A2

Our data on assessments could be used so that each assessment be modelled in the framework of an ordered logit or probit model, with appropriate controls for selection bias. [v] By adopting the two transformed variables *focus on learning* and *focus on short-term effects*, we are however able to win the following advantages. First, as is usual when Likert-scales are applied, there is a tendency to respond with the middle alternative in the data (here "to some extent"). The transformed variables allow us to control that a respondent not only agrees with all three statements without further reflection, but actually is able to differentiate between the three different questions posed. Secondly, we would like to control for the extent to which the innovation activities of the workplace are orientated towards external relations with public research organisations. The best available data is to use the highest assessment for any type of linkage as a proxy. By regressing on the transformed variables instead of on each assessment, we are able to introduce this control without causing endogeneity problems. Third, as the group of firms which interact with public research organisations clearly is a selective group, we should seek to compensate for selection bias. However, the decision to interact with a public research organisation and the assessment of the utility of that interaction can theoretically be thought of as outcomes of the same basic model. Therefore, we would lack the ability to control for the selection mechanism through which the data has been censored (i.e. that assessments only are observed for interacting firms) if we were to model the assessments directly.

Supplementary data on sector codes, firm and work place size as well as location have been supplied by Statistics Sweden. Data on the number of patent applications filed at the Swedish patent bureau and the European Patent Office by the firm to which the workplace belongs has been added from the PATSTAT database. All variables used in the analysis are described in Table 1. Pairwise correlations are provided in the Appendix.

Name	**Description**	Whole sample: Mean (Std. Dev)	Non-missing linkages: Mean (Std. Dev)	Min	Max
Link-specific variables					
focus on learning	during 2004-2006, the link is assessed to have contributed more to impulses for innovation than to implementation of existing R&D projects with a long-term perspective (=1)	.177 (.382)	.177 (.382)	0	1
focus on short-term effects	during 2004-2006, the link is assessed to have contributed more to the execution of short-term R&D projects than to R&D projects with a long-term perspective (=1)	.165 (.372)	.165 (.372)	0	1
institute	link to institute (=1) rather than university (=0)	.400 (.490)	.278 (.449)	0	1
regional	link within county (=1) or outside (=0) county	.200 .400	.346 (.476)	0	1
foreign	link to foreign partner (=1) or domestic (=0) partner	.400 (.490)	.217 (.413)	0	1
student project	the link is only realised through student projects (=1), not through contacts with researchers	.100 (.300)	.100 (.300)	0	1
Workplace-specific variables					
highest assessment	highest assessment of link in three categories (impulses to innovation; implementation of long-term R&D projects, implementation of short-term R&D projects)	2.48 (.543)	2.60 (.527)	1	3
irregular	the respondent does not see a need to establish new contacts to PROs in the foreseeable future (even if such contacts may be reported for the period of this study)	.171 (.376)	.086 (.280)	0	1
urban region	situated in region with major urban centres and significant academic resources (=1)	.113 (.317)	.187 (.390)	0	1
science based sector	manufacturer of electronic or medical equipment, or producer of steel or iron (=1)	.120 (.325)	.148 (.356)	0	1
r&d sector	classified as performer of technical R&D (=1)	.223 (.417)	.360 (.480)	0	1
size1	20-49 employees (=1)	.220 (.414)	.181 (.386)	0	1
size2	50-99 employees (=1)	.158 (.365)	.122 (.328)	0	1
size3	100-199 employees (=1)	.203 (.402)	.183 (.387)	0	1
size4	200-499 employees (=1)	.275 (.447)	.303 (.460)	0	1
size5	500- employees (=1)	.144 (.352)	.211 (.409)	0	1
Firm-specific variables					
number of	number of workplaces in firm	2.90	3.91	1	30

workplaces		(4.38)	(5.83)		
patentee	firm has patent applications in the period 2001-2004 recorded in PATSTAT database	.546 (498)	.707 (.455)	0	1

Table 1: Variables and descriptive statistics. N.B.: Column 3 includes all 1455 observations, column 4 only the 443 observations for which assessment of linkages are observed.

