Signalling, absorptive capacity and the geographic patterns of academic knowledge exchange

Henry Lahr[1]
Centre for Business Research, University of Cambridge
h.lahr@cbr.cam.ac.uk

Alan Hughes
Centre for Business Research and UK-IRC, University of Cambridge
a.hughes@cbr.cam.ac.uk

Michael Kitson
Centre for Business Research and UK-IRC, University of Cambridge
m.kitson@jbs.cam.ac.uk

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Abstract
In this paper, we investigate the geographic distance in collaborations between academics and external organisations across different knowledge exchange channels. This analysis is based on a unique large sample of UK academics. We ask the following questions. First, how far does academic knowledge, explicit or tacit, travel? Second, which academics engage in which collaborations? Third, how does the type of knowledge exchange moderate the effect of individual and department-level absorptive capacity on geographic distance? Fourth, which quality signals or market characteristics affect the formation and distance of knowledge exchange collaborations? We find that the capacity to identify and absorb knowledge helps to explain the geographic distance in collaborations. In particular, age, academic seniority and specific types of professional experience are positively related to geographic distance in transfers of tacit knowledge. Strong common effects of seniority and research quality across channels suggest that the ability to signal the availability and quality of knowledge as a tradable asset dominates the explanatory power of absorptive capacity. The effects of support at the university level are weak, while regional concentration of business R&D expenditures increases collaboration distance.

Keywords: University-industry links, geographic proximity, research collaborations, technology transfer, knowledge diffusion, tacit knowledge, agglomeration economies

JEL classification: D83, O33, R12

[1] Contact author. Centre for Business Research, University of Cambridge, Trumpington Street, CB2 1AG, Cambridge, UK, +44 (0)1223 765340, h.lahr@cbr.cam.ac.uk.

1 Introduction

Relatively little is known about the role of geographic distance in knowledge exchange between academics and business. Despite attempts to attribute substantial and plausible productivity effects to a few transmission channels and agglomeration economies, mainly through academic publications and patents, the exact nature of a broad range of potentially geographically mediated knowledge exchange has received little attention. On the one hand, literature on localised knowledge spillovers (LKS, see Jaffe, 1989; Jaffe et al., 1993; Acs et al., 1994; Audretsch and Feldman, 1996; Mansfield and Lee, 1996; Anselin et al., 1997, 2000; Zucker et al., 1998; Adams, 2002; Audretsch et al., 2005; Abramovsky and Simpson, 2011) centres around accidental or unintentional diffusion processes and their regional effects, but places less emphasis on the diversity of transmission channels. On the other hand, research on university-business links and individuals' deliberate appropriation strategies investigates in great detail various transmission mechanisms and their antecedents, but neglects the geographical dimension. In particular, difficulties in observing and measuring person-to-person interactions across university boundaries on a large scale complicate research into the exchange of less formalised or tacit knowledge. This is especially important since most businesses started by academics are not based on disclosed and patented inventions in the university intellectual property system (Fini et al., 2010).

A substantial body of knowledge has been accumulated on processes and determinants of academic entrepreneurship and commercialisation activities. The channels that are studied most often are patenting by academics or in collaboration with industry, joint publications and joint research, new firm formation through university spin-offs, licensing of university technology, joint ventures, contract research, consulting and personnel exchange and meetings and conferences (Cohen et al., 1998; Agrawal, 2001; Thursby and Thursby, 2002; Colyvas et al., 2002; Link and Scott, 2005; Bercovitz and Feldman; 2008; Grimpe and Fier,

2010; Hughes and Kitson, 2012). The relative importance of these channels has been investigated from the perspective of the firm (Cohen et al., 1998, 2002) and from the perspective of the creator (Agrawal and Henderson, 2002). Abreu and Grinevich (2012) extend this choice of channels by additionally investigating the determinants of indirect and non-commercial appropriation mechanism that include informal advice and public lectures.

Since the extensive literature on university-business links often neglects the spatial dimension of knowledge flows, we add to this literature by examining the geographic diffusion of knowledge in uni- and bi-directional channels of tacit and explicit knowledge exchange involving universities and external collaborators. We expand the range of knowledge transfer channels (channels for potential knowledge spillovers) and spatially mediated, or localised, knowledge spillovers, building on D'Este et al. (2012). The channels analysed include a collaborative partner that is known to the academic who engages in knowledge exchange, in contrast to the predominantly anonymous transfer mechanisms such as patents or publications.

This paper contributes to the literature on localised knowledge spillovers and university-industry links in several dimensions. First, we investigate the role of geographic distance in people-based collaborations to generate knowledge (e.g. collaborative research projects) and collaborations to appropriate the returns from knowledge. Drawing upon a unique sample of 22,170 UK academics at 150 higher education institutions, we are able to identify the microeconomic determinants of geographic distance in academic knowledge exchange. This allows us to estimate the geographic reach of different types of knowledge from a source perspective: we observe how far knowledge travels from the universities' point of view, while the unit of analysis in most prior studies is the firm or the region (Ponds et al., 2010; Abel and Deitz, 2012). Our study has the advantage of staying close to Polanyi's

interpretation of tacit knowledge as *personal* knowledge and not identifying firms as primary carriers of knowledge.

Second, we test the explanatory power of individual and universities' absorptive capacity in models for the geographic distance between partners involved in knowledge exchange. We test their capacity to absorb new knowledge in external collaborations designed to exchange different types of tacit and codified knowledge and compare it to alternative explanations based on signalling and supply characteristics in the market for knowledge. Applying the concepts of absorptive capacity and signalling to external collaborations by academics and academic institutions helps to assess the moderating effect of key defining characteristics of channels for knowledge exchange on the relation between personal and institutional characteristics and geographic distance in knowledge exchange. For example, absorptive capacity is expected to be more important for tacit knowledge, while signalling should have an effect on distance in all knowledge exchange channels regardless of their type. We are thus able to assess the importance of the collaborations' particular attributes relative to the significance of general attributes of academic knowledge exchange in determining geographic distance.

Third, we simultaneously estimate the decision to engage in external collaborations and the geographic distance in these collaborations. This approach improves our understanding of similar and differential determinants of the collaboration decision and the geographic distance involved. Modelling collaborations as two-part selection processes, in which the decision to collaborate and location are simultaneously determined, takes account of the conditional nature of the distance data, which are not observed for non-collaborators. This method has the advantage of using the full sample of UK academics without being restricted to a subsample. Taking cross-equation correlation into account also reduces the risk of biased estimates in the distance equation that might occur due to self-selection.

We find that geographic distance can be explained in part by the capacity to identify and assimilate new knowledge, but primarily by research quality and supply signals. Variables that capture unobservable prior knowledge, such as age, median department age or professional experience, are positively related to distance. Differential effects of these variables across knowledge exchange channels suggest an interaction mechanism between the type of knowledge flow, such as tacit vs. explicit knowledge, and absorptive capacity. Overall, we find many effects that are common to all channels. Signals of academic quality and market characteristics determine both likelihood and geographic distance in academic knowledge exchange. Academic position and research quality show uniform and strong effects across channels. University resources, however, contribute relatively little to the explanatory power of our models and even decrease geographic distance in some channels.

The paper is structured as follows. Section 2 discusses geographical proximity, absorptive capacity and the relevant qualities of knowledge and formulates hypotheses. Section 3 outlines our dataset and estimation methodology. Section 4 presents results and section 5 concludes.

2 Conceptual framework and hypotheses

Localised knowledge spillovers and transfers are closely linked to the concept of tacit knowledge and the absorptive capacity of the person engaging in knowledge exchange. We use different collaborative activities, proxying for different types of knowledge exchange, to ask the questions: how are knowledge transfers and spillovers achieved; what is the geographical reach of intentional knowledge exchange; and how is geographic distance affected by absorptive capacity at the individual, department and university level? To answer these questions, we focus on knowledge embodied in individuals who have the skill and knowledge to engage in external collaborations, what Zucker and Darby (1996) and Feldman

(1999) call “ideas in people” as opposed to the paper trails of publications or knowledge embedded in new goods or services.

2.1 Tacit and codified knowledge

A key property of much knowledge is its degree of explicitness or ability to be expressed in some commonly shared code. Scientific publications, reports, mathematical expressions, specifications, manuals and so forth fall into this category of explicit, or propositional, knowledge. At the spectrum’s other end are pieces of personal knowledge that are less formalised, embodied in persons, sometimes difficult to access even for the bearer of the knowledge. A collection of hands-on skills and know-how and unwritten rules form what Michael Polanyi (1958, 1966, 1967) termed “tacit knowledge” – a type of knowledge that is not captured by language or other symbolic codes. The carrier of such knowledge might know about his/her knowledge (of, say, how to ride a unicycle or how to write efficient computer code), but cannot express it in a language that would allow a recipient to reproduce the described set of actions.

