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Shaping the formation of university–industry research collaborations: what type of proximity does really matter?

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Abstract

Research collaborations between universities and industry (U-I) are considered to be one important channel of potential localized knowledge spillovers (LKS). These collaborations favour both intended and unintended flows of knowledge and facilitate learning processes between partners from different organizations. Despite the copious literature on LKS, 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 article 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 clustering and technological complementarity among the firms participating in such partnerships.

Keywords: University–industry research collaborations, proximity, geography, industrial clustering, technological complementarity

JEL classifications: O31, O32, O33, R10

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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). Localised 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 (localized and non-localized)

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, on the role played by geographical proximity in driving the formation of university–industry (U-I) research linkages and, from an empirical viewpoint, on the operationalization 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—as for instance cognitive and organizational 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 characteristics 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 exchanges and unintended flows, regardless of the actual transmission mechanisms of knowledge (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 article, 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 some of the factors moderating the impact of spatial proximity in shaping the formation of U-I 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 different forms of proximity may play in such interactions.

The article is organized 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 localized, 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., 2011). 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: (i) studies of localized knowledge spillovers (LKS); (ii) studies of the systemic nature of knowledge and innovation, i.e. from ‘Systems of Innovation’ to ‘Triple Helix’; and (iii) 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 localized 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 LKS has turned the attention away from a wider and more 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) organizations: 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, which 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 the SI and TH 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. U-I 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; Tödtling et al., 2006, 2009; Lawton Smith, 2007; Laranja et al., 2008; Huggins et al., 2008).

While the LKS approach places more weight on spillovers from academic research, and the SI/industrial clustering literatures emphasize 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 externalities 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 remain an important condition for the generation and exchange of non-standardized 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 they 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). Therefore, in this work we rest on the assumption that geographical proximity between universities and business firms encourages the formation of such kind of partnerships.

2.2. Factors moderating the role of geographical proximity

The importance of agglomeration economies and the advantages of clustering have been addressed in a longstanding and prolific literature that spans across discipline boundaries. Untraded interdependencies, informal flows of knowledge, interactive learning, face-to-face contacts and 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-organizational knowledge exchanges, of which the bulk are represented by inter-firm linkages. U-I knowledge relationships are often associated with specialised 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 localized knowledge collaborations leads firms to establish partnerships with local universities and research institutions (e.g. Cooke, 2001; Charles, 2003; Kitigawa, 2004; Giuliani, 2005; Tödtling et al., 2006; Hershberg et al., 2007).

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 tend to point to 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](#); [Balconi et al., 2011](#)).

The extent to which either proximity among the knowledge bases of actors (cognitive proximity) or proximity due to accumulation of interactive experience between actors (organisational proximity) are conditions for effective partnerships, in particular how these relate to geographic proximity, has not yet been studied in depth ([Balconi et al., 2011](#)). It is not yet clear whether these various kinds of proximity¹ should be seen more as complements or as substitutes. For instance, is the location of a firm in a cluster associated with greater, or reduced, importance for geographical 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 located there.

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 formalized 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](#); [Nooteboom et al., 2007](#)).

As emphasized also in recent research on related variety (e.g. [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

1 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](#)).

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.

Our notion of cluster, as detailed in Section 4 below, cannot by definition rely on simple co-location: the latter may spur greater possibilities of face-to-face contacts which support the establishment of trust, while undertaking related industrial activities and complementary technologies leads to the creation of a collective knowledge base, which enhances learning processes by the members—that is firms—located in the cluster (Balconi et al., 2011).

Following the above discussion, we put forward two competing hypotheses:

Hypothesis 1a—Clustering 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 if the firm is part of an industrial cluster.

Hypothesis 1b—Clustering and geographical proximity are substitutes: 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.

Likewise, the empirical literature has not yet achieved definite conclusion on the extent of substitutability between geographical and organizational proximity, with reference to actual research linkages among different institutional partners. 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 organizations' 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 the benefits of geographical proximity, making nearby connections more likely as the capacity for organizational proximity grows. On the other hand, it may be the case that the disadvantages associated with initiating or operating partnerships over a geographical distance is mitigated by organizational 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 organizational capabilities—at both intra- and inter-organizational level—that mitigate the problems associated with geographical distance, e.g. uncertainty, information asymmetry, lack of coordination and opportunism (e.g. Mora-Valentin et al., 2004; Veugelers and Cassiman, 2005).