In the stratified sample, 79 % report some form of formalised interaction with public research organisations. Of these, 12 % report only contacts through shorter student projects. Dividing these figures by geographical distance, we find that 64% (53 % when excluding student projects) have regional contacts, 54 % (47%) have domestic, extra-regional contacts, and 29 % (29 %) have foreign contacts.

We next model the likelihood of a specific workplace to be interacting with PROs at each of these three levels of geographical distance. As established in the Schumpeterian literature on innovation, we model the decision to interact with PROs as a function of size and variables proxying for innovation intensity (cf. Johansson & Lööf, 2007); here we base that control on indicators related to sectors and to patenting activities. Firms in urban regions and firms which patent are also frequently found to interact more frequently with PROs than other firms, and the appropriate controls are applied here. The results are presented in Table 2.[vi] Regional interaction is mainly explained by workplace size; domestic, extra-regional interaction is driven by a combination of size and R&D indicators, and foreign interaction is exclusively driven by the variables proxying for R&D activities.

Variable	Regional interaction	Domestic, extra-regional interaction	Foreign interaction
number of workplaces			
size 2			
size 3	***		
size 4	***	**	
size 5	**	**	
r&d sector	***	***	***
science based sector			**
patentee		**	***
pseudo R2	0.13	0.10	0.21

Table 2: Probit model. **LEGEND:** *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Robust Huber/White standard errors are reported.

We conclude that our data is able to reproduce established findings of the literature that size and indicators of R&D intensity (including sector-based variables) are good determinants of interaction with scientific institutions. Furthermore, our analysis suggests that size and R&D indicators are important mediators of the importance of geographical proximity in knowledge-intensive interaction. In the next section, we will analyse whether they also provide support for the hypotheses on linkage focus as an alternative mediators, as presented in the previous section.

5. Model and results

For each linkage, we model the perceived scope of the linkage as a function of firm characteristics and - at the focus of our investigation - of the characteristics of the linkage. We use two binary indicators of the perceived scope of the linkage, i.e. we model whether a linkage is perceived to be *focused on learning* and *focused on short-term effects* respectively. As these perceptions are only observed if a firm has made use of the respective type of linkage, we also need to jointly model the decision to activate each type of linkage. For each of our two outcome variables, we thus apply a probit model with sample selection. The specification of the model is given by

$$y_i^{*} = x_i^{'}\beta + \lambda \varepsilon_i +_{\tau} \tau_i i \qquad (1)$$

$$S_i^{*} = z_i^{'}\gamma + \varepsilon_{\varepsilon} + \xi_i \qquad (2)$$

In equation (1), y_i is a binary variable representing the perceived scope of each linkage, $\mathbf{x}_i$ represents a vector of factors determining the outcome of this variable, ε_i and τ_i are residual terms and represents a vector of parameters to be estimated. In equation (2), S_i is a binary variable equal to 1 if the firm reports to have used this particular type of linkage and 0 otherwise. $\mathbf{z}_i$ represents a vector of factors determining the decision to use this type of linkage, ε_i and ζ_i are residual terms and γ represents a vector of parameters to be estimated. ε_i,τ_i and ζ_i are assumed independently normally distributed with mean 0 and variance 1, and the parameter λ in equation (1) is a free factor loading parameter. These assumptions on the residual terms corresponds to an assumption that the residual terms of equation (1) and equation (2) have a bivariate normal distribution with mean 0 and variance 1. With the notation above, the correlation σ between the residuals can be identified as

$$\rho = \frac{\lambda}{\sqrt{2(\lambda^2 + 1)}}. \qquad (3)$$

The model can now be estimated without inducing sample selection bias, even if the behaviour in the observed linkages is systematically different from what we would observe if non-observed linkages could be observed (i.e. if $\sigma \neq 0$).

The model in equation (1) and (2) is estimated by maximum likelihood.[vii] The sample selection equation (2) is based on the firm-level model developed in the previous section (see Table 2). Since regional linkages are found more commonly and foreign linkages more seldom than domestic, extra-regional linkages and linkages to institutes are reported less frequently than linkages to universities (see Table 1), we control also for these variables.

