Geographic proximity and firm-university innovation linkages: evidence from Great Britain

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Abstract: We investigate evidence for spatially mediated knowledge transfer from university research. We examine whether firms locate their R&D labs near universities, and whether those that do are more likely to co-operate with, or source knowledge from universities. We find that pharmaceutical firms locate R&D near to frontier chemistry research departments, consistent with accessing localised knowledge spillovers, but also linked to the presence of science parks. In industries such as chemicals and vehicles there is less evidence of immediate co-location, but those innovative firms that do locate near to relevant research departments are more likely to engage with universities.

Keywords: Innovation; Geography; Spillovers; Public Research

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Executive Summary

This paper provides new evidence on the role of geographic proximity in firm-university innovation linkages for Great Britain and investigates the existence of spatially mediated knowledge transfer from university research. We combine novel data on the location of firms' R&D and on innovative firms' interactions with universities, with measures of the presence and quality of university research in relevant subject areas at a high level of geographic dis-aggregation. This allows us to construct continuous spatial measures, enabling a better understanding of how physical distance affects firm-university interactions.

First, we look at the extent to which business-sector R&D is located in the vicinity of university research departments, relative to other factors such as proximity to production facilities or the availability of skilled workers. Second, conditional on location, we examine whether innovative firms situated closer to university research are more likely to engage with universities, either through formal collaborative research agreements or more informal knowledge sourcing.

We find some evidence of co-location of R&D facilities in pharmaceuticals with high research-rated chemistry departments, consistent with geographically localised knowledge spillovers and the importance of accessing academic knowledge for firms in this industry. London and the South East of England appear to play an important part in the story, as does the prevalence of science parks, which is itself likely to be linked to university presence.

In other industries such as chemicals, vehicles and machinery co-location with production appears to play a more important role than immediate proximity to universities. But it may be that the scale of R&D and production facilities in these industries restricts location choices, leading firms to locate outside urban areas, and further away from city centre university research. However, conditional on location, for innovative firms in the chemicals and vehicles sectors we do find evidence in line with geographic proximity to related research facilitating formal and informal knowledge flows from universities. Our results should be taken as indicative descriptive evidence rather than necessarily implying a causal relationship. However, we think that our findings are relevant to understanding whether geographic proximity matters in firm-university interactions, and the importance of other factors that might influence where firms locate their R&D in the wider context of regional policy.

1 Introduction

This paper provides new evidence on the role of geographic proximity in firm-university innovation linkages for Great Britain and investigates the existence of spatially mediated knowledge transfer from university research. There has been wide policy and academic interest in the economic impact that higher education institutions (HEIs) have on innovative activity in their host regions. Differences in innovation rates are often considered an important factor underlying regional disparities in economic performance and constitute an important policy concern in the UK and elsewhere (HM Treasury, 2001). Indeed, many countries have implemented regional innovation policies based on the presence of HEIs. The UK government has emphasised interaction between research institutions and business, and the role of geographic innovative clusters in improving innovation performance (HM Treasury, 2004), and many countries provide financial incentives to foster collaboration between firms and universities.

Evidence suggests that academic knowledge benefits firms and that the mechanisms through which non-market spillovers occur may be localised (Jaffe, 1989). Geographic proximity may be crucial if the primary mechanism through which knowledge is transferred is direct personal interactions enabled by social networks (Breschi and Lissoni, 2006). However, physical proximity may be less relevant if knowledge is codified or if tacit knowledge is transferred through well established links, such as formal collaboration agreements or alumni connections. Academic knowledge may also be transferred to (local) businesses through spin-out companies, consultancy or the supply of trained post-graduate research scientists.

We investigate two related research questions. First, whether firms locate their research and development (R&D) facilities near to university research departments, and second, conditional on location, whether innovative firms situated closer to university research are more likely to engage with universities, either through formal collaborative research agreements or more informal knowledge sourcing. We combine novel data on the location of firms' R&D and on innovative firms' interactions with universities, with measures of the presence and quality of university research in relevant subject areas at a high level of geographic dis-aggregation. This allows us to examine the role of geographic proximity using continuous spatial measures, enabling a better understanding of how physical distance affects firm-university interactions. Knowledge spillovers are inherently difficult to measure and a common approach is to use information from patent citations to track knowledge flows (Jaffe et al., 1993, Griffith et al., 2007). Instead we exploit survey data where firms are asked directly how important information from universities is for their innovative activity, (Cassiman and Veugelers, 2002 use equivalent data for Belgium).

We find some evidence that pharmaceutical firms locate their R&D facilities near to (within 10km) of world-class rated chemistry research departments, consistent with the importance of accessing localised knowledge spillovers. But in this industry and others the location of R&D also appears to be linked to the presence of science parks. Many UK R&D-intensive and science-based start-up businesses including university spin-outs locate in science parks which aim to support and promote technology transfer among innovative organisations. Science parks are frequently linked to local universities, which often played a role in their establishment. In the chemicals, vehicles and machinery industries we find that R&D facilities tend to be located in areas with higher manufacturing employment and which are relatively specialised in the respective industry, rather than in immediate proximity to universities. This suggests that the co-location of R&D with production, both within and external to the firm, might be more important in these industries.