As before, then, we can formulate these views as two competing hypotheses:

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 joint research collaborations.

Hypothesis 2b—Organizational and geographical proximity are substitutes: 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 joint research collaborations.

2.3. 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 LKS 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 as to whether and to what extent co-location of different actors necessarily implies a dense network of social ties through which knowledge flows effortlessly.

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-organizational linkages (see, for a review, Breschi et al., 2005). In addition, a large proportion of such studies, including those on co-invention or co-authorship, are 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-organizational knowledge flows (and potential spillovers) from and to academic research. Such partnerships are aimed at 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 section below.

3. Data and method

3.1. Data set

Our analysis focuses on publicly funded U-I research partnerships. These data allow 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 both manufacturing and service sectors.

Our data set comprises collaborative research grants awarded by the UK Engineering and Physical Sciences Research Council (EPSRC) over the period 1999–2003.² The data set covers 2210 research projects involving 4525 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. Two thousand and thirty-one different business units are involved in these partnerships,³ together with 1566 principal investigators affiliated to 318 departments in 84 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 five digits of the ISIC) involved in the partnerships.

We have the full postcodes of each business unit⁴ and university; after geocoding these, we compute ‘as crow-flies’, or great circle, distances between firm and university, or firm and firm. Distances (in kilometres) 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.

3.2. The model

One of the main attributes of this study is that the data set 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

2 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.

3 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.

4 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.

potentially 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 number of university–business pairs that could have happened but did not. Since each project involves exactly one university, we construct the non-occurrences by matching every observation on a firm in 2003 with each of the universities not in the observed project. We have 84 universities in total, so this procedure gives us 83 non-occurrences for each occurrence. We then obtain logit estimates of the likelihood of tie formation.⁵

We exploit the longitudinal dimension of the data by using the first four years (i.e. 1999–2002) of our U-I research partnership data to build explanatory variables, as detailed below. We test our hypotheses on the information about instances of occurring and non-occurring partnerships in the year 2003.⁶

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.

4.1. Dependent variable

As discussed above, we are interested in explaining the probability of U-I 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 five-year period (2003), and takes the value zero for the non-occurrences. Our total number of observations amounts to 52,920 (630×84), of which 630 are actual collaborations.

4.2. Independent variables

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

4.2.1. 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

5 We also estimated these models using the Rare Events Logit of [King and Zeng \(2001, 2002\)](#), 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.

6 For this purpose, we checked that 2003 was not anomalous with respect to the previous years covered in our database (1999–2002): university–industry research partnerships follow a similar composition across time in terms of industry category of the firms, and both scientific discipline and regional location (NUTS1 level) of universities.

of the distance between them in kilometers, to a minimum of 200 m (e.g. if both are in the same postcode and the measured distance is 0).

4.2.2. Organizational proximity

The engagement of organizations in research collaborations may depend on unobserved characteristics that lay behind differences in the propensity to enter such interactions in the first place. Here, we account for such organizational capabilities that may mitigate the effects of spatial proximity by considering the collaborative experience gained by firms and universities through previous participation in joint research partnerships. The variable *PriorPartnership* takes a value of 1 when a firm–university pair from the 2003 estimation sample is observed in the 1999–2002 sample, reflecting shared experience in participating in joint research projects between the two organizations.

4.2.3. Indices of the clustering of business units

We use two approaches to get measures of clustering from the 2031 business units in our data set. The first is, for each business unit i , to sum the inverse of the square root of distance (with an arbitrary minimum distance of 200 m) from that firm to all other business units:

$$CI = \sum_{j=1}^N d_{ij}^{-1/2} \quad (1)$$

where i and j refer to business units; d_{ij} is the distance between business units i and j in kilometres; N is the total number of firms in the data set in all years, 1999–2003. This measure treats all business units in the data set 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. On the basis of the discussion carried out in Section 2, we think that this measure is worth testing, 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 five 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 does deal with the foregoing objection to CI: it starts with the individual inverse root 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 technological 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 6–281 observations per industry (Appendix Table A1). Construction of our complementarity index follows the approach by 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 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 k and l is:

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

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

We use the technological complementarity index to weight the spatial 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):

$$TCCI_i = \sum_{j=1}^N (d_{i,j}^{-1/2} \times R_{k,l}) \quad (3)$$

4.2.4. Control variables

We 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 conduct 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. We weight each observation in the construction of this index by the university's share of grants, by count, in the relevant academic discipline (10 disciplines) during the years 1999–2002 (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). There are M universities, and $d_{i,m}$ is the distance from firm i to university m . The university clustering index (UCI) is then given by:

$$UCI_i = \sum_m^M [d_{i,m}^{-1/2} \times \text{university } m\text{'s share of grants in discipline}] \quad (4)$$

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 in 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.