For the outcome probit model of equation (1), we present the results of four different model specifications. The first model includes three kinds of controls extending the variables on linkage geography. First, we control for whether the linkage is limited to student projects, which is expected to decrease the probability of a focus on learning and increase the probability of a focus on short-term effects. Second, we control for the size of the firm. Previous literature has established that larger firms benefit more clearly from PRO linkages than smaller firms (Cohen et al., 2002; Lööf & Broström, 2008), and larger firms are likely to develop different patterns in external contacts than smaller firms. Size controls are constituted by both the number of workplaces in the firm and the size of the individual workplace. As shown in Table 3, no workplace level size variable is individually significant, but a joint test indicates that they are strongly significant.

We next introduce two alternative proxies for the degree of importance assigned to R&D contacts with public research organisations. In model 2, the variable *highest assessment* is introduced. In model 3, we instead introduce the variable *irregular*. Judging from their estimates, the former proxy is more adequate in the models explaining whether a linkage is *focused on learning*, and the latter proxy more adequate in the models explaining whether a linkage is *focused on short-term effects*. In models 4 and 5, we also add a control for the organisational form of the PRO, which can be either a public research institute or a university. Albeit there is a remarkable lack of evidence on this issue (Broström & McKelvey, 2009), public research institutes are by many considered to be a more appropriate contact for short-term projects, whereas universities are more typically seen as a source of new ideas, and thus more typically associated with learning effects. However, the high degree of collinearity between this variable and *regional* and *student project* risks causing severe problems (see also the Appendix for correlations). In the first case, this is induced by the survey, which only asked respondents to differentiate between contacts within the own region and the rest of Sweden for university contacts. In the second case, collinearity arises from the fact that only universities have student projects as a form of interaction with firms.

In summary, we believe that model specification 2A for the first set of models and model specification 3B for the second set are most reliable for the variable *regional*, as they may suffer from less omitted variable bias than model 1 and avoid the collinearity problems of models 4 and 5. On the contrary, we believe that the variable *foreign* is most reliably modelled in specifications 4 and 5, respectively, where the maximum amount of omitted variable bias is avoided. These preferred estimates are marked in bold in Table 3.