We find evidence that in some industries innovative firms sited nearer to related university departments are more likely to engage with HEIs. For example, chemicals firms located closer to high-rated materials science departments are more likely to co-operate with local universities and to source information from universities, and firms in the vehicles industry located nearer to mechanical engineering departments are more likely to co-operate with local universities. Hence, while we find that in general firms in these industries do not locate their R&D in close proximity to related university research, those innovative firms that are geographically close tend to engage more with the research base, in line with geographic proximity facilitating firm-university interaction in these sectors.

The paper contributes to the empirical literature on the existence of geographically mediated spillovers,[1] and in particular the effects of university research on regional innovation activity, (e.g. Jaffe, 1989, Anselin et al., 1997, Harhoff, 1999, Karlsson and Andersson, 2005, Woodward et al., 2006).[2] Using U.S. data Woodward et al. (2006) find a positive but small impact of proximity to university research (measured by total university R&D

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[1] Jaffe et al. (1993) find evidence consistent with geographic localisation of knowledge spillovers and more recently Griffith et al. (2007) find that the geographic localisation has fallen over time in line with falls in communication and travel costs. See also Thompson and Fox-Kean (2005), Henderson et al. (2005) and Breschi and Lissoni (2006).

[2] See also Audretsch and Feldman (1996, 1999) and Cohen et al. (2002). Feldman (1999) provides a review.

expenditures in science and engineering) on numbers of high-tech start-ups. Instead we examine the location of firms' R&D with respect to the presence and research quality of individual university science and engineering departments. The research builds on previous work on this issue for Great Britain, Abramovsky et al. (2007), by using continuous measures of spatial proximity, and extends the research by considering firm-university interactions directly. As such the paper also relates to the literature on the role of geographic proximity in business-university connections.[3] Rosa and Mohnen (2008) using Canadian data find that an increase in distance decreases the proportion of total R&D expenditure that firms paid to universities. Ponds et al. (2007) use data on co-publications and find that geographic proximity is more relevant for collaboration between organisations with different institutional backgrounds, such as firms and universities, than for purely academic sector collaboration, although firm-university collaborations are also prevalent at a national scale, (see also Adams, 2002 for evidence on spillovers between different types of organisation).

The paper is structured as follows. We begin in Section 2 with a description of the data. Section 3 examines the co-location of R&D labs and university research and Section 4 investigates the role of geographic proximity in firm-university interactions. In each case we outline our empirical approach and discuss our findings. Section 5 concludes.

2 Data and descriptive statistics

We outline each of the datasets used in the analysis and provide some descriptive statistics.

2.1 Business Sector R&D Activity

We use the UK Office for National Statistics (ONS) establishment-level Business Enterprise Research and Development (BERD) data for the period 2000-2003, which provide information on the population of establishments performing intramural R&D in Great Britain. Each establishment's full postcode, industry and ownership status are registered.[4] The ONS collects more detailed information about R&D expenditure by surveying a sample of establishments from this population. The sample includes a census of large R&D-performing establishments and a stratified sample of the remainder of the population. Because not all establishments are surveyed each year, in our analysis we rely mainly on

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[3] Many studies examine firms' propensity to engage in collaborative R&D with universities, but do not consider the role of geographic proximity, e.g. Cassiman and Veugelers, (2002) and Abramovsky et al. (2009).

[4] Establishments can report on R&D carried out in plants at more than one location, but in 2000 95% reported on a single plant. The ONS constructs the population of R&D-doing establishments using information from other official sources. Data on the population of *all* businesses, of which those in the BERD are a subset, form the sample frame for the Community Innovation Survey (Section 2.2).

basic information available for the whole population of R&D-doers rather than on the more detailed information on the precise type of R&D conducted, which is only reported by large R&D-performing establishments.[5] We use one piece of information that is not reported for all establishments - the product group for which R&D is being conducted, discussed below.

Our measure of the presence of business R&D activity is constructed at the postcode district level, defined by the first part of the full postcode, for example "OX1" or "OX15".[6] We use postcode districts as the unit of observation to tie in with our second analysis of firm-university interactions using the Community Innovation Survey where this is the finest level of geographic information available. Postcode districts vary in geographic size according to whether an area is rural or urban, so in our empirical analysis we pay careful attention to controlling for a range of other factors that may determine the concentration of R&D establishments and universities in a particular postcode district.

Our measure is a count of the average number of establishments carrying out intramural R&D between 2000 to 2003, in a product group. Product group information is not collected for smaller, sampled establishments and non-sampled establishments.[7] However, each company's Standard Industrial Classification (SIC) code is known and the ONS assumes that R&D expenditure is for the product group corresponding to that SIC category. For example, R&D being carried out in a small firm that operates in the chemicals industry will be assigned to the chemicals product group. This results in a large number of small R&D establishments being classified as R&D services providers, whereas it is very likely that they do R&D for other product groups. This means that we may not be capturing the locations of all R&D activity devoted to the product groups we consider, (although we will be capturing the locations of establishments accounting for the vast majority of expenditure).

We focus on eight product groups that account for 69% of total intramural R&D in 2003: pharmaceuticals; chemicals; machinery; electrical machinery; TV and radio equipment; vehicles; precision instruments and aerospace. Table 1 breaks down total intramural R&D expenditure and counts of R&D-doing establishments by product group. The table indicates

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[5] This more detailed information is imputed for non-sampled and non-respondent establishments, see National Statistics (2005) for further details, but we do not use this information.

