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S3.2. Research-intensive clusters, technopoles, Science Cities

Shaping the formation of university-industry research collaborations: what type of proximity does really matter?[1]

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Abstract

Research collaborations between universities and industry (U-I) are considered to be one important channel of potential localised knowledge spillovers. These collaborations favour both intended and unintended flows of knowledge and facilitate learning processes between partners from different organisations. Despite the copious literature on localised knowledge spillovers, still little is known about the factors driving the formation of U-I research collaborations and, in particular, about the role that geographical proximity plays in the establishment of such relationships. Using collaborative research grants between universities and business firms awarded by the UK Engineering and Physical Sciences Research Council (EPSRC), in this paper we disentangle some of the conditions under which different kinds of proximity contribute to the formation of U-I research collaborations, focussing in particular on technological complementarity among the firms participating in such partnerships.

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1. Introduction

A central tenet of theories on regional innovation and growth is that spatially mediated knowledge externalities are a fundamental ingredient of agglomeration economies, and play a driving role in explaining differences in economic and innovative performance between regions (e.g. Jaffe et al., 1993; Audretsch and Feldman, 1996; Anselin et al., 1997; Varga, 1998; Feldman, 1999; van Oort, 2004). Localized knowledge spillovers refer to the advantage that social actors accrue in accessing and using knowledge that spills over from other co-located actors. Universities are generally considered to be key actors in the production of this type of externality. Due to their explicit mission towards the generation and dissemination of knowledge and innovation, universities are deemed to play an important role as potential sources of (localised and non-localised) knowledge spillovers (e.g. Rosenberg and Nelson, 1994; Etzkowitz and Leydesdorff, 1997; Morgan, 1997; Salter and Martin, 2001; Mowery and Sampat, 2005; Gulbrandsen et al., 2011).

Despite the copious literature on the spatially bounded nature of knowledge spillovers from academic research, much confusion and disagreement still remain, from a theoretical viewpoint, about the factors driving the formation and the spatial patterns of university-industry (U-I) research linkages and, from an empirical viewpoint, about the operationalisation and measurement of the channels through which knowledge flows.

On the first point, with regard to the role played by geographical proximity in knowledge creation and diffusion processes, some authors have argued that it may well be overestimated, due to neglect of other forms of proximity – notably cognitive and organisational proximities – and their interplay with spatial features (e.g. Malmberg and Maskell, 2002; Boschma, 2005; Torre and Rallet, 2005; Massard and Mehier, 2010).

On the second point, it has been argued that the characteristic of tacitness commonly associated with knowledge, together with the free, unintentional and disembodied nature of *pure* knowledge externalities, have been often misinterpreted. This has given rise to a loose concept of spillover applied indiscriminately to indicate both deliberate and unintended exchanges, and both flows and dissemination channels, regardless of the actual transmission mechanisms (Breschi and Lissoni, 2001a,b; Breschi et al., 2005). In this sense, the frantic search for spillovers "has obscured the wide set of mechanisms through which local universities actually contribute to firms' research efforts" (Breschi and Lissoni, 2001a, 271).

In this paper, we aim at contributing to these two fronts. We focus on research collaborations between universities and businesses, which are one specific channel of knowledge flows (and potential spillovers) from and to academic research, and we investigate the role of spatial proximity, and of the factors moderating its impact, in shaping the formation of university-industry collaborations. The empirical analysis draws on a database of collaborative research grants between universities and business firms awarded by the UK Engineering and Physical Sciences Research Council (EPSRC) in the period 1999–2003. By focussing on a direct measure of U-I relationships and examining the conditions under which research collaborations do, and do not, form, we believe that we can better understand U-I linkages and the role that proximity may play in such interactions.

The paper is organised into six sections. The following Section 2 reviews different conceptual approaches to U-I research linkages found in the literature, and sets the research questions and hypotheses. Section 3 presents the database and the method used in the empirical analysis. Section 4 explains the construction of our key variables, while Section 5 discussed the results obtained. Section 6 concludes by highlighting the main findings and the implications for both theory and policy.

2. Theoretical framework

2.1 U-I collaborations and the role of geographical proximity

The role of geographical proximity in shaping the relationship between businesses' innovative activities and university research has had a central place in studies of spatially mediated, or localised, knowledge externalities. A substantial body of literature has found support for the existence of geographically bounded spillovers from university research to industrial innovation (e.g. Jaffe, 1989; Acs et al., 1994; Mansfield and Lee, 1996; Anselin et al., 1997; Henderson et al., 1998; Fritsch and Schwirten, 1999; Arundel and Geuna, 2004; Abramovsky et al., 2007; Laursen et al., 2010). We can broadly distinguish three different strands of literature interested in the collaboration between university and business worlds for the creation and diffusion of new knowledge: 1) studies of localised knowledge spillovers (LKS); 2) studies of the systemic nature of knowledge and innovation, i.e. from 'Systems of Innovation' to 'Triple Helix'; 3) and, overlapping with the second group, studies on industrial clustering, local and regional systems and development.