Since tacit knowledge can only be acquired through informal take-up of learned behaviour and routines and requires direct interaction (Howells, 2002), transfers of tacit knowledge are costly. Transaction costs are affected by the spatial relationship between agents, that is, costs tend to increase with distance (Audretsch and Stephan, 1996; Zucker and Darby, 1996). Tacit knowledge becomes more difficult to transfer across large distances, in contrast to pure explicit knowledge, which can be transmitted over long distances without requiring interaction between sender and receiver. The cost of transmitting knowledge, which varies with the degree of explicitness and codifiability, is largely responsible for the drive to codify most, if not all, human knowledge (Roberts, 2001).

Although explicit knowledge is easily transferred, it may require tacit knowledge for interpretation and assimilation (Boschma, 2005). For example, Jensen and Thursby (1998)

find that licensing officers at US research universities believed that more than two thirds of the inventions licensed required co-operation between the academic and the licensing firm in order to commercialize a product successfully. According to Polanyi (1958, p.20), "tacit thought forms an indispensable part of all knowledge", as it is either tacit itself or rooted in tacit knowledge required to be understood by the recipient (Polanyi, 1966). We classify channels of knowledge exchange into "tacit" or "explicit", to indicate the dominant form of knowledge, not to indicate an explicit bi-modal distinction between the different channels.

2.2 Absorptive capacity

In this paper, we use the concept of absorptive capacity to universities in knowledge exchange collaborations. Absorptive capacity can be defined as a firm's ability to identify, assimilate and exploit knowledge from external sources for the purpose of innovation and new product development (Cohen & Levinthal, 1989, 1990). This capacity, particularly at the identification and assimilation stage, is important for the exchange of new knowledge in university-business links, the generation of new knowledge and the translation of knowledge by academics for collaboration partners. The concept emerged alongside the related ideas of the resource-based view of the firm (Wernerfelt, 1984) and the knowledge-based theory of the firm (Grant, 1996). Cohen and Levinthal (1990) argue that the ability to evaluate and utilize outside knowledge largely depends on the quality and level of previously accumulated related knowledge, which they relate to a firm's investment in research and development. They explicitly include the ability to exploit less commercially focused knowledge such as basic scientific research.

When analysing knowledge spillovers in the pharmaceutical industry, Cockburn and Henderson (1996, 1998) argue that the degree of connectedness between universities and firms is important for knowledge spillovers. They find that larger research programmes in pharmaceutical companies are more productive, not only because of economies of scale, but

also because they realize economies of scope by developing diverse portfolios of research projects that enable the firm to capture internal and external knowledge spillovers. Lim (2009) combines absorptive capacity and connectedness and argues that absorptive capacity is grounded in firms' connectedness, and R&D investment is only one component of connectedness. A persistent theme in the literature is the belief that connectedness and internal diversity provide search benefits in terms of faster innovation and higher returns on these inventions. Zucker et al. (2002) argue that team production increases the ability to capture tacit knowledge. When firms look for new opportunities outside the boundaries of the firm, absorptive capacity interacts with financial slack to shape the breadth and depth of search strategies (Bradley et al., 2001). Fabrizio (2009) finds that firms with more external collaborations benefit more from their internal basic research. Because of the risk of a tautological analysis – collaborations themselves are sometimes seen as "potential absorptive capacity" (Jansen et al., 2005) – we strictly focus on *prior* knowledge and resources available before engaging in collaborations.

When applied to external collaborations by academics, the concept of absorptive capacity suggests that prior knowledge, connectedness with other internal and external sources of knowledge as well as available resources for knowledge assimilation should assist in the process of knowledge exchange. The more informal and less codified the knowledge, the stronger should be the moderating effect of absorptive capacity. The experienced academic with departmental resources (other academics with relevant knowledge, university offices dedicated to knowledge transfer) can thus help the receiver re-code and understand the knowledge being transferred. If an external recipient speaks language A and the sending academic speaks (not necessarily natural) languages B, the transfer is greatly improved if the academic also knows language A.

Absorptive capacity reduces the cost of transmitting knowledge and hence improves the rate of return for exchange transactions. Tacit knowledge exchange would benefit more strongly, since communication capacities and prior knowledge reduce the number of costly personal interactions at a distance. Previously unprofitable transactions at the geographic margin can become profitable, increasing the academic's range of interactions. Geography itself can have a direct effect on knowledge exchange, if the similarity of languages and codes or their availability decreases with the distance from the sender. People in one location (work group, department, town, industry cluster) share a common language that enables efficient knowledge exchange. Shared codes can also be described as non-geographical, cognitive proximity (Nooteboom, 2000; Boschma, 2005), which, notwithstanding its unique attributes, is often highly correlated with geographic proximity.

Interpretation, translation or re-coding of explicit knowledge into a language internally understood in receiving businesses can be facilitated through the help of academics who exchange knowledge and also "translate" it into the recipient's code. Such re-coding of knowledge may depend on the academics' prior experience with the external partner's environment, for example, business experience or the contextual knowledge of having been employed in or owned a firm. Publications and other forms of academic output may need to be interpreted to be useful for the external partner. We would therefore expect a positive effect of professional experience on the geographic distance in exchange of tacit knowledge and a smaller, but still positive, effect in more explicit exchanges.

We expect that capacities that aid in acquiring or translating tacit knowledge increase the geographic distance of external collaborations whereas these capacities have a smaller or no effect in external collaborations that generate or transfer explicit knowledge. The degree to which the type of collaboration interacts with absorptive capacity is determined by the explicitness of knowledge. In other words, we expect external partners to transfer, generate

and assimilate knowledge at any distance regardless of the partner's absorptive capacity if the knowledge is entirely explicit and easily understood by the recipient. For example, training company employees should become easier if the trainer has the knowledge required to translate academic knowledge into the frame of reference used by the employees. This contextual knowledge reduces the cost of transferring academic knowledge, because it reduces the number of costly personal interactions, which in turn increases the distance of profitable collaborations.

Hypothesis 1: Professional experience, age and position are positively related to distance but more so in transfers of tacit knowledge.

2.3 Signalling and the market for knowledge

In markets without perfect information, knowledge transfers occur in two phases. Before the actual knowledge generation or exchange transaction can take place, both parties involved must establish the channel and obtain the knowledge that an exchange is possible with another remote or local agent. The information about potential collaboration partners must reach both ends of the transaction: both parties must know of each other's existence. Signalling the availability of academic knowledge is clearly important if academics aim to appropriate the returns from knowledge generation (as opposed to merely accidental knowledge externalities or spillovers; see, for example, Breschi and Lissoni, 2001, 2009).

A scholar's eminence in a specific field, landmark publications or a large research team can help bridge geographic distances to tap demand for knowledge in distant locations. Similarly, university departments dedicated to technology transfers and licensing can aid in this process, although Geuna and Nesta (2006) find that licensing does not seem to be profitable for most universities, while only some succeed in attracting substantial revenues. University rankings or research evaluations (such as the Research Assessment Exercise

(RAE) in the UK) may be used as a signalling device, a higher score implying collaborations over larger distances. Additionally, firms may use academic publications to identify researchers of interest rather than using the publication itself as a vehicle for knowledge exchange (Abreu et al., 2008).

The likelihood of academics forming connections with external partners and their location heavily depends on the local availability of customers, clients and suppliers of complementary knowledge. Local supply and demand of knowledge is at the core of a broad stream of literature on high-tech clusters and their effect on local businesses (Iammarino and McCann, 2006; Huber, 2012). While we do not attempt to summarise this literature here, we emphasise that the relationships between agglomeration economies, local competition and the geographic distance of academics' collaboration activities can produce complex patterns. For example, academics might derive a national or international competitive advantage from sourcing knowledge from local businesses. Similarly, academics might find that demand for knowledge by local businesses is more than they can supply, rendering long-distance travel unnecessary. In our analyses, we aim to capture local supply and demand condition by variables related to the density of firms, universities and business R&D expenditure.

Our distinction between generation and exchange of knowledge reflects the purpose of the collaboration to trade (appropriate returns of) knowledge or to share the cost and risk of discovery. Knowledge can be seen as a commodity at this level of observation. Accordingly, the signalling function of research quality, department and university size and technology transfer staff at the university level may increase the likelihood that collaborations are formed. The joint discovery of knowledge depends on both parties' skills and knowledge capital used for the production of knowledge. The geographic distance of collaboration would then depend on the local availability of such capital. Similarly, if local demand for knowledge

is smaller than the amount of knowledge supplied by large local universities, markets would tend to be located at greater distances.

Hypothesis 2a: Research quality, departmental and university resources increase the distance in collaborations.