Table 1. Technological complementarity index (R_{kl}): selected industry pairs

R_{kl}	Industry k	Industry l	J_k	J_l	J_{kl}
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)					
-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 for partnerships initiated in 2003, $n = 630$

Variable	Mean	S.D.	Min	Max
Geographical Proximity (Geoprox)	0.1560244	0.2605328	0.0395815	2.236068
University Clustering Index (UCI)	7.663496	2.06983	3.855949	28.77287
Clustering Index (CI)	140.9319	25.23941	73.2767	209.7949
Technological Complementarity Clustering Index (TCCI)	-18.82062	77.75205	-244.3775	248.8183
Prior Partnership	0.0285714	0.166731	0	1

Finally, we have industry controls for all 40 industry categories. Interacting these with GeoProx, less an omitted dummy, gives us 78 additional variables. We run our models both with and without these dummies and interactions.

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 2003.

Table 3 reports logit estimates. Model 1 includes only GeoProx as a regressor; as expected, and in line with most of the empirical literature, the coefficient is positive, and statistically significant at the 0.001 level.

In the remaining models, GeoProx is also entered by interaction with other variables. The continuous variables with which GeoProx has been interacted have been standardised (mean zero, unit S.D.) for estimation purposes: when these variables are at their means, the coefficient on GeoProx, 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-occurrences 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 CI, and the interaction of CI and GeoProx. The coefficient on the interaction is negative and statistically significant at the 0.001 level, which we interpret as evidence for substitution between U-I geographical proximity and business firms' clustering (*Hypothesis 1b*). In Model 3, we replace CI with the TCCI, and here the evidence for substitution is even stronger, with a larger coefficient and statistical significance again at 0.001.

Models 4 and 5 add several variables to Models 2 and 3: PriorPartnership, and the controls for university clustering (UCI), 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 positive, but nowhere close to statistically significant, leaving us with support for neither complementarity (*Hypothesis 2a*) nor substitutability (*Hypothesis 2b*) of organizational and geographical proximity.

Table 3. Logit estimates for the probability of research partnership occurrence

	Model 1	Model 2	Model 3	Model 4	Model 5
Geoprox	2.627*** (0.188)	3.315*** (0.235)	3.283*** (0.227)	3.225*** (0.270)	3.350*** (0.271)
Cluster Index (CI)		0.0159 (0.0457)		0.0708 (0.0580)	
CI * Geoprox		-0.610*** (0.135)		-0.704*** (0.182)	
Tech. Comp. CI (TCCI)			0.0626 (0.0470)		0.0796 (0.0479)
TCCI * Geoprox			-0.761*** (0.173)		-0.777*** (0.179)
University Cluster Index (UCI)				-0.114 (0.0645)	-0.0996 (0.0511)
UCI * Geoprox				0.176 (0.190)	0.00781 (0.110)
PriorPartnership				1.737*** (0.370)	1.716*** (0.368)
Geoprox * Prior Partnership				0.739 (1.790)	1.134 (1.815)
Constant	-4.696*** (0.0469)	-4.754*** (0.0490)	-4.759*** (0.0491)	-4.770*** (0.0510)	-4.789*** (0.0516)
Observations	52,920	52,920	52,920	52,920	52,920
Pseudo R ²	0.022	0.025	0.025	0.031	0.030
AIC	6691.1	6669.4	6672.8	6642.7	6643.1
BIC	6708.9	6704.9	6708.3	6713.7	6714.1

Standard errors in parentheses.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