[6] UK postcodes identify postal delivery points. They comprise an outward code of 2 to 4 characters, e.g. "OX1" and an inward code of 3 characters, e.g. "1NF". The first one or two characters of the outward code are the postcode area, e.g. "OX" for Oxford, of which there are around 125, and the full outward code is the postcode district, of which there are around 2,900, which identifies the local delivery office that mail should be sent to.

[7] Product groups use the same breakdown as industry groups, see Table A.1 in the Appendix.

that R&D expenditure is highly concentrated: expenditure in pharmaceutical products accounts for a quarter of the total, followed by aerospace with 12% and vehicles with 9%. In 2003 10,492 establishments were classified as performing intramural R&D. The distribution of establishments is much less concentrated across products; the same eight product groups account for around 30% of total establishments conducting R&D, implying that a small number of establishments account for a large share of total expenditure, (large firms account for around 75% of total R&D performed in UK businesses, National Statistics, 2005). As an additional exercise we also look at the location of small R&D services labs operating in natural sciences and engineering. These comprise a further 15% of establishments.

Table 1. Total intramural R&D in 2003, by product group

Product group	Expenditure		Establishments	
	£bn	%	Number	%
Pharmaceuticals	3.24	24%	158	2%
Aerospace	1.65	12%	72	1%
Vehicles	1.17	9%	236	2%
Machinery	0.97	7%	782	7%
TV and radio equipment	0.93	7%	250	2%
Chemicals	0.54	4%	382	4%
Electrical machinery	0.44	3%	442	4%
Precision instruments	0.40	3%	558	5%
R&D services (natural science and engineering)	0.33	2%	1,584	15%
Other	3.91	29%	6,028	57%
Total	13.57	100%	10,492	100%

Source: Authors' calculations using BERD (Source: ONS) data.

2.2 *Firm-University Interactions*

To obtain information on firm-university linkages we use data from the Community Innovation Survey (CIS), which is conducted every four years by EU member states to collect information on firms' innovative activity. We focus our analysis on innovative firms defined as those that have introduced a product or process innovation or have ongoing or abandoned innovative activities or have innovation-related expenditures in the last three years. We combine the CIS3 data for 1998-2000 and the CIS4 data for 2002-2004 for Great Britain to derive indicators of business-university R&D interactions. We use two pieces of information. First, whether a firm co-operates with HEIs in the local area. This variable equals one if a firm reports that it co-operates with any university within approximately 50 miles (80km) in the CIS3 (question 13) and within 100 miles (160km) in the CIS4 (question 18). Second, whether a firm sources knowledge for its innovative activities from HEIs. Firms are asked how important different information sources have been for their innovation activities (question 12, CIS3, question 16, CIS4). Our variable takes the value one if the firm placed low, medium or high importance on information from HEIs, and zero if information from HEIs was not used. The data allow us to locate innovative firms within postcode districts. We conduct our analysis for four of the main product groups above (chemicals excluding pharmaceuticals, machinery, vehicles and precision instruments) where sample sizes are large enough, and additionally for manufacturing and non-manufacturing sectors as a whole.[8]

Table 2. Co-operation with, and sourcing information from HEIs

	Manufacturing				**Other industries**			
	C	**NC**	**S**	**NS**	**C**	**NC**	**S**	**NS**
No. observations	209	5,336	1,787	3,758	258	9,592	2,133	7,761
% of total obs.	3.8%	96.2%	32.2%	67.8%	2.6%	97.4%	21.6%	78.4%
Log (employees)	3.95	3.57	4.02	3.43	3.30	3.20	3.37	3.16
% of employees with science/engineering degree	13.06	4.52	8.23	3.55	23.44	7.37	16.34	5.73
Financial public support for innovation (dummy)	0.42	0.11	0.21	0.08	0.34	0.06	0.16	0.05
R&D intensity	0.31	0.05	0.19	0.01	0.46	0.07	0.28	0.03

Note: Excluding first two rows, calculations are weighted using inverse sampling weights. C = co-operates with, NC = does not co-operate with universities located within 50 miles (CIS3) or 100 miles (CIS4). S = sources information, NS = does not source information from HEIs.
Source: Authors' calculations using CIS3 and CIS4.

The CIS contains further information on firm characteristics which might affect the likelihood that firms engage with HEIs and which we use as control variables. These are a measure of size (log employees); the percentage of the firm's employees qualified to degree level or above in science and engineering; whether a firm received financial public support for innovation activities; and R&D intensity (measured by intramural R&D expenditure over turnover for the year 2000 in the CIS3 and 2004 for CIS4). Table 2 provides further detail. The values of these characteristics are typically higher for those firms that either enter into collaboration agreements (C) or source information (S) for innovative activities. The table also provides information on the percentage of innovative firms that have HEI links. Firms are much more likely to source information from HEIs (32% in manufacturing and 22% in

[8] While the BERD data represent the population of R&D-doing establishments, the CIS is a sample drawn from the population of all UK firms. Sample sizes are not large enough to carry out analyses for the pharmaceuticals, electrical machinery, TV and radio equipment and aerospace industries. The sample is stratified across 11 regions of Great Britain, by industry and by firm sizeband. The average response rate in the CIS4 was 58% and varied across regions from 54% to 59%. We weight our regressions using inverse sampling weights.

other industries), than to have a formal co-operative venture with a local university (4% and 3%) respectively.