Hypothesis 2b: Department and university size increases distance.

The direction of knowledge flows is similarly related to demand and supply. Local demand and supply of knowledge in clusters may reduce the distance of exchange activities. Bi-directional transfers will take place over larger distances if local supply is limited, because academics would not be able to locally source the knowledge provided by the partner. Outflows of knowledge would be unaffected by local supply of knowledge (which would simply be a competitor), but would rather be affected by local demand for knowledge.

Hypothesis 3a: Locally available knowledge capital (R&D) reduces the distance for activities to generate knowledge, because academics are able to collaborate locally.

Hypothesis 3b: Local business density decreases the distance in collaborations, because academics are able to collaborate locally.

Net demand and supply effect are an empirical question. We could, for example, also observe more local collaboration if a university is located in regional cluster, because demand for talent is local, but supply is not (Audretsch and Stephan, 1996). That is, academics at universities in clusters do not need to travel to clients elsewhere, although they might be indifferent with regard to location.

3 Method

3.1 Datasets and variables

The statistical analyses in this paper are based on several data sources which are merged with the CBR Survey dataset of 22,170 UK academics at the core. The dependent variables in our analyses and most explanatory variables are contained in the CBR survey (Hughes et al., 2010; Abreu et al., 2009), which was carried out between autumn 2008 and summer 2009. The survey covered all individuals employed at UK higher education institutions who were active in research or teaching in 2008-9. The population of UK academics so defined consists of 125,900 individuals, which implies a response rate of 17 percent. The workable sample size is 16,790 academics due to missing data in our dependent variables, a small proportion of non-recoverable missing values in independent variables and individuals that do not consider themselves to be in a research or teaching position.

The sample encompasses all grades of staff across all major disciplines at 150 higher education institutions. Table 1 shows that: professors represent 20 percent of the working sample; 33 percent are readers and senior lecturers; 24 percent are lecturers; 19 percent are research fellows or research associates; and 5 percent are other junior staff, such as research or teaching assistants. Compared to HESA[2] statistics, which are known to underestimate the number of professors, our sample contains more professors, readers and senior lecturers. HESA data for the same period show 42 percent female staff, which corresponds to 40 percent in our dataset. In terms of academic disciplines, our sample composition is well aligned with HESA data.

[Table 1 about here]

The outcome variable of primary interest in this paper is the geographic distance to external partners in university collaborations. External partners are defined as private, public

[2] Higher Education Statistics Agency, http://www.hesa.ac.uk/

and charitable organisations. We focus on six knowledge exchange channels: joint publications with individuals from external organisations; joint research with external organisations (original work undertaken by both parties); attending conferences which have participation by individuals from external organisations; organising the hosting of personnel from external organisations on a short- or long-term basis; consultancy services (no original research undertaken); and training company employees through teaching or personnel exchange. The respondents indicated whether they engaged in each activity within the past three years and the geographic location of the organisations involved in the collaboration. This location is measured on a Likert scale with choices {Local Area (10 miles), Region, Rest of UK, Overseas}. Since the survey allowed for multiple answers on each Likert scale, we measure the maximum distance at which each collaboration took place.

Based on the theoretical framework, we categorise collaborative activities of academic along the dimensions *purpose*, *direction* and type of *knowledge*. Figure 1 shows this classification and examples: we conceptually distinguish discrete tacit and explicit knowledge classes, but note that this classification should be understood as a continuum between the two extremes, in the spirit of Polanyi's writings. Similarly, collaborative activities can be pure revenue-generating exercises (on the *transfer – out* branch), but can also have an emphasis on joint knowledge generation (exchange).[3]

[Figure 1 about here]

Our choice of explanatory variables is in line with the literature on university-business links (Perkmann et al., 2012; D'Este and Patel, 2007) and accounts for the specifics of

[3] Note that the branch *"generate – out"* would be an unusual activity in universities, since academics would engage in a collaboration in which only the external partner gains new knowledge. Similarly, an "*in*" branch is not shown because this branch could be subsumed under "academic research", which, in itself, is usually not seen as a diffusion activity.

localised knowledge transfers. In addition to the usual controls for age, gender, academic position, academic discipline and the type of research carried out, we employ a range of proxies for academics' capabilities to generate, transfer and absorb knowledge. Absorptive capacity can be linked to individual characteristics, such as management responsibility or previous employment experience in small or large firms, start-ups or the public sector. An academic's immediate work and research environment and available organisational resources supporting knowledge transfers are measured by: department size; median age of academic staff; whether the university is a member of the Russell Group or a post-1992 institution; the number of commercial partner engagement staff at the university; and the availability of an exploitation company or department responsible for technology transfers. We measure research quality by total research income at the department and by an indicator whether the respondent held a research council grant during the survey period.

In addition to data from the CBR survey of academics, and to reduce common method bias, we use employment and age data from HESA and heidi[4] to proxy for environmental characteristics at the department level. When asking respondent about their discipline, the CBR survey provides 16 alternatives and a free text entry. To each of these choices, we assign the matching HESA/heidi discipline(s). Departmental data are then merged with the survey data by university and department. University characteristics are obtained from the HE-BCI survey[5] in 2007. These are indicators for a local or regional focus in the universities' mission statements, incentives for staff to engage in business collaborations and the above-mentioned existence of technology exploitation mechanisms and commercial partner engagement staff. We further obtained data on research income by institution and cost centre from HESA, which we match by institution and discipline. To facilitate a causal

[4] Higher Education Information Database for Institutions, http://www.heidi.ac.uk
[5] Available from the Higher Education Funding Council for England (hefce) at http://www.hefce.ac.uk/whatwedo/kes/measureke/hebci/

interpretation of our results, the time period covered in these additional data sources is chosen to correspond to the beginning of the survey period in 2006.

At the regional level, business expenditure on research and development and business employment proxy for the demand and supply conditions in the local markets for knowledge. R&D expenditure by businesses in each on the 12 UK regions and devolved administrations in 2006 are obtained from official ONS statistics[6]. The number employed by local businesses in 2006 is defined by using a measure of regional proximity based on the spatial distance between the 124 UK postcode areas. We first obtain employment data from Bureau van Dijk's FAME database and assign it to postcode areas, which are represented by the first two letter of the postcode (e.g."CB" in "CB2 1AG"). For each postcode area, we then calculate the geographic distance to surrounding postcode areas using great-circle distances derived from the Haversine formula and the postcode areas' latitude and longitude. Business employment provided by FAME is then aggregated for all postcode areas within a 10-mile radius from the area's centre.

Some of our dependent and independent variables contain missing values, most of which appear to be randomly scattered throughout the survey. Listwise deletion of these records would cause a substantial loss of statistical precision due to reduced sample size. We address this problem by imputing a small number of missing values – less than 3 percent per variable – based on data-driven regression models for each variable in order to maintain the statistical relationships between independent variables. We did not impute missing values in dependent variables or explanatory variables at the university level to reduce potential imputation biases.

[6] Office for National Statistics (ONS), Research and Development in UK Businesses, Available at http://www.ons.gov.uk/ons/rel/rdit1/bus-ent-res-and-dev/2011/tsd-berd.html

3.2 Estimation

The modelling strategy we employ is motivated by the choice character of university-industry collaborations and the discrete nature of our survey data. We use an ordered probit model with selection to address both aspects. This model can be thought of as a two-step process, in which academics first choose whether or not to collaborate with external partners and then enter into collaboration at a specific distance. We observe both outcomes. It is reasonable to expect that both the decision to collaborate and the partner's distance will to some extent depend on the same variables, as the rationale for collaboration most likely involves similar cost components and benefits as the choice of the distance at which such collaboration takes place. If unobserved heterogeneity in variables determining both outcomes is correlated, estimation of a distance equation without taking account of self-selection would produce biased results. Hence, the econometric design calls for a correction of self-selection or simultaneous estimation of both equations. We choose the more parsimonious and more efficient approach and estimate both equations simultaneously by Maximum Simulated Likelihood.