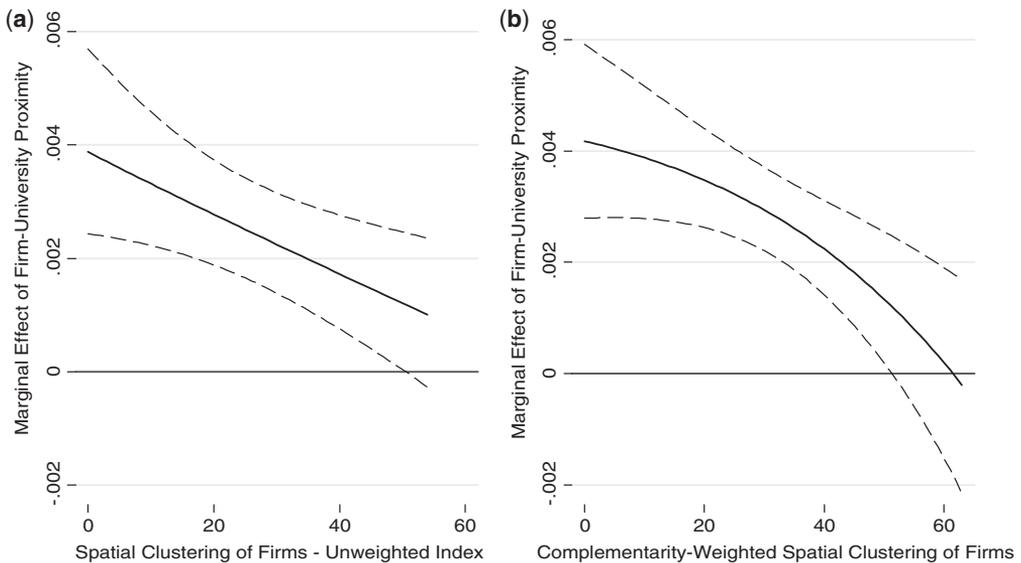


Figure 1. (a) Marginal effect of firm–university proximity probability of partnership as clustering of firms varies. (b) Marginal effect of firm–university proximity probability of partnership as clustering of firms, weighted by technological complementarity, varies.

We also run Models 4 and 5 with 39 industry dummies, and interactions of these with GeoProx. Inclusion of this large number of controls, not surprisingly, increases the standard errors of most coefficients; all signs remain the same; the only interesting change in the size of estimated effects is that the TCCI effect and GeoProx interaction both become larger, reinforcing our conclusion with regard to *Hypothesis 1b*. Full results are in an appendix available from the authors.

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 b. 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.

In conclusion, our findings provide preliminary support to the substitution effect between clustering and geographical proximity: being located in a dense cluster of knowledge-intensive firms carrying out complementary technological activities seems to relax the importance of research linkages with local academic institutions. Inter-firm knowledge linkages (and possible spillovers) may contribute to the firm’s ability to establish, or gain from, partnerships at a greater distance (Gordon and McCann, 2000); on the other hand clustered firms involved in distant interactions with non-local organizations may enjoy lower risks of cognitive and social lock-in (Malmberg and Maskell, 2002).

6. Conclusion

Collaboration requires proximity, but what kind of proximity, and how do different proximities interact? Our results, not surprisingly, show that geographical proximity makes U-I research partnerships more likely. We also find that prior joint 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. In other words, while both geographical and organizational proximity have a very strong positive impact on the likelihood of partnership formation, the impact of spatial proximity is neither attenuated nor enhanced by the level of organizational 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.

Much of the extant literature has supported the role of universities in generating and sustaining clusters. Indeed, 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 especially 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 in the 'golden triangle' of the Southeast: greater London, Cambridge and Oxford.

Our results, however, support an entirely different policy direction. We find that the role of geographical proximity in the formation of new partnerships is weakened when firms are located in dense clusters. This effect is particularly strong in the case of technologically related clusters. In this latter case, when firms located in dense clusters 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 distance, 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 point 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.

Further research is in progress in order both to extend the time period covered by our database and to integrate it with other micro-data to take into account partner-specific characteristics for firms and university departments. The scope for research collaboration between university and industry varies greatly at the territorial level and in some contexts is potentially high, provided that public and private resources are devoted at identifying and supporting the most effective partnership for the observed region. The relevance of the topic for regional development policies thus calls for extension and validation of the results presented here.