2.3 *Measuring University Research Presence and Quality*

We use the results of the most recent Research Assessment Exercise (RAE) in 2001 to map the presence and the quality of research carried out by universities, and their specific research departments in Great Britain. The Higher Education Funding Council for England carries out the RAE to produce ratings of research quality which are used to allocate the main grant for research use among universities. Each university submits research activity for assessment on all or some fraction of the research staff in departments of their choice. In 2001 there were 2,598 submissions by 173 UK universities on 68 research areas.[9] Each department submission is rated within a scale of 1, 2, 3, 4, 5 and 5*, with a higher number indicating higher rated research. Top rated departments receive a funding weight over three times higher than lower quality research departments (HEFCE, 2005). In some cases departments from the same university chose to send more than one submission, and we use the maximum rating achieved. We exclude Northern Ireland leaving us with 2,448 research departments across all disciplines.

For each postcode district we construct measures of overall university presence, a count of universities within a 10km radius, and a count of universities between a 10km and 50km radius of the centre of the postcode district. We construct the distance between the centre of a postcode district and a university using National Grid references. We calculate the central point of each postcode district by taking the mean of the Eastings and Northings of all the postcodes within each postcode district from the National Statistics Postcode Directory (NSPD). We then link each university's full postcode with the NSPD to obtain Eastings and Northings and use Pythagoras' theorem to calculate the Euclidean distance between the centre of each postcode district and each university.[10]

We use information on each department submission to construct a measure of the presence and quality of *relevant* university research activity for each of the product groups for each

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[9] The RAE results are publicly available at http://www.hero.ac.uk/rae/Pubs/index.htm. Though it is not mandatory, the incentives for participation are very high as public research funding depends on this assessment.

[10] We assume that all parts of the university are located at the postcode of the central administrative office. As Eastings are perpendicular to Northings the theorem can be used to calculate the distance between the two points (i.e. the hypotenuse of a triangle). The distance d_{ik} between the postcode district centre *i* and university *k* will be given by $d_{ik} = \sqrt{(e_i - e_k)^2 + (n_i - n_k)^2}$, where *e* and *n* are Eastings and Northings co-ordinates.

postcode district. To define relevant research we use the results of the 1994 Carnegie Mellon Survey (CMS) that reports the importance of ten research fields (biology, chemistry, physics, computer science, materials science, medical and health science, chemical engineering, electrical engineering, mechanical engineering and mathematics) for different manufacturing industries.[11] We consider a field as relevant for a product group if it was rated moderately or very important (a score of at least three on a four-point scale) for the corresponding industry by over 50% of survey respondents (see Tables A.1 and A.2 in the Appendix). We assign each of the RAE departments to the ten CMS fields as shown in Table A.3 in the Appendix.

Then, for each postcode district and *research field* we construct the following variables: a count of departments located within 10km of the centre of the postcode district; a count of departments located between 10km and 50km of the centre; a count of departments rated 5 and 5* within 10km of the centre; and a count of departments rated 4 or below within 10km of the centre. It is worth noting that the departments are rated on their research quality but not necessarily on how well they interact with business, which might be important for a firm deciding where to locate its R&D.[12] Further, although the most recent RAE was carried out in 2001, the research submitted for assessment was carried out in the five years to the end of 2000. Descriptive statistics for these measures are provided in Sections 3 and 4.

We also construct a measure of the log of the total number of research students in all departments within 10km of the centre of each postcode district which is intended to capture the potential contribution of local universities to the local labour market, in particular with respect to skills relevant for innovation.[13]

2.4 Further data

We use a number of further control variables in our analysis. We include a measure of economic density at the postcode district level to capture urbanisation externalities and the fact that more populated postcode districts are likely to be physically smaller than rural ones. This is measured by the log of the number of full postcode addresses at the postcode district

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[11] The CMS is a survey of R&D managers of manufacturing R&D units located in the U.S. The survey asks firms' R&D managers to evaluate, by field, the importance to their R&D of the contribution of public research conducted over the prior 10 years using a four-point Likert scale. See Cohen et al. (2002) for a full description.

[12] The definition of research for the RAE includes work of direct relevance to the needs of commerce and industry. However, there are concerns that in practice the assessment panels that determine research quality tend to rely on more academic benchmarks, such as output in important journals, than world-class research in collaboration with businesses, *Lambert Review of Business–University Collaboration: Final Report*, (2003).

[13] We also consider the number of research students located between 10km and 50km and the number in all departments rated 5 and 5* or rated 4 and below in our different specifications.

level. We also include controls at the 'postcode area' level, where a postcode area is the first two letters of the postcode, e.g. 'OX' (see footnote 7). We include a measure of the skill composition of the workforce which may affect the type of firms operating in the area and also contribute to the innovation process and to knowledge spillovers (see, for example, Bartel and Lichtenberg, 1987). We use the percentage of the economically active population in that postcode area that are qualified to degree equivalent or above (Level 4), constructed from official labour market statistics for local and national areas (NOMIS, Labour Force Survey data).