The knowledge production function-based LKS approach to the study of U-I linkages (e.g. Jaffe, 1989; Acs et al., 1994; Audretsch and Feldman, 1996; Feldman and Audretsch, 1999; Anselin et al., 1997, 2000; Henderson et al., 1998; Varga, 1998; Audretsch et al., 2005; Fritsch and Slavtchev, 2007) has paid little attention to the precise channels for knowledge transmission, often failing to disentangle knowledge flows mediated through market-related exchanges from pure unintended knowledge spillovers (Breschi and Lissoni, 2001a,b, 2003, 2004; Breschi et al., 2005; Autant-Bernard et al., 2009; Massard and Mehier, 2010). What has been measured, it is claimed, is the *potential* for localised spillovers, which occur on the basis of various, often market-mediated mechanisms for knowledge transmission (Breschi and Lissoni, 2001a). In other words, the obsession for measuring the impact of localised knowledge spillovers has turned the attention away from a wider and articulated array of knowledge flows – some of them undoubtedly effects of agglomeration economies – that encompass direct and indirect forms of learning from linkages and interactions among actors in (co-located) organisations: the actual *transport* mechanisms of knowledge have been largely overlooked.

In contrast, the emphasis of knowledge and innovation as intrinsically interactive phenomena has been at the core of the study of U-I linkages according to both Systems of Innovation (SI) and Triple Helix (TH) approaches, that share strong roots in evolutionary economics. The SI framework has focussed on the interactions and networks among a variety of actors and institutions aimed at the generation, adaptation and diffusion of knowledge, privileging the firm as the core agent within such systems (e.g. Freeman, 1987, 1995; Lundvall, 1992; Nelson, 1993; Nelson and Rosenberg, 1993; Breschi and Malerba 1997; Edquist, 1997). The TH approach has instead placed University at the centre of a triadic relationship together with Industry and Government, to create knowledge, innovation and economic development (e.g. Etzkowitz and Leydesdorff, 1997, 2000; Leydesdorff and Etzkowitz, 1996, 1998).

In their original formulation both these approaches paid little attention to spatial aspects, other than the broad national one. Subsequently, however, the critical importance of sub-national levels of analysis has allowed overcoming the 'national bias', introducing more fine-grained geography into these analytical frameworks. University-industry linkages have been put at the centre of the debate on competitiveness and growth of regional and local economic and innovation systems and industrial clusters (e.g. Morgan, 1997; Braczyk et al. 1998; Fritsch and Schwirten, 1999; Howells, 1999; Keane and Allison, 1999; Cooke, 2001, 2002, 2004; Charles, 2003, 2006; Gunasekara, 2006; Lawton Smith, 2007; Laranja et al., 2008; Tödtling et a., 2006, 2009; Huggins et al., 2008a,b).

While the LKS approach places more weight on externalities from academic research, and the systems of innovation/industrial clustering literatures emphasise U-I interactions and networks among heterogeneous categories of actors, for the most part they share a similar underlying assumption about knowledge and geography: firms located nearby universities are more likely to benefit from knowledge spillovers from academia, as spatial proximity facilitates the interactions and face-to-face contacts necessary for the transmission of the tacit component of knowledge. In other words, the main tenet is that knowledge that spills over "is a public good, but a local one" (Breschi and Lissoni, 2001b, 980).

The contention that spatial proximity favours linkages between academia and business as a consequence of the *tacit* and *sticky* nature of knowledge is particularly applicable in the context of interactions involving highly advanced technical and scientific knowledge. Indeed, while technological and academic knowledge tends to circulate in global networks, traditional face-to-face contacts remains an important condition for the generation and exchange of non-standardised and complex knowledge (van Oort et al., 2008).

Research collaborations between universities and businesses constitute a prototypical example of interaction susceptible to benefit from spatial proximity, since research collaborations entail bi-directional (reciprocal) knowledge transfer, involve upstream, basic research, and require learning processes and the establishment of enduring social relationships between the partners involved (Katz and Martin, 1997; Ponds et al., 2007; D'Este and Iammarino, 2010).

Following the above discussion, we put forward the following hypothesis:

Hypothesis 1: The probability of a new research partnership between a university and a firm increases with the level of geographical proximity between those organisations.

2.2 Factors moderating the role of geographical proximity

The importance of agglomeration economies and the advantages of clustering have been addressed in a long standing and prolific literature that spans across discipline boundaries. Untraded interdependencies, informal flows of knowledge, interactive learning, face-to face contacts, network intensity, generate the bulk of territorial externalities (e.g. Saxenian, 1990, 1994; Storper, 1995; Storper and Venables, 2004; Rodriguez-Pose and

Crescenzi, 2008). Thus, knowledge linkages between universities and firms co-located in a cluster are to be seen as one component of a much larger set of inter-organisational knowledge exchanges, of which the bulk is represented by inter-firm linkages. University-firm knowledge relationships may be associated with specialized spatial concentrations of firms, either because the university-firm links stimulate the growth of such industrial clusters, or because the same capacity to benefit from localised knowledge collaborations leads firms to establish partnerships with local universities and research institutions.

Yet while geographical proximity can facilitate knowledge interaction, collaboration and, indeed, spillovers, it is neither a necessary nor a sufficient condition for the actual occurrence of knowledge flows, whether intentional or unintentional (Fischer, 2001; Malmberg and Maskell, 2002; Howells, 2002; Gertler, 2003; Boschma, 2005; Torre and Rallet, 2005). Sometimes it is assumed that co-location is necessary for the transmission of tacit knowledge, while explicit or codified knowledge can be transmitted over longer distances – yet the explicit/tacit distinction turns out to vary greatly depending on the shared codification capabilities of the actors involved (see, among others, Steinmueller, 2000; Cowan et al., 2000; Foray, 1998, 2004). Shared codification capabilities can be seen as a facet of some kind of non-spatial proximity – cognitive or organizational. These may facilitate knowledge sharing and other forms of cooperation; studies of such forms of proximity find a largely indirect role for the spatial dimension in fostering knowledge creation, interactive learning and innovative networks by bridging and reinforcing other forms of propinquity (e.g. Kirat and Lung, 1999; Nooteboom, 1999; Torre and Gilly, 2000; Boschma, 2005; Torre and Rallet, 2005; Moodysson and Jonsson, 2007; Ponds et al., 2007; Vicente et al., 2007).