References

- Abramovsky, L., Harrison, R., Simpson, H. (2007) University research and the location of business R&D. *Economic Journal*, 117: 114–141.
- Acs, Z., Audretsch, D., Feldman, M. (1994) R&D spillovers and recipient firm size. *The Review of Economics and Statistics*, 76: 336–340.
- Anselin, L., Varga, A., Acs, Z. (1997) Local geographic spillovers between university research and high technology innovations. *Journal of Urban Economics*, 42: 422–448.
- Anselin, L., Varga, A., Acs, Z. (2000) Geographic and sectoral characteristics of academic knowledge externalities. *Papers in Regional Science*, 79: 435–443.
- Arita, T., McCann, P. (2000) Industrial alliances and firm location behaviour: some evidence from the US semiconductor industry. *Applied Economics*, 32: 1391–1403.
- Arundel, A., Geuna, A. (2004) Proximity and the use of public science by innovative European firms. *Economics of Innovation and New Technologies*, 13: 559–580.
- Audretsch, D., Feldman, M. (1996) Spillovers and the geography of innovation and production. *American Economic Review*, 86: 630–640.
- Audretsch, D., Lehmann, E. E., Warning, S. (2005) University spillovers and new firm location. *Research Policy*, 34: 1113–1122.
- Autant-Bernard, C., Billand, P., Frachisse, D., Massard, N. (2009) R&D collaboration networks and spatial diffusion of knowledge. A comparison between Telecommunication and Microelectronics. IAREG Working Paper 4.2b. Available online at: www.iareg.org [Accessed 27 April 2012].
- Balconi, M., Lorenzi, V., Saviotti, P., Zucchella, A. (2011) Cognitive and geographic distance in research collaborations: the case of Italian biotechnology firms. Paper presented at the 9th Triple Helix International Conference, Stanford University, 11–14 July 2011.
- Bania, N., Eberts, R. W., Fogarty, M. S. (1993) Universities and the startup of new companies: can we generalize from Route 128 and Silicon Valley. *The Review of Economics and Statistics*, 75: 761–766.
- Belenzon, S., Schankerman, M. (2010) Spreading the word: geography, policy and university knowledge diffusion. CEPR Discussion paper Series no. 8002.
- Best, M. H. (2001) *The New Competitive Advantage: The Renewal of American Industry*. Oxford: Oxford University Press.
- Boschma, R. A. (2005) Proximity and innovation. A critical assessment. *Regional Studies*, 39: 61–74.
- Boschma, R., Eriksson, R., Lindgren, U. (2009) How does labour mobility affect the performance of plants? The importance of relatedness and geographical proximity. *Journal of Economic Geography*, 9: 169–190.
- Boschma, R. A., Iammarino, S. (2009) Related variety, trade linkages and regional growth in Italy. *Economic Geography*, 85: 289–311.
- Braczyk, H.-J., Cooke, P., Heidenreich, M., Krauss, G. (eds) (1998) *Regional Innovation Systems. The Role of Governance in a Globalized World*. London: UCL Press.
- Brambor, T., Roberts Clark, W., Golder, M. (2006) Understanding interaction models: improving empirical analyses. *Political Analysis*, 14: 63–82.
- Breschi, S., Lissoni, F. (2001a) Localised knowledge spillovers vs. innovative milieux: knowledge ‘tacitness’ reconsidered. *Papers in Regional Science*, 80: 255–273.