In our co-location analysis we include the log of total manufacturing employment in the postcode area to further control for the scale of each area and potential agglomeration externalities arising from co-location with production activity. We also include the percentage of total manufacturing employment in the postcode area that is in the relevant industry, (i.e. the industry corresponding to each product group), to control for potential industry localisation externalities and the co-location of R&D facilities with related production (see Audretsch and Feldman, 1996). These are constructed using the ONS plant-level ABI-ARD population data for 2000. We also include a measure of the presence of science parks located within 10km of the centre of each postcode district from the UK Science Park Association (UKSPA). Firms may locate in science parks due to a range of factors: access to university research or other specialised infrastructure; localisation benefits; or lower costs of establishing an R&D facility at this type of site. To the extent that science parks are located near to specific university research departments this is likely to make it more difficult to separately identify relationships with proximity to relevant research.

In our analysis of firm-university interactions we also experiment with measures of the propensity of nearby universities to interact with businesses. We use the 2005 Higher Education-Business and Community Interaction Survey which provides annual information on knowledge exchange between HEIs and businesses and the wider community in the UK. We use information on the proportion of university academic staff that provide services to third stream commercial partners and the proportion of total staff employed in a dedicated business and community (third stream) function to construct average measures of these activities across universities located within 10km of the centre of each postcode district.

3 Do firms locate their R&D near universities?

We begin by discussing some descriptive statistics on the variables used in our analysis and then outline our empirical approach and our findings.

3.1 Descriptive Statistics

Table 3. Descriptive statistics, main university research and control variables

Variable	Mean	Standard Deviation	Number of postcode districts with zero	Maximum
Count of universities within 10km	2.95	8.23	1,255	39
Count of between 10km and 50km	12.23	15.08	98	55
Count within 10km				
Biology	0.78	1.89	1,597	9
Chemistry	0.48	0.97	1,687	4
Medicine	4.11	10.02	1,454	50
Materials science	0.41	0.98	1,850	5
Mechanical engineering	0.62	1.39	1,696	6
Electrical engineering	0.63	1.58	1,737	7
Computer science	1.10	2.62	1,486	13
Physics	0.55	1.17	1,686	5
Count between 10km and 50km				
Biology	3.65	3.58	255	17
Chemistry	2.31	1.87	406	8
Medicine	16.26	18.21	264	69
Materials science	2.08	2.39	968	9
Mechanical engineering	2.81	2.60	611	10
Electrical engineering	2.51	2.51	524	9
Computer science	4.75	4.73	240	20
Physics	2.83	2.47	374	11
Count RAE rated 1-4 within 10km				
Biology	0.32	0.82	1,882	4
Chemistry	0.25	0.58	1,908	2
Medicine	2.14	4.72	1,482	25
Materials science	0.22	0.53	1,938	3
Mechanical engineering	0.25	0.57	1,893	2
Electrical engineering	0.32	0.91	1,957	4
Computer science	0.84	2.19	1,629	11
Physics	0.23	0.55	1,918	2
Count RAE rated 5 or 5* within 10km				
Biology	0.46	1.15	1,791	5
Chemistry	0.23	0.53	1,906	2
Medicine	1.97	5.48	1,725	25
Materials science	0.19	0.54	2,019	2
Mechanical engineering	0.36	0.94	1,905	4
Electrical engineering	0.32	0.75	1,863	3
Computer science	0.27	0.54	1,820	2
Physics	0.32	0.70	1,811	3
Control variables				
At the postcode area level				
Log (total manufacturing employment)	10.17	0.79	--	12.00
Industry % manufacturing employment	4.52	4.87	--	25.63
% population with L4 or above skills	25.00	4.48	--	40.96
At the postcode district level				
Log (density -count of postal addresses)	9.04	0.92	--	10.97
Log (research students within 10km)	2.94	3.43	--	9.28
Log (research students between 10km and 50km)	7.28	2.22	--	9.81
Log (research students rated 1-4 within 10km)	2.60	2.98	--	7.89
Log (research students rated 5 or 5* within 10km)	2.28	3.22	--	8.99
Number of science parks within 10km	0.39	0.67	1,623	4

Note: The number of postcode districts is 2,318.
Source: Authors' calculations using ARD-ABI data (Source: ONS), RAE, NSPD, NOMIS and UKSPA data.

Table 3 provides information on our measures of university presence across 2,318 postcode districts. The first row shows that postcode districts have on average 3 universities located within 10km of their centre, but there is variation with over half having no university located in their immediate proximity and with postcode districts in inner London having over 30 universities located within a 10km radius.[14] Not surprisingly postcode districts have a higher average number of universities located between 10km and 50km, around 12, and the number of postcode districts with zero universities located in that band is only 98.

The next part of the table covers the specific relevant departments which we use in analysis. The figures show that these departments are often concentrated in the immediate geographic proximity of a small number of postcode districts. Medicine departments are present within 10km in the largest number of districts,[15] while materials science departments are present near the fewest number of districts, with 1,850 having none within 10km. Most postcode districts have a relevant department between 10km and 50km. Again materials science departments are relatively rare and medicine and computer science departments the most common. Looking at the presence of departments rated 4 or below and rated 5 or 5*, there are few striking differences in the average number within 10km by rating. Descriptive statistics for the other control variables are shown in the final section of the table and descriptive statistics on the number of R&D labs by product group, our dependent variables, are displayed with the regression results in the bottom row of each table in Section 3.3.