	Focus on learning				Focus on short-term effects			
	Model 1A	Model 2A	Model 3A	Model 4	Model 1B	Model 2B	Model 3B	Model 5
Outcome equation								
regional[i]	.372** (2.45)	**.410*** (2.76)**	.353** (2.32)	.282* (1.83)	.040 (0.24)	.032 (0.20)	.021 (0.12)	.031 (0.18)
foreign[i]	-.463** (-2.41)	-.491*** (-2.64)	-.469** (-2.44)	**-.534*** (-2.98)**	-.392** (-2.14)	-.389** (-2.11)	-.411** (2.18)	**-.409** (-2.16)**
highest assessment		.217 (1.64)		.237* (1.86)		-.033 (-0.25)		
irregular			.143 (0.62)				.579*** (2.71)	.581*** (2.71)
institute				-.362** (-2.24)				.032 (0.19)
student project	-.480** (-2.08)	-.426* (-1.88)	-.484** (-2.12)	-.460** (-2.09)	.505** (2.54)	.500** (2.51)	.488** (2.42)	.488** (2.42)
number of workplaces	-.016 (-1.11)	-.011 (-0.73)	-.016 (-1.12)	-.009 (-0.60)	-.111*** (-2.87)	-.110*** (-2.86)	-.118*** (-2.99)	-.119*** (-2.98)
size2	-.333 (-1.40)	-.321 (0.169)	-.373 (-1.53)	-.308 (-1.37)	-.072 (-0.29)	-.075 (-0.30)	-.022 (-0.09)	-.022 (-0.09)
size3	-.236 (-1.14)	-.179 (-0.87)	-.185 (-0.89)	-.161 (-0.80)	.043 (0.21)	.034 (0.16)	.091 (0.42)	.092 (0.42)
size4	-.109 (-0.60)	-.034 (-0.18)	-.104 (-0.58)	-.003 (-0.02)	.265 (1.36)	.254 (1.27)	.265 (1.35)	.265 (1.34)
size5	-.231 (-1.06)	-.211 (-0.98)	-.239 (-1.09)	-0.168 (-0.80)	.342 (1.52)	.337 (1.48)	.248 (1.07)	.245 (1.05)
_cons	1.08*** (-4.69)	-1.76*** (-3.91)	-1.10*** (-4.84)	-1.74*** (-4.14)	-1.30*** (-6.06)	-1.20*** (-2.69)	-1.32*** (-6.15)	-1.32*** (6.05)
Wald chi2	24.15	28.78	24.52	37.10	28.49	28.39	33.58	33.64
Prob > chi2	0.002	0.001	0.004	0.000	0.000	0.001	0.000	0.000
Selection equation								
regional	.494*** (4.73)	.497*** (4.77)	.499*** (4.76)	.482*** (4.65)	.494*** (4.73)	.497*** (4.77)	.508*** (4.89)	.509*** (4.89)
foreign	-.654*** (-7.57)	-.653*** (-7.56)	-.661*** (-7.57)	-.652*** (-7.55)	-.654*** (-7.57)	-.653*** (-7.56)	-.658*** (-7.57)	-.658*** (-7.58)
pri	-.267*** (-3.13)	-.260*** (-3.04)	-.272*** (-3.15)	-.295*** (-3.46)	-.267*** (-3.13)	-.260*** (-3.04)	-.294*** (-3.51)	-.290*** (-3.39)
urban	.451*** (3.88)	.456*** (3.94)	.483*** (4.15)	.462*** (4.02)	.451*** (3.88)	.456*** (3.94)	.467*** (4.03)	.466*** (4.03)
science based sector	.315*** (2.81)	.316*** (2.83)	.334*** (2.97)	.316*** (2.85)	.315*** (2.81)	.316*** (2.83)	.273** (2.43)	.274** (2.43)
r&d sector	.747*** (7.58)	.749 (7.63)***	.734*** (7.36)	.743*** (7.57)	.747*** (7.58)	.749*** (7.63)	.734*** (7.34)	.732*** (7.38)
patentee	.389*** (4.59)	.384 (4.56)***	.352*** (4.14)	.380*** (4.54)	.389*** (4.59)	.384*** (4.56)	.321*** (3.81)	.322*** (3.81)
size2	-.018 (-0.14)	-.016 (-0.12)	-.031 (-0.24)	-.015 (-0.11)	-.018 (-0.14)	-.016 (-0.12)	.013 (0.10)	.013 (0.10)
size3	.164 (1.34)	.164 (1.34)	.089 (0.72)	.162 (1.33)	.164 (1.34)	.164 (1.34)	.153 (1.23)	.153 (1.23)
size4	.445*** (3.72)	.448*** (3.75)	.451*** (3.77)	.446*** (3.74)	.445*** (3.72)	.448*** (3.75)	.507*** (4.23)	.507*** (4.23)
size5	.523***	.523***	.538***	.521***	.523***	.523***	.585***	.585***

	(3.84)	(3.85)	(3.95)	(3.85)	(3.84)	(3.85)	(4.30)	(4.30)
_cons	-.943*** (-8.49)	-.947*** (-8.54)	-.927*** (-8.34)	-.926*** (-8.32)	-.943*** (-8.49)	-.947*** (-8.54)	-.926*** (-8.34)	-.928*** (-8.33)
LR test of indepence of equations (σ=0)	chi2(1) = 4.14 Prob > chi2 = 0.042	chi2(1) = 5.51 Prob > chi2 = 0.019	chi2(1) = 4.54 Prob > chi2 = 0.033	chi2(1) = 7.94 Prob > chi2 = 0.005	chi2(1) = 7.14 Prob > chi2 = 0.008	chi2(1) = 5.51 Prob > chi2 = 0.019	chi2(1) = 6.73 Prob > chi2 = 0.010	chi2(1) = 6.09 Prob > chi2 = 0.014

Table 3: Probit model with sample selection: **LEGEND:** *** significant at 1% level; ** significant at 5% level; * significant at 10% level. All results are robust for Huber/White standard errors, ensuring limited heteroskedasticity problems. i: reference alternative is domestic, non-regional linkage