- Breschi, S., Lissoni, F. (2001b) Knowledge spillovers and local innovation systems: a critical survey. *Industrial and Corporate Change*, 10: 975–1005.
- Breschi, S., Lissoni, F. (2003) Knowledge spillovers and local innovation systems: a critical survey. *Industrial and Corporate Change*, 10: 975–1005.
- Breschi, S., Lissoni, F. (2004) Knowledge networks from patent data: methodological issues and research targets. In H. Moed, W. Glänzel, U. Schmoch (eds), *Handbook of Quantitative Science & Technology Research*. Dordrecht, Netherlands: Kluwer Academic Publishers.
- Breschi, S., Lissoni, F., Montobbio, F. (2005) The geography of knowledge spillovers: conceptual issues and measurement problems. In S. Breschi, F. Malerba (eds) *Clusters, Networks and Innovation*, pp. 343–378. Oxford: Oxford University Press.
- Breschi, S., Malerba, F. (1997) Sectoral innovation systems. In C. Edquist (ed) *Systems of Innovation*, pp. 130–156. London: Pinter.
- Charles, D. (2003) Universities and territorial development: Reshaping the regional role of UK universities. *Local Economy*, 18: 7–20.
- Charles, D. (2006) Universities as key knowledge infrastructures in regional innovation systems, innovation. *Innovation*, 19: 7–20.
- Cooke, P. (2001) Regional innovation systems, clusters, and the knowledge economy. *Industrial and Corporate Change*, 10: 945–974.
- Cooke, P. (2002) *Knowledge Economies. Clusters, Learning and Cooperative Advantage*. London: Routledge.
- Cooke, P. (2004) Regional innovation systems: an evolutionary approach. In P. Cooke, M. Heidenreich, H. Braczyk (eds) *Regional Innovation Systems: The Role of Governance in a Globalized World*, pp. 1–18. London: Routledge.
- Cowan, R., David, P. A., Foray, D. (2000) The explicit economics of knowledge codification and tacitness. *Industrial and Corporate Change*, 9: 211–254.
- D'Este, P., Iammarino, S. (2010) The spatial profile of university-business research partnerships. *Papers in Regional Science*, 89: 335–350.
- Edquist, C. (1997) *Systems of Innovation. Technologies, Institutions and Organizations*. London: Pinter.
- Etzkowitz, H., Leydesdorff, L. (eds) (1997) *Universities in the Global Economy: A Triple Helix of University–Industry–Government Relations*. London: Cassell Academic.
- Etzkowitz, H., Leydesdorff, L. (2000) The dynamics of innovation: from national systems and ‘Mode 2’ to a triple helix of university–industry–government relations. *Research Policy*, 29: 109–123.
- Fabrizio, K. (2006) The use of university research in firm innovation. In H. Chesbrough, W. Vanhaverbeke, J. West (eds) *Open Innovation; Researching a New Paradigm*, pp. 134–160. Oxford: Oxford University Press.
- Feldman, M. P. (1999) The new economics of innovation, spillovers and agglomeration: a review of empirical studies. *The Economics of Innovation and New Technology*, 8: 5–25.
- Feldman, M. P., Audretsch, D. (1999) Innovation in cities: science-based diversity, specialisation, and localised competition. *European Economic Review*, 43: 409–429.
- Fischer, M. M. (2001) Innovation, knowledge creation and systems of innovation. *The Annals of Regional Science*, 35: 199–216.
- Foray, D. (1998) The economics of knowledge openness: emergence, persistence, and change of conventions in the knowledge systems. In N. Lazareic, E. Lorenz (eds) *Trust and Economic Learning*, pp. 162–189. Northampton, MA: Edward Elgar.
- Foray, D. (2004) *The Economics of Knowledge*. Cambridge: MIT Press.
- Freeman, C. (1987) *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.
- Freeman, C. (1995) The ‘national system of innovation’ in historical perspective. *Cambridge Journal of Economics*, 19: 5–24.
- Frenken, K., van Oort, F. G., Verburg, T. (2007) Related variety, unrelated variety and regional economic growth. *Regional Studies*, 41: 685–697.
- Fritsch, M., Schwirten, C. (1999) Enterprise-university co-operation and the role of public research institutions in regional innovation systems. *Industry and Innovation*, 6: 69–83.
- Fritsch, M., Slavtchev, V. (2007) Universities and innovation in space. *Industry and Innovation*, 14: 201–218.