3.2 Empirical Approach

Our empirical approach needs to encompass more than one underlying model of firm behaviour since our data cover a heterogeneous set of R&D establishments. Some, in particular those owned by multinational firms, are likely to be highly geographically mobile. For these firms the relevant decision is whether locating in close proximity to a university, all else equal, is likely to increase their R&D productivity relative to an alternative location. Evidence of co-location with university research departments could then indicate that geographic proximity is important to capitalise on beneficial knowledge spillovers. Other establishments will be small R&D start-ups. Here the relevant decision might be *whether* an individual chooses to set up a new business in the area where he or she lives or works, rather than *where* to set up a new business. Hence, in this case a positive association with particular research departments is potentially in line with individuals in those departments having a higher propensity to set up their own commercial ventures.

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[14] We investigate the robustness of our results to dropping London.

[15] Medicine covers many research departments from clinical medicine to pharmacology, see Table A.3.

Given this potential heterogeneity in the underlying decision process we estimate a negative binomial count data model to capture the general pattern of location outcomes in our data.[16, 17] We consider each product group separately as it is likely that the importance of university research and specific research departments for the location of private-sector R&D varies across products. For each product group we estimate the cross-section relationship between a count of establishments reporting positive intramural R&D in a postcode district and the presence of relevant university departments. The unit of observation is the postcode district and we consider all those that have either an R&D lab or a university within 50km of the centre. This gives us a total of 2,318 postcode districts, although the exact number varies across product groups. The basic specification is given by:

$$E(establishments_{ij}) = \exp(\mathbf{DEP}'_{\mathbf{ij}}\boldsymbol{\alpha}_{\mathbf{i}} + \mathbf{Z}'_{\mathbf{j}}\boldsymbol{\gamma}_{\mathbf{i}} + \mathbf{X}'_{\mathbf{ir}}\boldsymbol{\beta}_{\mathbf{i}}) \quad (1)$$

where the dependent variable is the number of R&D establishments (an average over 2000-2003) in product group *i* in postcode district *j*. The main explanatory variables are vectors of variables capturing geographic proximity of relevant research departments, DEP_{ij}, described above. Each regression also includes a vector of postcode district level variables Z_j - a count of the number of universities and the log of the total number of research students across all departments within a particular radius and the log of the number of postal addresses in a postcode district, plus a vector X_{ir} of other relevant industrial and labour market characteristics at the postcode area level *r*. The variables capturing university research are constructed from the 2001 RAE, but it is important to note that they refer to research outputs between 1995 and 2000. The remaining controls are dated 2000, apart from the log number of postal addresses density measure which is obtained from the 2006 NSPD. We also investigate the relationship between the location of R&D labs and the prevalence of science parks by including the number of science parks located within 10km of the postcode district.

While we attempt to control for other factors that may affect the location of business R&D the results from the above specification should be interpreted as correlations rather than causal relationships. For example, common unobserved factors may determine both the presence and quality of research departments and the location of R&D, or there may be

[16] See Harhoff (1999) for a discussion of these issues in the context of a study of firm formation in Germany.

[17] We use the negative binomial instead of the Poisson regression to account for overdispersion. In a Poisson distribution the mean and variance are equal. When the variance is greater than the mean the distribution is said to display overdispersion and Poisson estimation is inappropriate, yielding inefficient estimates. The negative binomial regression corrects for this.

reverse causation from the location of business R&D to the quality of research departments. In general these effects are likely to bias the results towards finding evidence for the co-location of business R&D and university research. We conduct some robustness checks focusing in the pharmaceuticals industry. We experiment with excluding postcode districts located in London, and also with including regional dummies to try to address common unobserved heterogeneity. We also look separately at specialised R&D labs, many of which are likely to conduct R&D in pharmaceuticals.

We present all results in the form of incidence rate ratios. An incidence rate ratio greater than one corresponds to a positive coefficient and below one to a negative coefficient in the negative binomial model. For ease of exposition the tables display incidence rate ratios minus one. For example, an incidence rate ratio of 1.3 is displayed as 0.3 and means that for a one-unit increase in the explanatory variable there is a 30% increase in the expected number of R&D-doing establishments in a postcode district. We report z-statistics in parentheses and indicate statistical significance at the 1%, 5% and 10% levels. Each table also presents information on the dependent variable's mean and standard deviation and the number of postcode districts where the dependent variable is zero.

3.3 Results

Table 4 shows results for the location of R&D establishments with respect to the presence of research departments located within 10km. Given the number of hypotheses being tested we would expect to find some significant effects. However, 3 out of the 21 estimated effects of the presence of specific departments are significant at the 5% level, indicating that the results are significantly stronger than would be expected by chance. We find that R&D establishments in the pharmaceuticals sector are more likely to be located in postcode districts with chemistry departments within 10km. The results in the first column suggest that an additional chemistry department within 10km is associated with a 65% increase in the expected number of R&D establishments. On average a postcode district has around 0.10 pharmaceuticals R&D establishments, although the distribution is very skewed. Note that an increase of one department is a large change – as shown in Table 3, the average number of chemistry departments within 10km, across all postcode districts is only 0.5.[18] Along similar lines, an additional materials science department within 10km of a postcode district is

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[18] Note that the coefficient on biology is positive but insignificant. However if chemistry departments are excluded the coefficient on biology becomes 0.318 and significant at the 10% level. This is likely to be because of the high positive correlation between the presence of biology and chemistry departments, at 0.93. Of the 631 postcode districts with a chemistry department within 10km, 595 have also a biology department within 10km.

associated with a 18% increase in the expected number of R&D establishments in chemicals. This pattern is consistent with the findings in Abramovsky et al. (2007) which examined co-location within larger discrete geographic units (postcode areas).