The model equations are

$$y_i^* = X_i\beta_i + \varepsilon_i \text{ for i=1,2 and } \begin{pmatrix}\varepsilon_1\\ \varepsilon_2\end{pmatrix} \sim N\left(\mathbf{0}, \begin{pmatrix}1 & \rho\\ \rho & 1\end{pmatrix}\right)$$
$$y_1 = I\left(y_1^* > 0\right)$$
$$y_2 = 0 \text{ if } y_2^* < \gamma_1$$
$$y_2 = 1 \text{ if } \gamma_1 \le y_2^* < \gamma_2$$
$$y_2 = 2 \text{ if } \gamma_2 \le y_2^* < \gamma_3$$
$$y_2 = 3 \text{ if } \gamma_3 \le y_2^*,$$

where y_1 equals unity if an academic engages in external collaboration and zero otherwise, X_i is a vector of explanatory variables. A subscript to indicate individual academics has been dropped for readability. In addition to the observed choice in y_1, we also observe a discrete

measure of regional distance between both parties involved in the collaboration. This measure, y_2, takes on the values {0,1,2,3} corresponding to the partner's location in {Local Area (10 miles), Region, Rest of UK, Overseas}. The latent variable y_i^* can be interpreted as an unobserved continuous measure of geographic distance. Correlation of errors between equations is estimated by the correlation coefficient ρ. Since these discrete choice models are only identified up to scale, error variances are normalised to unity. All models include the same set of explanatory variables in both equations. Coefficients in our models are identified by the functional form of the error distribution assumed and the estimation algorithm converges reliably. However, we can impose one exclusion restriction on the distance equation by arguing that incentives for university staff to engage with business and the community may affect the decision to collaborate, but not the location of collaboration partners.

4 Results

External activities of UK academics show a great variety in scope and geographic reach. In terms of scope: the great majority (86 percent) attend conferences that have participation by individuals from external organisations; almost half of the respondents engage in joint publications and joint research with external organisations; 41 percent provide consultancy services; 31 percent train company employees and 25 percent organise the hosting of personnel from external organisations (see Table 1). Although there is much focus on local and regional impact of universities, most academics collaborate on a national or international scale as shown in Figure 2. On average, academics travel internationally to attend conferences, whereas training of company employees takes place at a sub-national level.

[Figure 2 about here]

What concerns us in this paper are individual differences between academics and university departments in their ability to interact with external partners, thus explaining the geographic heterogeneity within each knowledge transfer channel. We interpret distance as a cost, since, *ceteris paribus*, the cost of doing business at a distance is likely to be greater than doing the same transaction locally. Signalling the possibility of knowledge exchanges, executing the actual transfer, translating new knowledge into one's own language or the external partners' as well as local supply and demand conditions all affect these costs. Our independent variables can be interpreted as characteristics of persons or organisations that enable agents to overcome the costs associated with knowledge transfer.

4.1 Absorptive capacity and tacit knowledge

Absorptive capacity is a framework that can help explain the geographic distance in knowledge transfers. Our results shown in Table 4 indicate that many aspects of absorptive capacity increase average distance in all activities. If knowledge transfer channels differ with respect to their requirements on absorptive capacity, we might expect to find differences in the effect of absorptive capacity on geographic distance across channels. In other words, results that show effects unique to one particular channel or a family of channels can be interpreted as a link between absorptive capacity and the channel's defining properties. If, on the other hand, we find the same effect of some variable, say seniority, on distance in all channels, the effect is likely due to a feature common to all knowledge transfers. One such feature could be the ability to advertise the availability of academic research in the market for knowledge, which increases with seniority.

[Tables 2 and 3 about here]

For our hypothesis on the effect of absorptive capacity on collaboration distance (H1), we find mixed results with respect to the variables under consideration. As shown in Table 4, age has a small effect compared to other variables, but shows a channel-dependent pattern. Age seems to support tacit knowledge transfers: Younger academics are at a geographic disadvantage when organising the hosting or training of externals. In traditional, more formalised academic activities, such as joint publications, joint research and attending conferences, age effects are inversely U-shaped or negative, suggesting that older academics may be reluctant to travel. An alternative interpretation derived from our categorisation of channels is that older academics are involved less in the generation of new knowledge, but more in knowledge exchanges (also indicated by the negative coefficients for younger academics in Table 3). Experienced researchers may gain a comparative advantage in transferring knowledge through accumulated past experiences: absorptive capacity.

Median department age is surprisingly detrimental to geographic diffusion, but only for explicit knowledge exchange and not tacit knowledge transfers. The effect of age seems to be localised in individuals *and* departments. Again, the differential effect between tacit and explicit knowledge exchange suggests a relative advantage of experienced academics to bridge the geographical gap. These findings are supported by our results for the propensity to engage in unidirectional knowledge transfers compared to engagement in knowledge generation or bi-directional knowledge exchange, as shown in Table 3. Academics working at departments with an above-median staff age are more likely to engage in outbound knowledge transfers. No such effect can be detected for bi-directional flows of knowledge.

[Table 4 about here]

Many capabilities to process knowledge are revealed by an academic's position (seniority), prior professional experience and whether they are in a leadership position.

Academic seniority can be interpreted as an indicator of absorptive capabilities in the sense of hypothesis H1, but no differences across collaborations can be found that would support such an interpretation. The coefficient pattern is almost identical for all collaborative activities, which would not be expected if position correlated with experience and the academic's ability to interpret and present tacit knowledge to external partners. Since academic seniority sends a strong signal about past research quality, it might be used by potential exchange partners to screen the market for viable sources of knowledge as we will argue below.

Management responsibilities, which can also proxy for absorptive capacity, have a significant effect, but are not solely associated with tacit knowledge exchange. Instead, they foster joint research and publications over greater distances and also increase the distance travelled to conferences as well as distance in company training. Distance in the remaining two channels, hosting of personnel and consulting, remains largely unaffected by management responsibilities. However, they consistently increase the propensity to collaborate, in line with findings by Grimpe and Fier (2009).

Professional experience in public, private and charitable organisations has a surprisingly mixed effect on geographic distance. We would expect that exposure to corporate environments would facilitate the transfer and exchange of knowledge from, and into, these environments. Employment in the private sector, however, makes no difference to any transmission channel apart from, unexpectedly, conferences. Similarly, entrepreneurs with experience in starting or owning a business are better at transferring explicit knowledge (conferences and consultancy services). Previous employment in the public sector reduces geographic distances in collaborations to generate knowledge (joint research and publications), but not in transfers. Academics with professional experience in charitable organisations, on the other hand, seem to have an advantage in these educational channels for outward knowledge transfer (consulting, training).

Female academics seem to be more active in people-focused activities, but at a shorter distance. They attend conferences more often, but engage less than men in joint research and joint publications. However, we find a negative effect on collaboration distance in all activities. This tendency to collaborate closer to their home universities is strongest for activities that generate knowledge and weaker, but still significant, for outbound and bi-directional knowledge transfers.

Variables indicating support on the department and university level have a limited impact on both the propensity to collaborate and geographic distance. Distance is largely unaffected by the number of department and university staff. We only find a small positive effect of university size in bi-directional knowledge transfers. The number of university staff employed to engage with commercial partners increases the likelihood of these activities, but not their distance. It even reduces geographic reach in some activities, which suggests that these offices or departments may concentrate on local opportunities. An explicit local or regional focus in the university's mission statement has no effect, but reduces interaction distance for trainings, similar to the effect of technology exploitation companies and transfer offices.

In sum, the empirical evidence for absorptive capacity as a key variable in academic knowledge transfers is weak. There is no clear pattern of significant effects that distinguishes tacit from explicit knowledge transfers. Most indicators for absorptive capacity either show the same effect for all channels or affect specific channels, inconsistently with hypothesis 1. For example, the distance travelled in collaborations depends on academic seniority in much the same way across all collaboration types, whereas channels can be distinguished by age into typical research activities (such as joint publication, joint research and conferences) and people-based activities (hosting and training), but not primarily along the tacit/explicit dimension. The very specific association of professional experiences and individual channels

suggests that there are many capacities unique to each channel that are more important than general absorptive capacity. Nevertheless, the strong and consistently significant effects of some variables, for example, academic position and research income, also hints at causal mechanisms common to all knowledge exchange.

4.2 Signalling in the market for knowledge

The ability of academics to signal the quality of their research or simply its availability for collaborations and knowledge transfers can facilitate the formation of collaborations over greater distances, because remote potential collaboration partners can learn about the availability of knowledge and better estimate its value. Hence, according to our hypotheses 2a and 2b, we expect research quality, departmental and university resources to increase the distance in collaborations. In contrast to absorptive capacity, which should have the strongest impact in transfers of tacit knowledge, quality signals would most likely affect all channels in a similar way.

Research quality, interpreted as a strong signal of valuable collaboration opportunities, positively affects geographic distance as expected. Total research income from public and private sources on the department level has a strong and positive impact on collaborations. This finding supports the hypothesis that the exchange of knowledge across distance is initiated by signals that transmit the availability of such knowledge to market participants. Overall, a positive effect of research income can be found for all channels. We find a similar, but slightly weaker, effect if we measure research quality by the proportion of research classified as 4-star ("world-leading in terms of originality, significance and rigour") in the 2008 Research Assessment Exercise. The effect of research quality on the propensity to collaborate, however, is concentrated mostly on knowledge generation activities. The signalling effect seems to be limited to the department level: Members of the Russell Group

of research universities do not enjoy additional benefits with regard to collaborative activities across geographic distance if we control for the departments' research quality.