The models predicting *focus on learning* have positive estimates for *regional* and negative estimates for *foreign*. We thus conclude that we find robust support for H1. The models predicting *focus on short-term effects* have positive estimates for *foreign*, albeit only at the 5% significance level, and non-significant estimates for *regional*. We thus conclude that we find some support for H2. We furthermore note that while the regional level seems to be a relevant arena facilitating learning effects, we do not find any indications of a difference between regional and domestic extra-regional contacts focused on short-term effects. A tentative explanation is that the specialised competence and equipment sought at PROs when focusing on short-term effects are so thinly distributed over Sweden that contacts within the own region only is a relevant alternative in some cases. A complementary interpretation is related to the definition of regions in our survey, which used administrative borders. Access to public research organisations is better understood as related to a functional rather than an administrative region (Andersson & Karlsson, 2004; Johansson & Lööf, 2007).

6. Conclusions

This paper studies the role of geographic proximity for interaction on R&D, by exploring the special case of university-industry contacts. While numerous studies suggest that geographic proximity generally facilitates spillover effects between university and industry, the geographical dimension is largely understudied in studies of direct university-industry interaction. This paper contributes to the literature on when proximity matters for R&D interaction. A series of interviews focused at university-industry interaction suggest that benefits related to learning and impulses, which often are generated in close, continuous interaction in an unpredictable manner, and benefits related to short-term projects of a very 'applied' nature, which may require a high degree of trust between the involved partners, more frequently arise in interaction within close geographical proximity. When firms seek assistance in long-term projects, it is generally easier to work across geographical distances, since it is possible to modularize projects. For the typical case of large scale technology development projects, people can for example work through occasional long-distance travel (Storper & Venables, 2004).

To test this hypothesis, a survey to 425 Swedish manufacturing firms was conducted. Results support the notions that university-industry linkages in geographical proximity are more likely to be focused on the earliest and, albeit the results here are somewhat more ambiguous, the latest phases of an innovation cycle. Controls for the size and R&D intensity of the firm are applied.

The difference between the three outcomes of interaction are linked to systematic differences in the knowledge involved in the interaction, as captured by the notions of complexity and 'tacitness'. By identifying three effects from collaboration, and analysing the need for geographic proximity in terms of these effects, we are thus connecting to previous attempts to disentangle the role of proximity from the perspective of the knowledge involved. However, in contrast to earlier research on this topic, the approach offered in this paper offers two novelties. First, it allows going beyond the level of an industry or a firm to study in what contexts proximity matters the most for knowledge flows. Second, we are able to relate knowledge flows directly to their role in commercial innovation. Previous studies have sought to advance our understanding of the geographic distribution of the public goods produced in universities by distinguishing between different kinds of knowledge flows, where certain types are expected to be more sensitive than others to geographic distances. These attempts typically take a starting point in the assumption about heterogeneity of knowledge (scientific vs. technological, tacit vs codified etc). Other studies relate the need for physical proximity to the form of the interaction. In contrast to both these approaches, this paper deploys an analysis from the perspective of the user, rather than from the perspective of the knowledge producer.[viii]

In recognition of the fact that geographical patterns for interaction differ between sectors, this study was focused on engineering firms. In a further step, it would be valuable to extend the framework presented in this study to non-engineering firms, to investigate to what extent the findings on the need for geographical proximity that are reported here also apply to university-industry interactions in e.g. the life sciences, or on interaction with service-oriented firms. Since the underlying theoretical arguments of this paper with some modification is valid beyond the specific case of university-industry interaction, it would also be useful to analyse to what extent the findings of this paper can be replicated using data on inter-firm interaction in R&D.