Surprisingly, we also find a significant negative relationship between the presence of materials science departments and the number of R&D establishments in aerospace. The aerospace industry is characterised by considerable economies of scale and Table 1 shows that there are very few R&D establishments in this industry in our data. As shown in Table 3 the distribution of materials science departments is also strongly geographically concentrated - there are few postcode districts with departments within 10km, and these tend to be in major cities such as London and Manchester. It is likely that the nature of the aerospace industry, which requires very large business premises and access to infrastructure such as runways prohibits location in close proximity to the centres of large cities.

The control variables are also of interest. Conditional on the presence of relevant departments, the number of R&D establishments does not appear to be correlated with university presence in general or with the number of research students. The coefficient on the log of manufacturing employment in the postcode area is positive and highly significant in chemicals, machinery and vehicles. In all cases the coefficient on the measure of postcode area industry specialisation is also positive and significant, indicating that R&D establishments are likely to be located close to centres of manufacturing activity in their own industries. The coefficient on the number of postal addresses is positive and highly significant in all cases suggesting the presence of more general agglomeration economies. The proportion of the population educated to degree-level or above (L4+) enters positively and significantly in some sectors with the strongest relationship in pharmaceuticals.

Table 5 adds in the measures of the presence of research departments located between 10km and 50km from the centre of a postcode district. Only the coefficients related to the relevant research fields are displayed. For pharmaceuticals the coefficient on chemistry departments within 10km remains positive and significant and is substantially higher than that on chemistry departments located between 10km and 50km, which is significant at the 10%. This pattern of results points towards potential knowledge spillovers from chemistry departments to private-sector pharmaceuticals R&D and suggests that these may be increasing in geographic proximity.

For chemicals the coefficient on materials science departments located between 10km and 50km is positive and significant and of a similar magnitude to that on departments within 10km. R&D establishments in machinery and in vehicles are also more likely to be located in postcode districts with a higher number of materials science departments located between 10km and 50km. R&D facilities in the machinery sector are also more likely to locate in postcode districts with a higher number of mechanical engineering departments between 10km and 50km from the centre. Although indicative of some potential spillovers from relevant university research this pattern could be driven by firms in these industries locating their R&D outside immediate urban areas, potentially alongside production activity. As the results in Table 4 indicate, R&D activity in chemicals, machinery and vehicles is likely to be located in areas with a greater concentration of manufacturing employment, potentially due to planning requirements for large production facilities.

In Table 6 we investigate whether research quality matters, distinguishing between 5 and 5* departments deemed to be carrying out frontier research and those rated 4 and below. The results imply a very strong tendency for pharmaceuticals R&D to be located near to 5 and 5* rated chemistry departments. The finding for chemicals R&D and materials science departments is no longer significant when we split departments into higher and lower rated. For precision instruments, an industry that comprises a heterogeneous set of products from medical equipment to measurement instruments, we find a mixed pattern of results. R&D establishments tend to locate in postcode districts with a larger number of 5 and 5* rated medicine departments in close proximity. However we find negative coefficients on medicine departments rated 4 or below (this is also the case for pharmaceuticals) and electrical engineering departments rated 5 or 5*. It may be that this pattern is driven by the location of establishments carrying out R&D in medical equipment.

Table 4. Location of establishments conducting intramural R&D and university departments within 10km

	Pharma	Chemicals	Machinery	Elec. machinery	TV, radio equip.	Vehicles	Aerospace	Instruments
No. biology depts ≤ 10km	0.129							
	(0.69)							
No. chemistry depts ≤ 10km	0.648	-0.106						
	(2.27)*	(0.92)						
No. medicine depts. ≤ 10km	-0.037							-0.001
	(1.11)							(0.04)
No. material science depts ≤ 10km		0.178	-0.001		0.066	0.035	-0.374	
		(2.38)*	(0.02)		(0.52)	(0.35)	(1.96)*	
No. elec. engineering depts ≤ 10km				-0.144	-0.187			-0.151
				(1.50)	(0.67)			(1.33)
No. mech. engineering depts ≤ 10km			-0.067		-0.047	0.008	-0.150	
			(0.84)		(0.18)	(0.06)	(0.60)	
No. computer science depts ≤ 10km					0.006		-0.248	-0.100
					(0.05)		(1.09)	(1.32)
No. physics depts ≤ 10km					-0.134			
					(0.74)			
No. universities ≤ 10km	-0.045	-0.031	-0.022	-0.004	-0.013	-0.036	0.039	0.200
	(0.99)	(1.87)+	(1.28)	(0.19)	(0.41)	(1.35)	(0.59)	(0.78)
Log research students ≤ 10km	-0.004	0.013	-0.006	0.011	0.021	-0.031	0.077	0.013
	(0.10)	(0.59)	(0.43)	(0.67)	(0.74)	(1.21)	(1.44)	(0.69)
Log manufacturing employment	-0.075	0.186	0.245	0.110	0.038	0.431	0.330	0.037
	(0.58)	(2.38)*	(3.81)**	(1.43)	(0.45)	(4.02)**	(1.74)+	(0.59)
Industry % manufacturing emp.	0.076	0.050	0.045	0.086	0.079	0.043	0.063	0.062
	(3.92)**	(5.11)**	(6.34)**	(5.25)**	(7.34)**	(6.79)**	(5.00)**	(4.18)**
Proportion of pop L4+ skills	0.080	-0.012	-0.010	0.014	0.039	-0.011	0.025	0.030
	(4.19)**	(1.22)	(1.34)	(1.56)	(2.96)**	(0.79)	(1.13)	(3.19)**
Log number of postal addresses	0.750	0.901	0.925	1.140	1.464	1.093	1.976	0.868
	(3.47)**	(6.21)**	(10.80)**	(8.90)**	(8.20)**	(6.00)**	(4.30)**	(7.60)**
Pseudo R^2	0.05	0.05	0.07	0.06	0.08	0.07	0.10	0.05
Dependent variable mean (s.d.)	0.095 (0.411)	0.228 (0.533)	0.411 (0.716)	0.235 (0.562)	0.151 (0.462)	0.132 (0.394)	0.047 (0.331)	0.285 (0.609)
Obs (No. obs dep var zero)	2,269 (2,114)	2,273 (1,844)	2,280 (1,533)	2,271 (1,824)	2,271 (1,990)	2,268 (2,003)	2,268 (2,192)	2,274 (1,747)