These findings support Mansfield's (1995) observation that faculty ratings are directly related to the university's perceived contribution to industrial innovation, in spite of the view that many highly ranked departments heavily focus on basic research or research with long-term pay-offs. Individual research quality (measured by an indicator whether or not an academic held a research council grant during the survey period) does not contribute to knowledge exchange over greater distances. It does increase, however, the likelihood of cooperation in general. This result is consistent with Mansfield's (1995) finding in the US that practically all of the academic researchers who contributed to firms' new products and processes were at least partially supported by federal funds.

University and department size explains surprisingly little geographic variation. Although larger organisations can supply larger markets, this is not the case for knowledge exchange. Instead, larger departments train firm employees locally more often than small departments. A university's size only slightly increases the distance academics travel to conferences and the distance for the hosting of personnel from external organisations. Hence, hypothesis 2b on the positive effect of size cannot be supported.

In addition to the university's size, its age could have an effect on its capabilities to access distant markets. Higher education institutions that obtained university status through the Further and Higher Education Act 1992 or thereafter have significantly more localised activities than older universities, across all channels observed. It could be the case that post-1992 universities are more rooted in the local community by their origins as institutions that mainly taught professional, vocational and applied subjects. If universities build absorptive capacity through the accumulation of knowledge over time, geographic distance of knowledge exchange might increase. This seems unlikely, however, since a positive effect

can be observed for both tacit exchange and explicit transfers, which would not be expected for explicit knowledge exchange due to its lower requirements on personal interaction and translation of knowledge. This finding for post-1992 institutions may reflect an age effect, acting through accumulated reputation which serves as a signal in the market for knowledge. This explanation is plausible in the light of an insignificant effect of Russell Group membership. Group membership can be interpreted as a much less precise proxy for age than our post-1992 dummy variable, since the Russell Group members' age varies considerably.

Regional supply and demand conditions interact with the type of knowledge exchange. In areas with a large business population, we find more localised knowledge exchange through joint research and conferences, supporting hypothesis 3b. Contrary to our expectations, the availability of local markets does not affect the geographic variation in outbound transfers of knowledge, such as consulting or company training. Regional business expenditures on R&D, on the other hand, have a markedly positive impact on geographic distance. Research has found that firms who adopt "open" search strategies and invest in R&D are more likely than other firms to source knowledge from universities (Laursen and Salter, 2004), which would imply higher demand for academic knowledge in regions with large R&D expenditures and therefore *shorter* distances. Notwithstanding this demand effect, local R&D might positively affect academics' productivity and competitiveness, which in turn could help them build knowledge exchange transactions over greater distances.

The regional characteristics we employ in our models are not exhaustive, but capture much of the economic activity that takes place in a given geographic region. Instead of the number of business employees by postcode area, we also used the number of firms or their aggregate turnover. Both are highly correlated with total business employment, but have smaller predictive power, so we include only aggregate employment by postcode area. A similar case can be made for the local density of universities, which might capture local

supply and demand for knowledge. This variable, however, would also be highly collinear with local business employment, which in turn contains much of the variation in a possible "London dummy" variable.

Finally, the type of research performed by academics gives insights into the geographic collaboration patterns across disciplines and in terms of its suitability for immediate application in the business context. Consistent with Mansfield's (1995) results, we find that basic research operates at greater distances than applied research. This is reflected in joint publication and joint research as the main knowledge-generating activities, but not in any of the diffusion activities. This suggests that basic knowledge is generated globally, whereas its application is relatively localised.

These findings, in addition to the remarkable similarity across channels with respect to the effects of academic seniority, indicate a common basis for the variation in geographic distance we observe. An academic's position and departmental research quality send strong signals about the supply of knowledge, increasing the global reach of knowledge transfers. University resources have no role in the determination of collaboration distances, and commercial exploitation departments and university policies targeting the regional environment can even decrease geographical distance. Overall, the relative uniformity of knowledge transfer channels in relation to individual, departmental, university and regional characteristics lends support the hypothesis that signals about quality and supply of knowledge are an important characteristic of this market.

5 Conclusion

This paper explains the propensity to collaborate in academic knowledge exchange and the geographic distance in these collaborations. For this purpose, we apply the concepts of a researcher's or academic organisation's capacity to identify and absorb new knowledge and their ability to signal the supply of knowledge to a number of channels for knowledge

exchange: joint research, joint publications, attending conferences, hosting personnel from external organisations, consultancy services and training of company employees. We analyse which activities successfully bridge the spatial gap and which tend to have only local effects. Our findings contribute to the literatures on localised knowledge spillovers and on the channels of knowledge transfer in university-business links.

In order to identify the moderating effect of the type of knowledge exchange on geographic distance, we use information on people-based knowledge exchange between academics and external organisations. Our sample of UK academics is the largest to date and offers the key advantage of containing detailed information on formal and informal activities used by academics to generate and exchange knowledge with external partners. This helps us improve our understanding of the ways in which spillovers occur and how they are realised at the geographic level.

Results of our simultaneous estimations of the propensity to collaborate and geographic distance to collaboration partners reveal a limited geographic impact of absorptive capacity. We find evidence for the role of absorptive capacity in variables that capture unobservable prior knowledge, such as the academic's age, median department age or professional experience. For example, experienced academics seem to have a comparative advantage in transfers of tacit knowledge. These variables show differential effects across knowledge exchange channels. Some of these differences are found between tacit and explicit knowledge, which we interpret as interactions between the type of knowledge exchange and absorptive capacity. Effects of professional experience are surprisingly limited. Most of our indicators for professional experience and other personal characteristics of academics affect only specific channels without any pattern that could be interpreted as evidence for absorptive capacity.

Overall, channels appear more similar than is expected from the conceptualisation of exchange activities in terms of explicitness of knowledge, flow direction and purpose of the collaboration. There are several indications that signals of academic quality and market characteristics are important determinants of academic knowledge exchange over geographic distance. Academic position and research quality show uniform and strong effects across channels, which indicates the value of credible signals to reduce uncertainty in the market for knowledge. University characteristics, however, contribute relatively little to the explanatory power of our models. Regional business expenditures on R&D, in contrast to overall business employment (by postcode area), increase geographic distance in all channels. This finding suggests a significant contribution of local business to academics' productivity.

In general, geographic distance does not appear as a strong inhibiting factor for collaborations that could be substantially mitigated by the observed constructs. Despite the highly significant effects we find, a large proportion of individual heterogeneity in terms of the propensity to collaborate and its distance remain unexplained. The propensity to collaborate can be explained slightly better than collaboration distance if estimated individually. Future research could investigate whether determinants at the individual or macroeconomic level can help explain geographic distance, such as orientation- or culture-related barriers to collaboration (Tartari et al., 2012), in contrast to traditional transaction costs.

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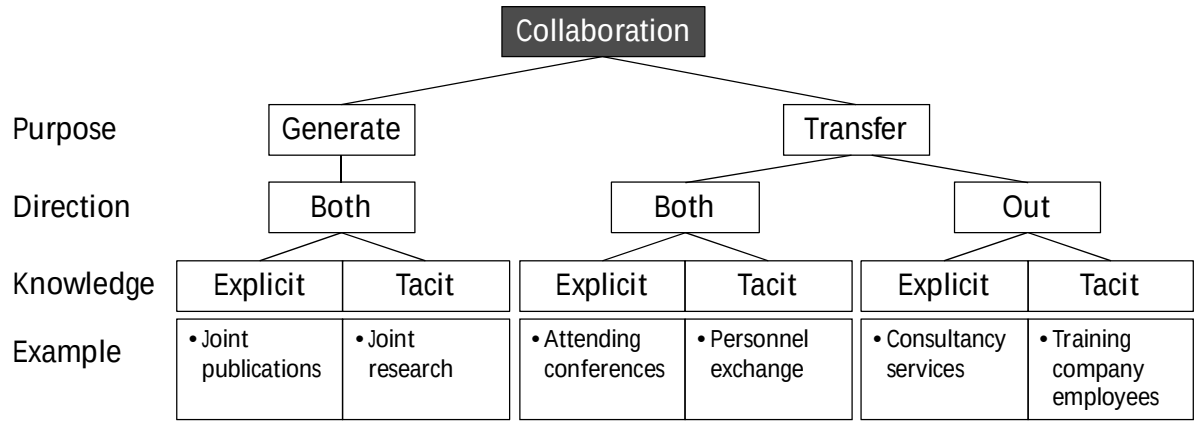