It is not clear whether these various kinds of proximity[2] should be seen more as complements or as substitutes. For instance, consider experience with collaborative U-I research, which we will assume leads to improvement in the capacity to coordinate and integrate new and old complementary knowledge between different organisations capabilities: we can call the joint stock of such experience, between any pair of potential U-I partners, a reflection of their organizational proximity. What will be the effect of organizational proximity on geographical proximity in new U-I partnerships? On the one hand, U-I collaborative experience could predict a stronger role for geographical proximity in the formation of further U-I ties, because either (i) geographical proximity simply makes for better ties, and thus ties that are more durable or more likely to emerge from a prolonged search, or (ii) the enhanced organizational proximity of partners complements benefits of geographical proximity, making nearby connections more likely as the capacity for organizational proximity grows. On the other, it may be the case that the disadvantages associated with initiating or operating partnerships over a geographical distance is mitigated by organisational proximity between partners (Ponds et al., 2007). For instance, collaborative experience gained through participation in different projects, and/or in projects with different partners, and repeated interaction with the same partner could produce management skills and organisational capabilities – at both intra- and inter-organizational level – that mitigate the problems associated to geographical distance, e.g. uncertainty, information asymmetry, lack of coordination, opportunism (e.g. Mora-Valentin et al., 2004; Veugelers and Cassiman, 2005). We can formulate these views as two competing hypotheses:

[2] It is far beyond the scope of this study to go through the definition of all forms of proximity identified in the literature (for a thorough review see Boschma, 2005). As intrinsic in the concept itself, moreover, it is somehow difficult to disentangle forms of proximity and their effects in strictly separate categories.

Hypothesis 2a: Organizational and geographical proximity are complements: the positive impact of geographical proximity on the formation of a new research partnership between a university and a firm is strengthened by the experience of partners in prior research collaborations.

Hypothesis 2b: Organizational and geographical proximity are substitutes: the experience of partnership relaxes the geographical constraint, and so the positive impact of geographical proximity on the formation of a new research partnership between a university and a firm is weakened by the experience of partners in prior research collaborations.

Is location of a firm in a cluster associated with greater, or reduced, importance for proximity in U-I collaborations? By 'cluster' we mean a spatial agglomeration of firms which are somehow interdependent. We need to approach this point with caution, because there is a huge case-based literature on technology-intensive clusters, from the Silicon Valley onwards, which makes much of relations between firms and local universities, to the extent that universities can easily be seen as the fonts from which clusters flow, as the prime sources of locally sticky knowledge, and as the hubs of local social networks. There are valuable insights to be gained from this literature, but cumulatively it necessarily produces a confirmation bias: studies of cluster cases do not (and cannot) compare the importance of university proximity for firms located within such a cluster, with the importance of university proximity to firms which are *not* so located.

The role of universities in generating and sustaining clusters *could* amplify the proximity bias in U-I collaborations, but whether or not it does is an empirical question. Moreover, if firms within clusters are interacting with each other as well as with the university, we need to consider what capabilities such interaction may produce in the areas of knowledge sharing and collaboration. As suggested above, such processes, particularly when they entail upstream or basic research, are likely to rely on complex and formalised codification systems, and are subject to rapid dynamic change: the organizational capabilities in question are not trivial. In addition, interactions of this kind imply *willingness* to share, and *mutual* knowledge flows (both intended and unintended). The capacity of the partners to absorb new knowledge thus requires cognitive proximity, that is shared knowledge bases, similar and complementary bodies of knowledge that allow to understand, process and exchange new knowledge (Nooteboom, 2000).

As emphasised also in recent research on related variety (Frenken et al., 2007; Boschma and Iammarino, 2009; Boschma et al., 2009), complementarity is critical: the effective creation of new knowledge often requires related and complementary capabilities. Best (2001) argues that the resurgence of Boston's Route 128 in the 1990s was due to its firms' capabilities in the area of technology integration, as distinct from a narrower Silicon Valley-type specialization. Empirically, this poses a problem in the identification of clusters – which knowledge bases are complementary, which technologies are ripe for integration? We return to that problem when discussing the variables used in this study, below. The question now is how the spatial clustering of firms in industries with similar or complementary knowledge bases affects the role of geographical proximity in the establishment of linkages between industry and university at the local level: it may reinforce the importance of U-I proximity; it is also possible, however, that the diversity of knowledge conditions across industries and clusters influences the frequency and density of inter-firm exchanges and networks and may determine knowledge links not constrained by any spatial boundary (Iammarino and McCann, 2006; Giuliani, 2007). Therefore the moderating effect of clustering and technological complementarity on geographical proximity could act in both directions

As before, then, there are two hypotheses to consider:

Hypothesis 3a: The positive impact of geographical proximity on the formation of a new research partnership between a university and a firm is strengthened if the firm is part of an industrial cluster.