- Gertler, M. S. (2003) Tacit knowledge and the economic geography of context, or the undefinable tacitness of being (there). *Journal of Economic Geography*, 3: 75–99.
- Giuliani, E. (2005) Cluster absorptive capacity. Why do some clusters forge ahead and others lag behind? *European Urban and Regional Studies*, 12: 269–288.
- Giuliani, E. (2007) The selective nature of knowledge networks in clusters: evidence from the wine industry. *Journal of Economic Geography*, 7: 139–168.
- Gordon, I. R., McCann, P. (2000) Industrial clusters: complexes, agglomeration and/or social networks? *Urban Studies*, 3: 513–532.
- Gulbrandsen, M., Mowery, D., Feldman, M. (2011) Introduction to the special section. Heterogeneity and University-Industry Relations. *Research Policy*, 40: 1–5.
- Gunasekara, C. (2006) Reframing the role of universities in the development of regional innovation systems. *The Journal of Technology Transfer*, 31: 101–113.
- Henderson, R., Jaffe, A., Trajtenberg, M. (1998) Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. *The Review of Economics and Statistics*, LXXX: 119–127.
- Hershberg, E., Nabeshima, K., Yusuf, S. (2007) Opening the ivory tower to business: university–industry linkages and the development of knowledge-intensive clusters in Asian cities. *World Development*, 35: 931–940.
- Howells, J. (1999) Regional systems of innovation? In D. Archibugi, J. Howells, J. Michie (eds) *Innovation Policy in a Global Economy*, pp. 67–93. Cambridge: Cambridge University Press.
- Howells, J. (2002) Tacit knowledge, innovation and economic geography. *Urban Studies*, 39: 871–884.
- Huggins, R., Johnston, A., Steffenson, R. (2008) Universities, knowledge networks and regional policy. *Cambridge Journal of Regions, Economy and Society*, 2: 321–340.
- Iammarino, S., McCann, P. (2006) The structure and evolution of industrial clusters: transactions, technology and knowledge spillovers. *Research Policy*, 35: 1018–1036.
- Jaffe, A. B. (1989) Real effects of academic research. *The American Economic Review*, 79: 957–970.
- Jaffe, A. B., Trajtenberg, M., Henderson, R. (1993) Geographic localization of knowledge spillovers as evidenced by patent citations. *Quarterly Journal of Economics*, 63: 577–598.
- Katz, J. S., Martin, B. R. (1997) What is research collaboration. *Research Policy*, 26: 1–18.
- Keane, J., Allison, J. (1999) the intersection of the learning regional and local and regional economic development: analysing the role of higher education. *Regional Studies*, 33: 896–902.
- King, G., Zeng, L. (2001) Logistic regression in rare events data. *Political Analysis*, 9: 137–163.
- King, G., Zeng, L. (2002) Estimating risk and rate levels, ratios, and differences in case-control studies. *Statistics in Medicine*, 21: 1409–1427.
- Kirat, T., Lung, Y. (1999) Innovation and proximity. Territories as loci of collective learning processes. *European Urban and Regional Studies*, 6: 27–38.
- Kitagawa, F. (2004) Universities and the learning region: creation of knowledge and social capital in the learning society. *Hitotsubashi Journal of Social Studies*, 36: 9–28.
- Laranja, M., Uyarra, E., Flanagan, K. (2008) Policies for science, technology and innovation: translating rationales into regional policies in a multi-level setting. *Research Policy*, 37: 823–835.
- Laursen, K., Reichstein, T., Salter, A. (2011) Exploring the effect of geographical distance and university quality on industry–university collaboration in the UK. *Regional Studies*, 45: 507–523.
- Lawton Smith, H. (2007) Universities, innovation, and territorial development: a review of the evidence. *Environment and Planning C: Government and Policy*, 25: 98–114.
- Leydesdorff, L., Etzkowitz, H. (1996) Emergence of a Triple Helix of university–industry–government relations. *Science and Public Policy*, 23: 279–286.
- Leydesdorff, L., Etzkowitz, H. (1998) The Triple Helix as a model for innovation studies. *Science and Public Policy*, 25: 195–203.
- Lundvall, B.-A. (ed) (1992) *National Systems of Innovation*. London: Pinter.
- Malmberg, A., Maskell, P. (2002) The elusive concept of localization economies: towards a knowledge-based theory of spatial clustering. *Environment and Planning A*, 34: 429–449.
- Mansfield, E., Lee, J.-Y. (1996) The modern university: contributor to industrial innovation and recipient of industrial R&D support. *Research Policy*, 25: 1047–1058.