Figure 1. Types of external collaborations

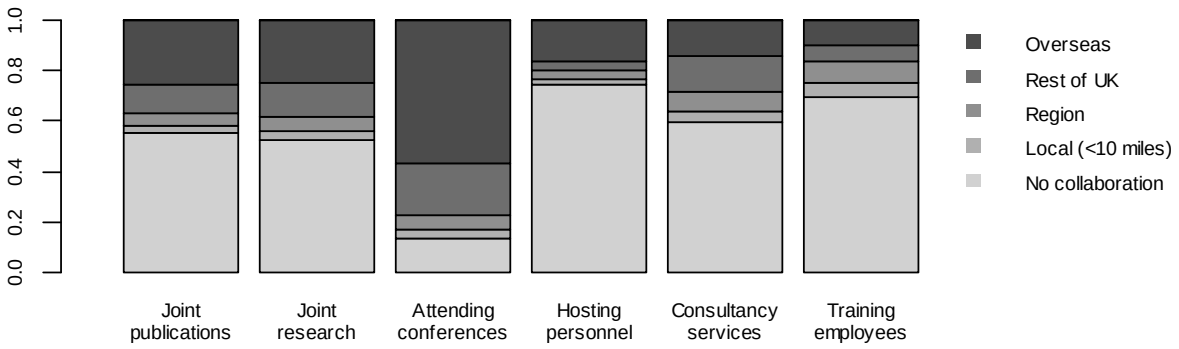

Figure 2. Location of collaboration partner

Table 1. Descriptive statistics

Variable	Obs.	Min.	Max.	Mean	Med.	SD	Description	Data source
Location: Joint publications	7455	1	4	3.343	4	0.893	The geographic location of the organisations involved in the collaboration "Joint publications with individuals of external organisations", measured as the maximum of 0=Local area (< 10miles), 1=Administrative region, 2=Rest of UK, 3=Overseas. Administrative regions are North East, North West, East Midlands, West Midlands, Yorkshire and the Humber, South East, South West, East of England, London, Wales, Scotland, Northern Ireland. Variable is non-missing if the respondent was engaged in this activity during the survey period.	CBR Survey 2009
Location: Joint research	8001	1	4	3.253	4	0.939	The geographic location of the organisations involved in the collaboration "Joint research with external organisations (original work undertaken by both parties)"	CBR Survey 2009
Location: Attending conferences	14430	1	4	3.523	4	0.769	The geographic location of the organisations involved in the collaboration "Attending conferences which have participation by individuals from external organisations"	CBR Survey 2009
Location: Hosting of personnel	4263	1	4	3.362	4	0.993	The geographic location of the organisations involved in the collaboration "Organising the hosting of personnel from external organisations on a short- or long-term basis"	CBR Survey 2009
Location: Consultancy services	6805	1	4	2.937	3	0.990	The geographic location of the organisations involved in the collaboration "Consultancy services (no original research undertaken)"	CBR Survey 2009
Location: Training company employees	5185	1	4	2.666	3	1.130	The geographic location of the organisations involved in the collaboration “Training company employees through teaching or personnel exchange”.	CBR Survey 2009
Person								
Professor	16790	0	1	0.202			Academic position of respondent	CBR Survey 2009
Reader	16790	0	1	0.329			Academic position of respondent	CBR Survey 2009
Lecturer	16790	0	1	0.238			Academic position of respondent	CBR Survey 2009
Fellow	16790	0	1	0.186			Academic position of respondent	CBR Survey 2009
Assistant	16790	0	1	0.045			Academic position of respondent	CBR Survey 2009
Under 30	16790	0	1	0.065			Age of respondent	CBR Survey 2009
30-39	16790	0	1	0.294			Age of respondent	CBR Survey 2009
40-49	16790	0	1	0.296			Age of respondent	CBR Survey 2009
50 and over	16790	0	1	0.344			Age of respondent	CBR Survey 2009
Female	16790	0	1	0.395			The respondent is female.	CBR Survey 2009
Applied research	16790	0	1	0.383			The research carried out by the respondent is applied research: an original investigation undertaken in order to acquire new knowledge directed towards an individual, group or societal need or use.	CBR Survey 2009

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Table 1. Descriptive statistics (continued)

Variable	Obs.	Min.	Max.	Mean	Med.	SD	Description	Data source
Basic research	16790	0	1	0.255			The research carried out by the respondent is basic research: theoretical, empirical or experimental work, undertaken primarily to acquire new knowledge about the underlying foundation of phenomena or observable facts, without any particular application or use in view.	CBR Survey 2009
User-inspired basic research	16790	0	1	0.274			The research carried out by the respondent is user-inspired basic research: theoretical, empirical or experimental work, undertaken primarily to acquire new knowledge about the underlying foundation of phenomena or observable facts, but also inspired by considerations of use.	CBR Survey 2009
None of the categories provided	16790	0	1	0.027			None of the above research categories apply to the respondent's research.	CBR Survey 2009
Type of research missing	16790	0	1	0.061			The respondent did not indicate any type of research	CBR Survey 2009
Employed in SME	16790	0	1	0.252			Professional experience: Employed in a small business (up to 250 employees)	CBR Survey 2009
Started or owned SME	16790	0	1	0.138			Professional experience: Started or owned a small business	CBR Survey 2009
Employed in large firm	16790	0	1	0.265			Professional experience: Employed in a large business (over 250 employees)	CBR Survey 2009
Employed in public sector	16790	0	1	0.326			Professional experience: Employed in a public sector organisation (external to the university sector)	CBR Survey 2009
Employed in charitable org.	16790	0	1	0.152			Professional experience: Employed in a voluntary or charitable organisation	CBR Survey 2009
Management responsibilities	16790	0	1	0.467			The respondent has management responsibility within his/her institution.	CBR Survey 2009
Engineering	16790	0	1	0.073			The respondent's discipline is Engineering or Materials Science.	CBR Survey 2009
Biology, Chemistry, Health	16790	0	1	0.309			The respondent's discipline is Biological Sciences or Chemistry or Health Sciences.	CBR Survey 2009
Humanities & Creative	16790	0	1	0.227			The respondent's discipline is Architecture, Building, Planning or Creative Arts or Education or Languages or other humanities.	CBR Survey 2009
Social sciences	16790	0	1	0.244			The respondent's discipline is Business, Financial Studies or Law, Social Sciences, Economics.	CBR Survey 2009
Mathematics, Physics	16790	0	1	0.132			The respondent's discipline is Mathematics, Computing or Physics, Astronomy, Earth Sciences.	CBR Survey 2009
Other disciplines	16790	0	1	0.015			The respondent's discipline is in any other discipline not mentioned above.	CBR Survey 2009
Any research council funding	16790	0	1	0.247			The respondent held a research council grant during the survey period.	CBR Survey 2009

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Table 1. Descriptive statistics (continued)

Variable	Obs.	Min.	Max.	Mean	Med.	SD	Description	Data source
Department								
Department staff	16790	0	7.542	4.967	4.997	1.057	Number of academic staff at department level (log), for academic year 2006-7	heidi
Median age at department	16790	34.700	55.200	42.821	42.800	3.321	Median age of academic staff at department level	heidi
Total research income per staff	16790	0	10.230	0.359	0.316	0.304	Total research income in £ thousands divided by the number of department academic staff, for academic year 2006-7	HEFCE
University								
University staff	16790	3.497	8.369	7.222	7.193	0.766	Number of academic staff at university level (log), for academic year 2006-7	heidi
Russell group	16790	0	1	0.430			The university is a member of the Russell group of public research universities.	CBR Survey 2009
Post-1992 institution	16790	0	1	0.253			The university is a former polytechnic, college or other Higher Education Institution that was given university status by the Further and Higher Education Act 1992.	CBR Survey 2009
Local focus	16790	0	1	0.053			The area of greatest priority in the university's institutional mission is the local city or town or local authority area (county or unitary).	HE-BCI survey 2007
Regional focus	16790	0	1	0.330			The area of greatest priority in the university's institutional mission is the administrative region (e.g. East Midlands, South West).	HE-BCI survey 2007
Commercial partner engagement staff (log)	16790	0	5.398	3.256	3.401	0.917	Number of staff employed in a dedicated Business and Community function (Full-time equivalents) (log)	HE-BCI survey 2007
Exploitation company or department	16790	0	1	0.978			University has a commercialisation company or department to manage consulting links and other external interactions	HE-BCI survey 2007
Incentives to engage	16790	2	5	4.002	4	0.714	Univerisites' rating of the level of incentives for staff to engage with business and the community, from 1=Barriers outweigh any incentives offered to 5=Strong positive signals given to all staff to encourage appropriate levels of industrial collaboration.	HE-BCI survey 2007
Region								
R&D by businesses (by region)	16790	5.056	8.202	6.801	6.782	0.879	Business R&D expenditure in £ million (log) by administrative region.	ONS
Business employment (by postcode area)	16790	9.247	16.128	12.923	12.717	1.817	Business employees in thousands within a 10-mile radius, based on postcode areas (log). Reference year is 2006. There are 124 postcode areas in the UK, which are represented by the first two letter of the postcode (e.g."CB" in "CB2 1AG"). For each postcode area, we calculate the geographic distance to surrounding postcode areas using great-circle distances derived from the Haversine formula and the postcode areas' latitude and longitude. Business employment provided by FAME is then aggregated for all postcode areas within a 10-mile disc.	FAME