Hypothesis 3b: The positive impact of geographical proximity on the formation of a new research partnership between a university and a firm is weakened if the firm is part of an industrial cluster.

3. Data and method

3.1. Research partnerships: a transport vehicle of intended and unintended knowledge flows

Measuring the actual channels through which knowledge is transmitted or spills over is far from straightforward. The bulk of the empirical research on localised knowledge spillovers has assumed co-location in geographically pre-defined spaces as a proxy for knowledge exchange. While co-location of university and business units is helpful to assess the extent to which *potential* knowledge relationships (and spillovers) are likely to be present, it is subject to concerns whether and to what extent co-location of different actors necessarily implies a dense network of social ties through which knowledge flows effortlessly. As Breschi and Lissoni put it: "[...] more research efforts should be placed on finding out how knowledge is transmitted, among whom, at what distance, and on the basis of which codebooks" (2001a, 270).

Accordingly, another stream of empirical research has captured knowledge flows by examining patents, patent citations, or publication data to identify instances of co-invention, paths of influence between inventors, or co-authorship (e.g. Jaffe et al., 1993; Anselin et al., 2000; Ponds et al., 2007; Belenzon and Schankerman, 2010). These studies attempting to capture the mechanisms of local knowledge transmission have also shown some limitations, such as the extent to which patent citations effectively reflect inter-personal or inter-organisational linkages (see, for a review, Breschi et al., 2005). In addition, a large proportion of such studies, including those on co-inventorship or co-authorship, is often biased towards the behaviour of particular fields of science and/or industrial activities (i.e. scientific fields susceptible to patent generation or high-tech manufacturing industries) – as for example biotechnology (e.g. Bania et al., 1993; Zucker et al., 1998; Fabrizio, 2006).

Here we focus on research collaborations between universities and businesses, which are one specific channel of inter-organisational knowledge flows (and potential spillovers) from and to academic research. Such partnerships are aimed to contributing to joint upstream research for the creation of new knowledge: they are therefore far from industrial applications, and exclude contract research paid by the company to have a specific, well-defined outcome. The raw data source for our empirical analysis is described in the sub-section below.

3.2. Dataset

Our analysis focuses on publicly funded university-industry research partnerships. This data allows us to go beyond some of the limitations encountered by previous empirical studies on three fronts. First, we focus on a specific type of linkage between universities and businesses, explicitly capturing a particular channel of knowledge flow. Second, we employ an accurate measure of spatial proximity, expressed in kilometres, between the interacting partners. And third, we cover a wide range of industrial sectors, encompassing firms in manufacturing and service sectors.

Our dataset comprises collaborative research grants awarded by the UK Engineering and Physical Sciences Research Council (EPSRC) over the period 1999–2003.[3] The dataset covers 2,210 research projects involving 4,525 distinct partnerships. These partnerships represent our main unit of analysis. The reason why the number of partnerships is higher than the number of projects is because more than one business might take part in a particular research project. 2,031 different business units are involved in these partnerships,[4] together with 1,566 principal investigators affiliated to 318 departments in 87 UK universities. The data identify both the scientific field of the academic partner (i.e. engineering and physical sciences, including chemistry, mathematics, computer science and all the engineering fields, which represent the bulk of the EPSRC funding) and the industry of the business units (both manufacturing and services, up to 5-digit of the ISIC) involved in the partnerships.

We have the full postcodes of each business unit[5] and university; after geocoding these, we compute ‘as crow-flies’, or great circle, distances between firm and university, or firm and firm. Distances (in kms) can be calculated for any possible university-business unit, or business unit-business unit pair. We use this in the construction of both geographical proximity and clustering variables, as detailed below.

3.3. The model

One of the main attributes of this study is that the data provides information on any potential partnership-pair. That is, it contains information for instances of actual research collaborations between universities and businesses and between business units (i.e. firms involved in the same partnerships), as well as information on university-business and business-business pairs for which collaborative partnerships could have potentially

[3] The EPSRC is one of the UK research councils responsible for administering public funding for research in the UK. It distributes more than 20% of the total UK science budget, being the largest council in terms of the volume of research funded.

[4] Business units refer to a pair {‘company name’, ‘specific location’}: this means that multiple locations of a single corporation are treated here as different business units, on the basis of the actual postcode recorded in the grant agreement.

[5] It is worth noticing that some partnerships– 5.4% of the total – are with companies located outside the UK, while all universities are located within the UK. We discard observations for partnerships with out-of-UK business units because they would make nonsense of our measures of clustering: single observations from Boston or Palo Alto would appear, in the measures we develop below, *not* to be located in dense clusters of research-intensive firms simply because relatively few business units in those areas engage in partnerships with UK universities.

happened but never occurred. This gives us a unique setting in which to explore the conditions that favour the formation of U-I research partnerships.

We follow Sorenson and Stuart (2001) and Sorenson et al. (2006) in examining the likelihood of research partnership formation by adopting a case-control approach. We pair each focal relationship (i.e. each instance of actual research collaboration that started in the year 2003) with a critical number (in this case 83 cases) of university-business pairs that could have happened but did not. We obtain logit estimates of the likelihood of tie formation.[6]

We exploit the longitudinal dimension of the data by using the first four years (i.e. 1999-2002) of our university-industry research partnership data to identify the co-occurrence matrix that allows us to build the proximity measures and other explanatory variables. We test our hypotheses on the information about instances of occurring and non-occurring partnerships in the year 2003.