Appendix

Correlation matrix for observed observations

	focus on learning	focus on short-term effects	regional	foreign	highest assessment	patentee	number of workplaces	institute	student project	irregular	size1	size2	size3	size4	size5	science based sector	r&d sector
focus on learning	1.00																
focus on short-term effects	0.20	1.00															
regional	0.10	0.00	1.00														
foreign	-0.10	-0.07	-0.38	1.00													
highest assessment	0.04	-0.07	-0.13	0.09	1.00												
patentee	-0.05	-0.08	-0.12	0.13	0.12	1.00											
number of workplaces	-0.09	-0.16	-0.07	0.12	-0.07	0.12	1.00										
institute	-0.10	0.02	-0.45	0.17	0.10	0.06	0.07	1.00									
student project	-0.05	0.18	0.19	-0.16	-0.17	-0.14	-0.09	-0.13	1.00								
irregular	0.01	0.12	-0.02	0.04	0.04	0.06	0.06	0.05	0.04	1.00							
size1	0.06	-0.01	-0.03	0.05	0.14	-0.27	-0.14	-0.04	0.01	-0.05	1.00						
size2	-0.03	-0.01	0.02	-0.00	0.08	-0.06	-0.04	-0.01	0.04	-0.07	-0.17	1.00					
size3	0.00	0.00	0.05	-0.03	-0.07	-0.03	-0.17	-0.02	0.02	-0.06	-0.22	-0.18	1.00				
size4	0.03	0.03	0.05	-0.06	-0.20	-0.06	0.01	0.01	0.00	-0.03	-0.31	-0.25	0.31	1.00			
size5	-0.07	-0.03	-0.09	0.05	0.07	0.29	0.25	0.06	-0.05	0.18	-0.24	-0.19	-0.25	-0.34	1.00		
science based sector	-0.06	0.09	-0.02	0.00	-0.08	-0.02	0.00	0.03	0.04	0.18	-0.16	0.05	0.00	0.07	0.10	1.00	
r&d sector	-0.07	-0.19	-0.09	0.14	0.29	0.20	0.27	0.05	-0.22	-0.07	0.39	0.12	0.01	0.29	0.14	-0.25	1.00

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[i] While the distinction between idea generation and innovation completion is important, it has also been found that interaction with universities may serve purposes both earlier (capacity creation) and later (marketing of innovation) in the innovation cycle (Broström & Lööf, 2008).
[ii] The evidence presented by Arundel & Geuna (2004) suggest that our hypotheses would not hold if tested on Europe's largest firms, but is not directly applicable on our sample.
[iii] Throughout the text, we use the term 'universities' to characterise all higher education institutions (HEIs). However, it should be noted that in the survey, the term 'higher education institutions' was used. In Sweden, as well as in many other countries, universities is but one type of HEIs.
[iv] Since the Swedish research institute sector is quite small, and concentrated to a few urban regions, the combination of public research institutes in own county would not be relevant for a large share of the respondents. To simplify the survey as much as possible, the category was omitted.
[v] Such an approach has been evaluated using the ssm wrapper for the gllamm program in Stata (Skrondal & Rabe-Hesketh, 2003), indicating support for hypotheses H1 and H2. However, these results show correlations between the error terms of the selection and the final equation not significantly different from 0, suggesting either that we are not able to model the decision to interact correctly, or that the decision to interact is dependent on the same variables as is the assessment of the utility of that interaction. These results can therefore not be trusted.
[vi] As described in Section 4, we did not distinguish between regional and other domestic linkages to PRIs in the questionnaire, on order to simplify it to respondents. In the estimations reported in Table 2, we have attempted to re-create that information by assuming that firms reporting to have interacted with domestic PRIs are referring to regional interaction if they are located in an urban region, and to extra-regional interaction if they are not. Compared to the data on interaction with universities, the only impact of this re-classification is that 22 additional firms are assigned as active in the category domestic, extra-regional interaction.
[vii] As simulation experiments have shown that the maximum likelyhood esetimator implmented in the STATA software may produce errors due to difficulties in numerical maximization (Freedman & Sekhon, 2008), a future objective for this draft paper is to compare the present estimates with the those produced by the ssm wrapper program (Miranda & Rabe-Hesketh, 2005), which uses adaptive quadrature rather than ordinary Gauss-Hermite quadrature in the Newton-Raphson algorithm.
[viii] The focus on the 'supply' side of knowledge flows most likely reflects the underlying traditional 'public good' notion of knowledge.