Table 2. Geographical patterns – Model statistics

This table and tables 3 and 4 present results of ordered probit models with selection for the likelihood of engaging in specific knowledge exchange activities and the distance at which the external partner is located. All six models consisting of a selection equation (table 4) and a simultaneous distance equation (table 3) are estimated by Maximum Simulated Likelihood. Standard errors based on the outer product of the gradient (OPG) are in parentheses. This table shows fit statistics and estimation-specific parameters: *cut-off* are the cut-off values in the ordered probit part of the model, *Rho* is the error correlation between the selection and outcome equations and *LR-test on rho* is the p-value for a likelihood ratio test on rho. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

	Joint publications		Joint research		Conferences		Hosting		Consultancy		Training	
cut-off 0|1	-2.378	(0.41) ***	-1.910	(0.38) ***	-2.564	(0.31) ***	-0.707	(0.63)	-1.724	(0.43) ***	-1.137	(0.62) *
cut-off 1|2	-1.738	(0.41) ***	-1.248	(0.38) ***	-1.952	(0.31) ***	-0.123	(0.64)	-0.966	(0.42) **	-0.355	(0.63)
cut-off 2|3	-0.872	(0.41) **	-0.411	(0.38)	-0.979	(0.30) ***	0.347	(0.65)	0.000	(0.42)	0.241	(0.63)
Rho	0.214	(0.19)	0.216	(0.15)	0.300	(0.10) ***	0.336	(0.32)	-0.134	(0.17)	0.143	(0.23)
LR-test on rho (p-value)		0.153		0.056		0.001		0.241		0.306		0.329
Log-Likelihood		-17678.991		-18470.009		-18265.013		-12706.007		-18348.915		-15950.643
Log-Lik. selection model		-10058.341		-9705.936		-5981.316		-8547.058		-9900.711		-9119.489
Log-Lik. outcome model		-7621.670		-8765.899		-12289.301		-4159.637		-8448.727		-6831.629
Log-Lik. selection Null model		-11532.467		-11619.443		-6816.379		-9512.887		-11334.971		-10378.723
Log-Lik. outcome Null model		-8052.217		-9170.366		-13205.463		-4347.013		-8816.297		-7093.518
McFadden Pseudo R^2		0.097		0.112		0.088		0.083		0.089		0.087
Observations		16790		16790		16790		16790		16790		16790

Table 3. Geographical patterns – Propensity to collaborate

	Joint publications		Joint research		Conferences		Hosting		Consultancy		Training	
Under 30 (reference category: 50 and older)	-0.225	(0.05) ***	-0.024	(0.05)	0.110	(0.06) *	-0.174	(0.06) ***	-0.244	(0.06) ***	-0.128	(0.06) **
30-39	0.022	(0.03)	0.095	(0.03) ***	0.190	(0.04) ***	-0.091	(0.03) ***	-0.088	(0.03) ***	-0.070	(0.03) **
40-49	-0.009	(0.03)	0.079	(0.03) ***	0.105	(0.03) ***	-0.033	(0.03)	-0.031	(0.03)	0.002	(0.03)
Female	-0.140	(0.02) ***	-0.097	(0.02) ***	0.126	(0.03) ***	-0.028	(0.02)	-0.171	(0.02) ***	-0.006	(0.02)
Reader (reference category: professor)	-0.275	(0.03) ***	-0.282	(0.03) ***	-0.207	(0.04) ***	-0.277	(0.03) ***	-0.264	(0.03) ***	-0.061	(0.03) *
Lecturer	-0.397	(0.04) ***	-0.388	(0.04) ***	-0.372	(0.05) ***	-0.383	(0.04) ***	-0.464	(0.04) ***	-0.197	(0.04) ***
Fellow	-0.347	(0.04) ***	-0.261	(0.04) ***	-0.347	(0.05) ***	-0.459	(0.04) ***	-0.603	(0.04) ***	-0.320	(0.04) ***
Assistant	-0.611	(0.06) ***	-0.482	(0.06) ***	-0.633	(0.07) ***	-0.592	(0.07) ***	-0.788	(0.07) ***	-0.287	(0.07) ***
Employed in SME	0.012	(0.03)	0.086	(0.03) ***	0.106	(0.03) ***	0.113	(0.03) ***	0.165	(0.03) ***	0.161	(0.03) ***
Started or owned SME	0.149	(0.03) ***	0.134	(0.03) ***	0.178	(0.04) ***	0.197	(0.03) ***	0.397	(0.03) ***	0.391	(0.03) ***
Employed in large firm	0.018	(0.03)	0.050	(0.03) *	0.091	(0.03) ***	0.103	(0.03) ***	0.081	(0.03) ***	0.249	(0.03) ***
Employed in public sector	0.103	(0.02) ***	0.124	(0.02) ***	0.257	(0.03) ***	0.145	(0.02) ***	0.139	(0.02) ***	0.228	(0.02) ***
Employed in charitable org.	0.114	(0.03) ***	0.134	(0.03) ***	0.290	(0.04) ***	0.113	(0.03) ***	0.208	(0.03) ***	0.205	(0.03) ***
Management responsibilities	0.245	(0.02) ***	0.307	(0.02) ***	0.243	(0.03) ***	0.388	(0.02) ***	0.234	(0.02) ***	0.248	(0.02) ***
Any research council funding	0.448	(0.03) ***	0.592	(0.03) ***	0.548	(0.04) ***	0.348	(0.03) ***	0.240	(0.03) ***	0.195	(0.03) ***
Basic research (reference: applied research)	-0.424	(0.03) ***	-0.571	(0.03) ***	-0.469	(0.04) ***	-0.285	(0.03) ***	-0.586	(0.03) ***	-0.553	(0.03) ***
None of the categories provided	-0.426	(0.07) ***	-0.660	(0.07) ***	-0.487	(0.07) ***	-0.372	(0.08) ***	-0.464	(0.07) ***	-0.392	(0.07) ***
User-inspired basic research	-0.145	(0.03) ***	-0.212	(0.03) ***	0.016	(0.04)	-0.068	(0.03) **	-0.233	(0.03) ***	-0.189	(0.03) ***
Type of research missing	-1.016	(0.06) ***	-1.385	(0.06) ***	-0.671	(0.05) ***	-0.233	(0.05) ***	-0.500	(0.05) ***	-0.050	(0.05)
Biology, Chemistry, Health (ref.: engineering)	-0.149	(0.05) ***	-0.239	(0.05) ***	0.001	(0.06)	-0.181	(0.05) ***	-0.343	(0.04) ***	-0.191	(0.04) ***
Humanities & Creative	-0.631	(0.05) ***	-0.750	(0.05) ***	-0.340	(0.07) ***	-0.352	(0.05) ***	-0.342	(0.05) ***	-0.579	(0.05) ***
Social sciences	-0.483	(0.05) ***	-0.571	(0.05) ***	-0.049	(0.07)	-0.331	(0.05) ***	-0.181	(0.05) ***	-0.202	(0.05) ***
Mathematics, Physics	-0.163	(0.05) ***	-0.253	(0.05) ***	-0.170	(0.07) **	-0.169	(0.05) ***	-0.476	(0.05) ***	-0.391	(0.05) ***
Other disciplines	-0.152	(0.10)	-0.311	(0.10) ***	0.262	(0.15) *	0.067	(0.09)	-0.191	(0.09) **	-0.033	(0.09)
Department												
Department staff	-0.007	(0.01)	-0.040	(0.01) ***	0.011	(0.02)	-0.048	(0.02) ***	-0.013	(0.01)	-0.009	(0.01)
Median age at department	0.003	(0.01)	0.000	(0.01)	0.010	(0.01) *	0.004	(0.01)	0.021	(0.01) ***	0.034	(0.01) ***
Total research income per staff	0.314	(0.06) ***	0.326	(0.06) ***	0.057	(0.08)	0.299	(0.07) ***	0.047	(0.06)	0.102	(0.06)
University												
University staff	-0.051	(0.03) *	0.006	(0.03)	-0.050	(0.03)	-0.019	(0.03)	-0.040	(0.03)	-0.002	(0.03)
Russell group	-0.072	(0.04) *	-0.008	(0.04)	0.028	(0.05)	0.045	(0.04)	0.058	(0.04)	-0.055	(0.04)
Post-1992 institution	-0.122	(0.03) ***	-0.015	(0.03)	-0.043	(0.04)	0.024	(0.04)	-0.069	(0.03) **	0.102	(0.03) ***
Local focus	0.043	(0.05)	-0.028	(0.05)	0.028	(0.06)	0.052	(0.05)	0.047	(0.05)	0.158	(0.05) ***
Regional focus	0.006	(0.02)	-0.013	(0.03)	0.004	(0.03)	-0.007	(0.03)	-0.024	(0.03)	-0.015	(0.03)
Commercial partner engagement staff (log)	0.045	(0.01) ***	0.025	(0.01) *	0.002	(0.02)	0.035	(0.02) **	0.009	(0.01)	0.043	(0.02) ***
Exploitation company or department	0.009	(0.07)	0.009	(0.07)	-0.136	(0.10)	0.057	(0.08)	0.046	(0.08)	-0.127	(0.08)
Incentives to engage	-0.032	(0.02) **	-0.023	(0.02)	0.001	(0.02)	0.013	(0.02)	0.010	(0.02)	0.016	(0.02)
Region												
R&D by businesses (by region)	-0.028	(0.01) **	-0.014	(0.01)	-0.052	(0.02) ***	-0.021	(0.01)	-0.005	(0.01)	-0.031	(0.01) **
Business employment (by postcode area)	-0.013	(0.01) **	-0.018	(0.01) ***	-0.003	(0.01)	-0.021	(0.01) ***	0.000	(0.01)	0.000	(0.01)
Intercept	0.950	(0.30) ***	0.872	(0.30) ***	1.513	(0.37) ***	-0.174	(0.32)	-0.265	(0.30)	-1.635	(0.32) ***