4. Main constructs: dependent variable and proximity measures

In this section we describe the main variables that we use in the analysis, paying particular attention to the construction of the proximity measures on the basis of the theoretical framework discussed in Section 2.

Dependent variable

As discussed above, we are interested in explaining the probability of university-industry research partnership formation. Our dependent variable takes the value 1 for actual occurrences of university-business unit partnerships which start in the final year of our 5-year period (2003), and takes the value zero for the 83 randomly drawn non-occurrences. Our total number of observations amounts to 52,920, of which 630 are actual collaborations.

Independent variables

Our independent variables are measures oriented to capture the different dimensions of proximity.

Geographical proximity

We measure geographical proximity (Geoprox) as the inverse of the square root of distance ($1/d_{ij}$), where i refers to firm and j refers to university, and d_{ij} is the square root of the distance between them in kilometers, to a minimum of 200 meters (e.g., if both are in the same postcode and the measured distance is 0).

Organisational proximity

The engagement of organisations in research collaborations may depend on unobserved characteristics that lay behind differences in the propensity to enter such interactions in

[6] We also estimated these models using the Rare Events Logit of King and Zeng (1999a,b), and the coefficients are similar. The principal difference with the rare events correction is in the predicted probability of the event, while under rare events assumptions the coefficients of an ordinary logit are consistent, though biased.

the first place. Here, we account for such organisational capabilities that may mitigate the effects of spatial proximity by considering the collaborative experience gained by firms and universities through previous participation in research partnerships. Organisational proximity is measured by the extent of the two partners' prior engagement in research collaborations, between 1999 and 2002. For each firm and each university, we take the number of partnerships in the earlier period. For each partnership, the variable PriorPartnership is the square root of the product of the firm's and the university's prior experience.

Indices of the clustering of business units

We use two approaches to get measures of clustering from the 2,031 business units in our dataset. The first is, for each business unit *i*, to sum the inverse distances (with an arbitrary minimum distance of 200 meters) from that firm to all other business units:

$$\mathbf{CI_i} = \sum_{j=1}^{N} \frac{1}{d_{i,j}} \qquad (1)$$

where *i* and *j* refer to business units; d_{ij} is the square root of the distance between business units *i* and *j* in kilometers; N is the total number of firms in the dataset in all years, 1999-2003. This measure treats all business units in the dataset as equally relevant to each other, with clustering a function of distance alone: the inclusion of, say, financial services and cement manufacture in the same measure might seem to do violence to the notion of a cluster, which requires some form of relatedness or interdependence. We think that this measure is worth testing, however, because all of the business units in question are units of technologically sophisticated firms which have undertaken at least one collaborative upstream research project with a UK university, in the fields of physical sciences or engineering, in the four years in question: it is not entirely far-fetched to regard all the firms in this study as being of a type.

Our second measure, however, does deal with the foregoing objection to CI: it starts with the individual inverse distance observations which make up CI, and weights each by an index of the technological complementarity of the two industries, *k* and *l*, represented by firms *i* and *j*. We obtain this index by taking the frequency with which firms in industries *k* and *l* participate in the same research projects, relative to what we would expect if each firm joined projects randomly. To avoid endogeneity of the complementarity measure, the index is calculated only on the first four years of our overall sample, i.e. for projects beginning in the years 1999-2002. We use forty industry categories, with a range of 6 to 281 observations per industry (Table A.1 in Appendix). Construction of our complementarity index follows the approach of Nesta and DiBiaggio (2003) and Nesta and Saviotti (2005), who measure the relatedness of technological categories in patent applications.[7] For two industries, *k* and *l*, the number of times firms from both industries

[7] Nesta and Saviotti (2005), refining the model of Teece et al. (1994), treated the degree of relatedness of two *technological categories* as a function of the frequency with which patents included both categories, compared to an expected value of joint appearance under the assumption of random assignment. Since a particular category could not be assigned to a particular patent more than once, the expected value Nesta and Saviotti's model has a hypergeometric distribution. In our case, technological complementarity of two *industries* is treated as a function of the frequency with which firms from those industries participate in the same research projects. In this case, two or more firms from the same industry may participate in a project; our expected value therefore follows a Poisson distribution.

are involved in the same collaborative research project is $J_{k,l}$. We take into account multiple participants from the same industry in a single project: if two business units from industry k and one from l participate in the same project, this produces two k,l interactions and one k,k interaction.

Let $\mu_{k,l}$ be the expected number of interactions under random matching, taking the number of partnerships entered into by firms from each industry as given, and let $\sigma_{k,l}$ be the standard deviation of $\mu_{k,l}$. Then our *index of technological complementarity* (R) for the two industries is:

$$R_{k,l} = \frac{J_{k,l} - \mu_{k,l}}{\sigma_{k,l}} \qquad (2)$$

Table 1 displays examples of the most and least technologically related industries in our database.

[Table 1 about here]

We use the technological complementarity index to weight the proximity of pairs of firms in the clustering index: the proximity (inverse root distance) for each pair of firms is multiplied by the value of $R_{k,l}$ for the industries, k and l, represented by that pair of firms. This gives us the *technological complementarity clustering index* (TCCI):

$$\mathbf{TCCI_i} = \sum_{j=1}^{N} \left(\frac{\mathbf{1}}{d_{i,j}} * R_{k,l} \right) \qquad (3)$$

Control variables
Our first control is a service industry dummy; we group construction and utilities with manufacturing.