- Massard, N., Mehier, C. (2010) Proximity and innovation through an 'Accessibility to Knowledge' lens. *Regional Studies*, 43: 77–88.
- Moodysson, J., Jonsson, O. (2007) Knowledge collaboration and proximity. *European Urban and Regional Studies*, 14: 115–131.
- Mora-Valentin, E. M., Montoro-Sanchez, A., Guerras-Martin, L. A. (2004) Determining factors in the success of R&D cooperative agreements between firms and research organizations. *Research Policy*, 33: 17–40.
- Morgan, K. (1997) The learning region: institutions, innovation and regional renewal. *Regional Studies*, 31: 491–503.
- Mowery, D. C., Sampat, B. N. (2005) The Bayh-Dole Act of 1980 and university–industry technology transfer: a model for other OECD governments? *Journal of Technology Transfer*, 30: 115–127.
- Nelson, R. R. (ed) (1993) *National Innovation Systems: A Comparative Study*. New York: Oxford University Press.
- Nelson, R. R., Rosenberg, N. (1993) Technical innovation and national system. In R. Nelson (ed) *National Innovation Systems: A Comparative Analysis*. Oxford: Oxford University Press.
- Nesta, L., DiBiaggio, L. (2003) Strategy and knowledge dynamics: the case of biotech. *Industry and Innovation*, 10: 329–347.
- Nesta, L., Saviotti, P. (2005) Coherence of the knowledge base and the firm's innovative performance: evidence from the U.S. pharmaceutical industry. *Journal of Industrial Economics*, 53: 123–142.
- Nooteboom, B. (1999) *Inter-Firm Alliances. Analysis and Design*. London: Routledge.
- Nooteboom, B. (2000) *Learning and Innovation in Organizations and Economies*. Oxford: Oxford University Press.
- Nooteboom, B., Van Haverbeke, W., Duysters, G., Gilsing, V., van den Oord, A. (2007) Optimal cognitive distance and absorptive capacity. *Research Policy*, 36: 1016–1034.
- Ponds, R., van Oort, F., Frenken, K. (2007) The geographical and institutional proximity of research collaboration. *Papers in Regional Science*, 86: 423–443.
- Rodriguez-Pose, A., Crescenzi, R. (2008) Research and development, spillovers, innovation systems, and the genesis of regional growth in Europe. *Regional Studies*, 42: 51–67.
- Rosenberg, N., Nelson, R. R. (1994) American universities and technical advance in industry. *Research Policy*, 23: 323–348.
- Salter, A., Martin, B. R. (2001) The economic benefits of publicly funded basic research: a critical review. *Research Policy*, 30: 509–524.
- Saxenian, A. (1990) Regional networks and the resurgence of Silicon Valley. *California Management Review*, 33: 89–111.
- Saxenian, A. (1994) *Regional Networks. Industrial Adaptation in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.
- Sorenson, O., Rivkin, J. W., Fleming, L. (2006) Complexity, networks and knowledge flow. *Research Policy*, 35: 994–1017.
- Sorenson, O., Stuart, T. E. (2001) Syndication networks and the spatial diffusion of venture capital investments. *American Journal of Sociology*, 106: 1546–1588.
- Steinmueller, W. E. (2000) Does information and communication technology facilitate 'codification' of knowledge? *Industrial and Corporate Change*, 9: 361–376.
- Storper, M. (1995) The resurgence of regional economies, ten years later: the region as a nexus of untraded interdependencies. *European Urban and Regional Studies*, 2: 191–221.
- Storper, M., Venables, A. J. (2004) Buzz: face-to-face contact and the urban economy. *Journal of Economic Geography*, 4: 351–370.
- Teece, D. J., Rumelt, R., Dosi, G., Winter, S. (1994) Understanding corporate coherence: theory and evidence. *Journal of Economic Behavior and Organisation*, 23: 1–30.
- Tödtling, F., Lehner, P., Kaufmann, A. (2009) Do different types of innovation rely on specific kinds of knowledge interactions? *Technovation*, 29: 59–71.
- Tödtling, F., Lehner, P., Tripl, M. (2006) Innovation in knowledge intensive industries: the nature and geography of knowledge links. *European Planning Studies*, 14: 1035–1058.
- Torre, A., Gilly, J. P. (2000) On the analytical dimension of proximity dynamics. *Regional Studies*, 34: 169–180.
- Torre, A., Rallet, A. (2005) Proximity and localization. *Regional Studies*, 39: 47–59.

- van Oort, F. G. (2004) *Urban Growth and Innovation. Spatially Bounded Externalities in the Netherlands*. Aldershot: Ashgate.
- van Oort, F. G., Burger, M. J., Raspe, O. (2008) Interfirm relations and economic clustering in the Dutch Randstad region. In U. Blien, G. Maier (eds) *The Economics of Regional Clusters: Networks, Technology and Policy*, pp. 145–165. Cheltenham: Edward Elgar.
- Varga, A. (1998) Local academic knowledge spillovers and the concentration of economic activity. ERSA conference papers ersa98p493, European Regional Science Association.
- Veugelers, R., Cassiman, B. (2005) R&D Cooperation between Firms and Universities, some empirical evidence from Belgian Manufacturing. *International Journal of Industrial Organisation*, 23: 355–379.
- Vicente, J., Dalla Pria, Y., Suire, R. (2007) The ambivalent role of mimetic behavior in proximity dynamics: evidence from the ‘Silicon Sentier’. In J. Surinach (ed) *Knowledge Externalities, Innovation Clusters and Regional Development*. Northampton, MA: Edward Elgar.
- Zucker, L., Darby, M. R., Brewer, M. B. (1998) Intellectual human capital and the birth of US biotechnology enterprises. *The American Economic Review*, 88: 290–306.

Appendix

Table A1. 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 & boats	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	3320 ^a	100	632 ^a	100

^aThe total no. of observations for period 1999–2002 excludes a few firms for which the ISIC code could not be attributed, while for 2003 includes two firms for which the postcode was not recorded in the EPSRC grant.