Table 4. Geographical patterns – Distance to external partner

	Joint publications		Joint research		Conferences		Hosting		Consultancy		Training	
Under 30 (reference category: 50 and older)	0.041	(0.08)	0.174	(0.07) **	0.194	(0.05) ***	-0.333	(0.13) **	0.110	(0.09)	-0.182	(0.09) **
30-39	0.184	(0.04) ***	0.185	(0.04) ***	0.285	(0.04) ***	-0.104	(0.07)	0.163	(0.04) ***	0.060	(0.05)
40-49	0.064	(0.04) *	0.093	(0.04) ***	0.123	(0.03) ***	-0.034	(0.05)	0.009	(0.03)	-0.021	(0.04)
Female	-0.243	(0.04) ***	-0.203	(0.03) ***	-0.119	(0.02) ***	-0.103	(0.05) **	-0.141	(0.04) ***	-0.125	(0.03) ***
Reader (reference category: professor)	-0.332	(0.05) ***	-0.411	(0.05) ***	-0.346	(0.04) ***	-0.370	(0.10) ***	-0.396	(0.04) ***	-0.373	(0.05) ***
Lecturer	-0.462	(0.07) ***	-0.553	(0.07) ***	-0.409	(0.05) ***	-0.528	(0.14) ***	-0.464	(0.06) ***	-0.528	(0.07) ***
Fellow	-0.351	(0.07) ***	-0.390	(0.06) ***	-0.415	(0.05) ***	-0.510	(0.17) ***	-0.268	(0.08) ***	-0.411	(0.09) ***
Assistant	-0.613	(0.13) ***	-0.680	(0.10) ***	-0.837	(0.08) ***	-0.752	(0.24) ***	-0.689	(0.13) ***	-0.735	(0.11) ***
Employed in SME	0.054	(0.04)	0.024	(0.03)	0.086	(0.03) ***	0.014	(0.06)	-0.029	(0.04)	-0.008	(0.04)
Started or owned SME	0.056	(0.04)	0.029	(0.04)	0.152	(0.03) ***	0.032	(0.08)	0.107	(0.05) **	0.125	(0.07) *
Employed in large firm	-0.023	(0.03)	-0.005	(0.03)	0.001	(0.03)	0.032	(0.06)	0.050	(0.03)	0.089	(0.05) *
Employed in public sector	-0.073	(0.03) **	-0.064	(0.03) **	-0.007	(0.03)	-0.076	(0.06)	-0.043	(0.03)	-0.008	(0.05)
Employed in charitable org.	0.026	(0.04)	0.089	(0.04) **	0.031	(0.03)	0.016	(0.06)	0.113	(0.04) ***	0.119	(0.05) **
Management responsibilities	0.103	(0.05) **	0.101	(0.04) **	0.133	(0.03) ***	0.061	(0.12)	0.020	(0.04)	0.099	(0.05) *
Any research council funding	0.021	(0.06)	-0.006	(0.06)	0.225	(0.04) ***	0.107	(0.11)	-0.071	(0.04) *	-0.020	(0.05)
Basic research (reference: applied research)	0.211	(0.07) ***	0.136	(0.07) **	-0.160	(0.04) ***	-0.037	(0.10)	0.029	(0.08)	-0.220	(0.11) **
None of the categories provided	0.000	(0.13)	-0.065	(0.14)	-0.228	(0.07) ***	-0.087	(0.19)	-0.045	(0.11)	-0.296	(0.13) **
User-inspired basic research	0.067	(0.04) *	0.052	(0.04)	-0.017	(0.03)	0.020	(0.05)	0.029	(0.04)	-0.045	(0.05)
Type of research missing	-0.396	(0.19) **	-0.543	(0.21) **	-0.731	(0.07) ***	-0.432	(0.13) ***	-0.184	(0.09) **	-0.234	(0.07) ***
Biology, Chemistry, Health (ref.: engineering)	-0.104	(0.05) *	-0.173	(0.05) ***	-0.245	(0.05) ***	-0.261	(0.09) ***	0.139	(0.06) **	-0.190	(0.07) ***
Humanities & Creative	-0.118	(0.10)	-0.194	(0.10) **	-0.396	(0.06) ***	-0.322	(0.14) **	0.148	(0.07) **	-0.149	(0.12)
Social sciences	-0.122	(0.08)	-0.160	(0.08) **	-0.309	(0.05) ***	-0.325	(0.13) **	0.220	(0.06) ***	0.040	(0.07)
Mathematics, Physics	0.161	(0.06) ***	0.096	(0.06) *	-0.044	(0.06)	-0.109	(0.10)	0.014	(0.08)	-0.122	(0.09)
Other disciplines	0.096	(0.12)	0.040	(0.12)	-0.130	(0.10)	0.188	(0.16)	0.353	(0.12) ***	0.265	(0.12) **
Department												
Department staff	-0.013	(0.02)	-0.001	(0.02)	0.006	(0.01)	-0.023	(0.03)	-0.001	(0.02)	-0.054	(0.02) **
Median age at department	-0.031	(0.01) ***	-0.009	(0.01)	-0.015	(0.01) ***	-0.006	(0.01)	-0.016	(0.01) **	0.000	(0.01)
Total research income per staff	0.527	(0.10) ***	0.482	(0.09) ***	0.510	(0.07) ***	0.356	(0.15) **	0.517	(0.08) ***	0.363	(0.09) ***
University												
University staff	0.024	(0.04)	-0.015	(0.03)	0.045	(0.03) *	0.090	(0.05) *	0.022	(0.03)	0.027	(0.04)
Russell group	-0.062	(0.05)	0.015	(0.05)	-0.004	(0.04)	-0.009	(0.07)	0.019	(0.05)	-0.035	(0.06)
Post-1992 institution	-0.134	(0.05) ***	-0.225	(0.04) ***	-0.111	(0.03) ***	-0.179	(0.06) ***	-0.161	(0.04) ***	-0.199	(0.05) ***
Local focus	-0.084	(0.06)	0.020	(0.06)	0.002	(0.05)	0.133	(0.09)	-0.041	(0.06)	-0.025	(0.07)
Regional focus	-0.028	(0.03)	-0.014	(0.03)	0.014	(0.03)	0.019	(0.05)	-0.050	(0.03)	-0.103	(0.04) ***
Commercial partner engagement staff (log)	-0.003	(0.02)	0.005	(0.02)	-0.011	(0.02)	-0.029	(0.03)	-0.047	(0.02) **	-0.009	(0.02)
Exploitation company or department	0.091	(0.10)	0.099	(0.09)	-0.016	(0.08)	0.233	(0.15)	-0.094	(0.11)	-0.337	(0.12) ***
Region												
R&D by businesses (by region)	0.059	(0.02) ***	0.048	(0.02) ***	0.033	(0.01) **	0.060	(0.03) **	0.065	(0.02) ***	0.069	(0.02) ***
Business employment (by postcode area)	-0.002	(0.01)	-0.022	(0.01) ***	-0.019	(0.01) ***	-0.001	(0.01)	0.002	(0.01)	-0.002	(0.01)