We also control for the spatial concentration of universities from the standpoint of each business unit. We do this because we expect that the proximity of actual U-I partners will be affected by the proximity of the business unit to universities which do funded collaborative research in the relevant discipline. For each partnership observation, we create an index of university clustering around the business unit in the partnership, in a manner analogous to the clustering of business units (notice, then, that this index will take different values for the same business unit if that business unit engages in two or more partnerships involving different academic disciplines). We weight each observation in the construction of this index by the university's share of grants in the relevant academic discipline (ten disciplines) during the years 1999-2002. The index of the clustering of each firm relative to universities is indicated in expression (4) below, where there are M universities, and $d_{i,m}$ is the square root of the distance from firm i to university m. The *university clustering index* (UCI) is given by:

$$\mathrm{UCI_i} = \sum_{m=1}^{M} \left[\frac{\mathbf{1}}{d_{i,m}} * \textbf{university's share of grants in discipline} \right] \qquad (4)$$

5. Results

Descriptive statistics for the variables included in the model are presented in Table 2, which displays the figures for the variables used in the analysis, taking into account the 630 observations that correspond to the actual occurrence of partnerships in year 2003.

[Table 2 about here]

Table 3 reports logit estimates. Model 1 includes only GeoProx as a regressor; as expected, the coefficient is positive, and statistically significant at the 0.001 level. This holds through all specifications, confirming Hypothesis 1.

In the remaining models, GeoProx is also entered by interaction with other variables. The variables with which GeoProx has been interacted have been standardized (mean zero, unit s.d.) for estimation purposes: when these variables are at their means, GeoProx coefficient and the main effects for the variables with which GeoProx is interacted are valid. However, since the distribution of properties of business units in the sample does not vary between the occurrences and non-occurences of partnerships, we do not expect to learn anything from the main effects of CI or TCCI: what interests there is the interaction with GeoProx.

Model 2 adds PriorPartnership, the interaction of PriorPartnership and GeoProx, and the controls for university clustering (UCI), industry (the Services dummy), and interactions of these with GeoProx. The coefficient for PriorPartnership, our proxy for organizational proximity, is positive as we would expect, and statistically significant at the 0.001 level. The coefficient for the interaction of PriorPartnership and GeoProx is negative, but nowhere close to statistically significant, leaving us with support for neither complementarity (Hypothesis 2a) nor substitutability (Hypothesis 2b) of organizational and geographical proximity.

Model 3 adds CI, and the interaction of CI and GeoProx. The coefficient on the interaction is negative and statistically significant at the 0.01 level, which we interpret as evidence for substitution between U-I geographical proximity and business firms' clustering (Hypothesis 3b). In Model 4, we replace CI with the Technological Complementarity-weighted Cluster Index (TCCI), and here the evidence for substitution is stronger, with a larger coefficient and statistical significance at the 0.001.

[Table 3 about here]

It is difficult to make a substantive interpretation of interaction effects such as these from simply reading the coefficients. With minor modifications to the Stata code provided by Brambor et al. (2006), we simulate changes in the effect of GeoProx over the range of values of each of the two clustering indices. The results of these simulations are shown in Figures 1a and 1b. With the un-weighted index, CI (Figure 1a), the effect of geographical proximity on partnership formation loses statistical significance at the 0.05 level as CI approaches its maximum. When the index is weighted for technological complementarity (TCCI, shown in Figure 1b), the point estimate reaches zero and becomes slightly negative at the maximum of the index.

6. Conclusion

Collaboration requires proximity, but what kind of proximity, and how do different proximities interact? We find, not surprisingly, that geographical proximity makes university-industry research partnerships more likely. We also find that prior experience in such partnerships – which we take as a measure of organizational proximity – makes partnerships more likely, but has no statistically significant effect on the importance of geographical proximity. Our most surprising and, we think, important, finding, is that the geographical clustering of technologically complementary firms makes the proximity of industry and university partners far less important – in the case of the most densely clustered firms, entirely unimportant.

Technology-intensive agglomerations typically include both firms and universities. The role of universities in the origins and ongoing life of such agglomerations is well known; previous research on patent citations has suggested that knowledge spillovers from university research tend to be local. Firms within a technologically dynamic cluster are understood to benefit from increasing returns generated by the clustering of firms, as well. If technologically dynamic clusters have social value, exhibit increasing returns, and depend on *nearby* universities, an implication is that scarce public research resources should be concentrated in universities proximate to existing clusters, and/or in a very small number of places where the prospect for cluster development appears especially good. Such is, indeed, the *de facto* policy in the UK, where both the densest clusters of technologically sophisticated firms, and a disproportionate share of public research funding, are found the ‘golden triangle’ of the Southeast: greater London, Cambridge, Oxford.

Our results, however, support an entirely different policy direction. We find that when firms located in dense clusters of technologically related firms engage in collaborative research with universities, they do so essentially independently of the university’s location: firms in dense clusters of technology-intensive businesses appear to have capabilities in the area of collaboration which enable them to ignore distances, at least on the scale of a country the size of the UK. We should note that between any two cities in the UK, it is possible with air travel to make a round trip in a day, with time for a meeting, a limit which Arita and McCann (2000) find to be important in the formation of inter-firm R&D collaborations: for this reason we would hesitate to generalize our results to a geographical unit substantially larger than the UK, such as the USA, European Union, or China.

With this caveat in mind, our results indicate that firms which are not located in dense clusters, place a significant weight on geographical proximity to their university research partners. This suggests that greater geographical dispersion of university research capabilities would *not* harm firms located in the densest clusters, and *would* help firms located further from these clusters in terms of the formation of research partnerships with universities.

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Table 1 - Technological Complementarity Index (R_{kl}): selected industry pairs

Rkl	Industry k	Industry l	Jk	Jl	Jkl
Top-10 (Greatest Complementarity)					
14.8714	Mfg basic chemicals	Mfg pesticides, paint & varnishes	42	56	19
11.3152	Casting of metals	Mfg aircraft & spacecraft	20	80	12
11.0210	Electricity, gas & water supply	Electricity, gas & water supply	94	94	31
10.0592	Agriculture & Mining	Mfg pesticides, paint & varnishes	35	56	12
9.6016	Mfg pesticides, paint & varnishes	Mfg pesticides, paint & varnishes	56	56	15
9.5999	Mfg pharmaceuticals	Mfg pharmaceuticals	46	46	12
9.5882	Real estate & Renting of machinery and equip.	Legal , accounting, and other consultancy	22	156	16
9.3886	Casting of metals	Real estate & Renting of machinery and equip.	20	22	5
8.8647	Financial intermediation & insurance	Architectural & engin. technical consultancy	66	195	33
8.8264	Mfg basic precious & non ferrous metals	Mfg fabricated metal prod.	14	35	5
Bottom-10 (Lowest Complementarity)					
Rkl	**Industry k**	**Industry l**	**Jk**	**Jl**	**Jkl**
-1.4090	Mfg office mach. & computers	Electricity, gas & water supply	40	94	0
-1.4126	Mfg motor vehicles, bodies and parts	R&D	63	110	1
-1.4222	Mfg glass, ceramics, bricks, concrete, etc.	Construction	43	89	0
-1.4430	Mfg basic chemicals	Electricity, gas & water supply	42	94	0
-1.4463	Mfg aircraft & spacecraft	Construction	80	89	1
-1.5245	Mfg medical & surgical equip.	Electricity, gas & water supply	47	94	0
-1.5372	Mfg pesticides, paints & varnishes	Mfg aircraft & spacecraft	56	80	0
-1.5711	Mfg transport equip & repair of ships & boats	Electricity, gas & water supply	50	94	0
-1.7576	Mfg motor vehicles, bodies and parts	Electricity, gas & water supply	63	94	0
-2.1243	Mfg aircraft & spacecraft	R&D	80	110	0

Table 2. Descriptive Statistics

Variables	Mean	St. Dev.	Min.	Max.	Obs.
Geographical Proximity (Geoprox)	0.156	0.260	0.039	2.236	630
Clustering Index (CI)	140.932	25.239	73.277	209.795	630
Tech. Complementarity Clustering Index (TCCI)	-18.821	77.696	-244.378	248.818	630
Organisational Proximity (PriorPartnership)	0.118	0.173	0.000	1.000	630
University Clustering Index (UCI)	7.663	2.069	3.856	28.773	630
Services (dummy)	0.476	0.499	0.000	1.000	630

Table 3 Logit estimates for the probability of research partnership occurrence

	(1) occur	(2) occur	(3) occur	(4) occur
Geographical Proximity (GeoProx)	2.471***	2.640***	2.520***	3.117***
	(0.178)	(0.351)	(0.422)	(0.349)
PriorPartnerships		3.134***	3.113***	3.592***
		(0.327)	(0.329)	(0.342)
PriorPartnerships * Geoprox		-1.408	-1.327	-3.362
		(2.157)	(2.160)	(2.157)
Clustering Index (CI)			0.0649	
			(0.0610)	
Tech. Complementarity Clustering Index (TCCI)				0.236***
				(0.0535)
GeoProx * CI			-0.539**	
			(0.179)	
GeoProx * TCCI				-0.960***
				(0.200)
University Cluster Index (UCI)		-0.136*	-0.161*	-0.172**
		(0.0557)	(0.0703)	(0.0584)
UCI * GeoProx		0.0743	0.272	0.151
		(0.0989)	(0.193)	(0.141)
Services		-0.193	-0.241*	-0.301**
		(0.102)	(0.106)	(0.104)
Services * GeoProx		0.0306	0.484	0.512
		(0.445)	(0.518)	(0.447)
Constant	-4.679***	-4.868***	-4.849***	-4.912***
	(0.0463)	(0.0706)	(0.0737)	(0.0713)
Observations	52920	52920	52920	52920
Pseudo R^2	0.021	0.039	0.041	0.044
AIC	6699.0	6583.9	6575.4	6556.3

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Standard errors in parentheses

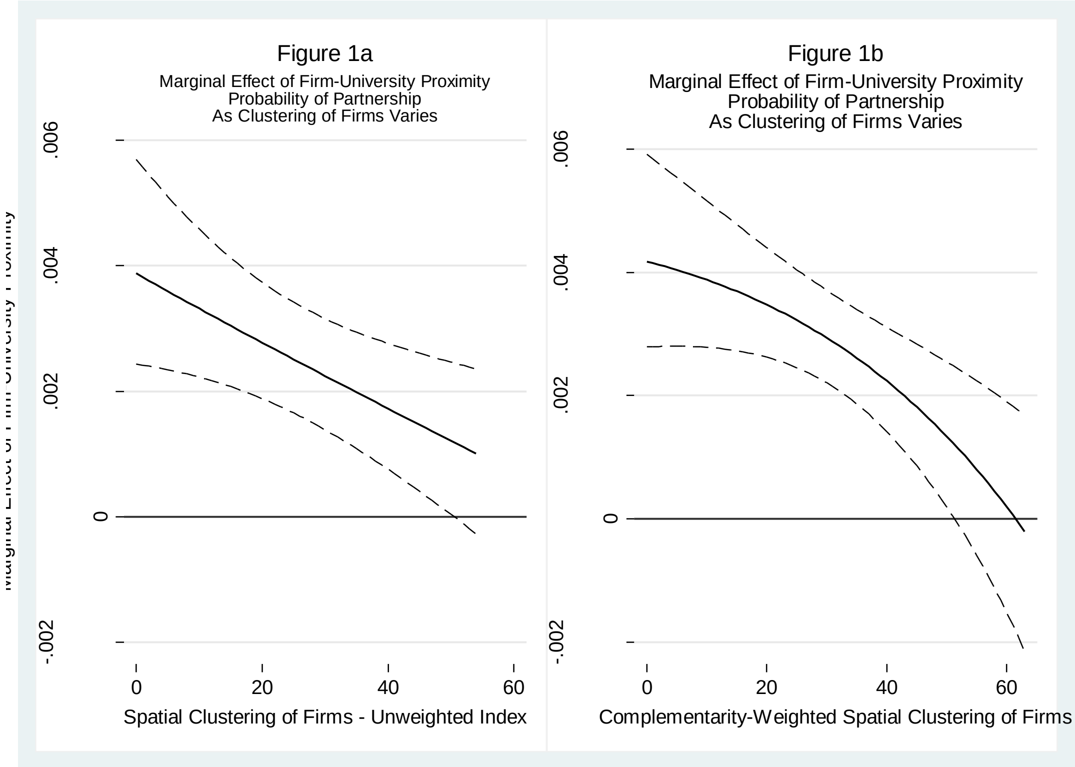
Figure 1a
Marginal Effect of Firm-University Proximity
Probability of Partnership
As Clustering of Firms Varies
.006
.004
.002
0
-.002
0
20
40
60
Spatial Clustering of Firms - Unweighted Index
Figure 1b
Marginal Effect of Firm-University Proximity
Probability of Partnership
As Clustering of Firms Varies
.006
.004
.002
0
-.002
0
20
40
60
Complementarity-Weighted Spatial Clustering of Firms

Appendix A.1 –Industries and observations

	1999-2002		2003	
	Obs	Pct	Obs	Pct
Agriculture & Mining	51	1.54	10	1.58
Mfg food prod. & beverages	20	0.6	2	0.32
Mfg textiles & leather	17	0.51	5	0.79
Mfg pulp & paper & printing	10	0.3	4	0.63
Mfg coke petrol. & nuclear fuel	6	0.18	1	0.16
Mfg basic chemicals	80	2.41	14	2.22
Mfg pesticides, paints & varnishes	80	2.41	5	0.79
Mfg pharmaceuticals	71	2.14	13	2.06
Mfg other chemicals soaps & detergents	51	1.54	7	1.11
Mfg rubber & plastic products	52	1.57	8	1.27
Mfg glass, ceramics, bricks, concrete,	60	1.81	15	2.37
Mfg basic iron & steel, & other iron-steel	59	1.78	9	1.42
Mfg basic precious & non ferrous metals	20	0.6	4	0.63
Casting of metals	23	0.69	3	0.47
Mfg fabricated metal prod.	41	1.23	10	1.58
Mfg cutlery & other fabricated metals	13	0.39	5	0.79
Mfg machinery & equip NEC	192	5.78	31	4.91
Mfg office mach. & computers	74	2.23	16	2.53
Mfg electrical machinery & apparatus	104	3.13	9	1.42
Mfg radio, TV & communication equip.	147	4.43	13	2.06
Mfg medical & surgical equip.	75	2.26	14	2.22
Mfg instruments & meas. appl., optical	120	3.61	24	3.8
Mfg motor vehicles, bodies and parts	76	2.29	7	1.11
Mfg aircraft & spacecraft	119	3.58	16	2.53
Mfg transport equip & repair of ships &	71	2.14	10	1.58
Manuf. NEC	21	0.63	8	1.27
Electricity, gas & water supply	147	4.43	45	7.12
Construction	106	3.19	23	3.64
Wholesale & retail trade	225	6.78	52	8.23
Hotels, restaurants, transport services & travel	44	1.33	13	2.06
Telecommunications	60	1.81	9	1.42
Financial intermediation & insurance	85	2.56	14	2.22
Real estate & Renting of machinery and	31	0.93	15	2.37
Software consultancy & supply	137	4.13	16	2.53
Other computer & related activities	40	1.2	1	0.16
R&D	159	4.79	41	6.49
Legal , accounting, and other consultancy	202	6.08	48	7.59
Architectural & engin. technical consultancy	281	8.46	59	9.34
Other business activities	90	2.71	19	3.01
Misc public, defence & personal service	60	1.81	14	2.22
Total	3,320	100	632	100