Note: Dependent variable: number of establishments conducting intramural R&D, (average 2000-2003). Values shown are incident rate ratios minus one, robust z-statistics in parentheses. +, *, ** significant at the 10%, 5%, 1% level. Source: Authors' calculations using BERD, ARD-ABI (Source: ONS), RAE, NSPD and NOMIS data.

Table 5. Location of establishments conducting intramural R&D and university departments within 50km

	Pharma	Chemicals	Machinery	Elec. machinery	TV, radio equip.	Vehicles	Aerospace	Instruments
No. biology ≤ 10km	0.145							
	(0.76)							
No. chemistry ≤ 10km	0.849	-0.098						
	(2.64)**	(0.84)						
No. medicine ≤ 10km	-0.050							0.012
	(1.35)							(0.46)
No. material science ≤ 10km		0.134	-0.049		0.095	-0.003	-0.355	
		(1.72)+	(0.81)		(0.69)	(0.03)	(1.69)+	
No. elec. engineering ≤ 10km				-0.123	-0.195			-0.199
				(1.19)	(0.68)			(1.72)+
No. mech. engineering ≤ 10km			-0.039		-0.095	-0.051	-0.128	
			(0.46)		(0.35)	(0.36)	(0.48)	
No. computer science ≤ 10km					-0.031		-0.311	-0.127
					(0.22)		(1.32)	(1.56)
No. physics ≤ 10km					-0.109			
					(1.43)			
No. biology 10km – 50km	0.006							
	(0.07)							
No. chemistry 10km – 50km	0.194	0.030						
	(1.82)+	(0.56)						
No. medicine 10km – 50km	-0.024							0.016
	(0.93)							(1.32)
No. material science 10km – 50km		0.101	0.046		-0.007	0.082	0.020	
		(3.23)**	(2.11)*		(0.12)	(2.22)*	(0.25)	
No. elec. engineering 10km – 50km				0.012	0.046			-0.010
				(0.29)	(0.36)			(0.18)
No. mech. engineering 10km – 50km			0.076		-0.131	-0.032	-0.054	
			(2.24)*		(0.35)	(0.55)	(0.41)	
No. computer science 10km – 50km					-0.005		-0.123	-0.003
					(0.07)		(0.98)	(0.05)
No. physics 10km – 50km					0.018			
					(0.16)			
Pseudo R^2	0.05	0.06	0.07	0.06	0.08	0.08	0.10	0.05

Note, and number of observations as for Table 4. Controls as in Table 4 plus no. universities and log no. research students 10km – 50km. IRRs minus 1, (z-statistics). +, *, ** significant at the 10%, 5%, 1% level.
Source: Authors' calculations using BERD, ARD-ABI (Source: ONS), RAE, NSPD and NOMIS data.

Table 6. Location of establishments conducting intramural R&D and the quality of university research

	Pharma	Chemicals	Machinery	Elec. machinery	TV, radio equip.	Vehicles	Aerospace	Instruments
No. biology 4 or below ≤ 10km	-0.049							
	(0.22)							
No. chemistry 4 or below ≤ 10km	0.593	0.051						
	(1.63)	(0.37)						
No. medicine 4 or below ≤ 10km	-0.106							-0.081
	(2.26)*							(2.65)**
No. material science 4 or below ≤ 10km		0.214	-0.033		-0.057	0.074	-0.518	
		(1.44)	(0.30)		(0.28)	(0.41)	(1.41)	
No. elec. engineering 4 or below ≤ 10km				-0.15	0.151			-0.027
				(1.09)	(0.44)			(0.20)
No. mech. engineering 4 or below ≤ 10km			-0.111		-0.365	0.044	0.114	
			(1.09)		(1.43)	(0.27)	(0.35)	
No. computer science 4 or below ≤ 10km					-0.051		-0.16	-0.109
					(0.35)		(0.72)	(1.31)
No. physics 4 or below ≤ 10km					-0.231			
					(1.00)			
No. biology 5,5* ≤ 10km	-0.489							
	(1.25)							
No. chemistry 5,5* ≤ 10km	2.327	-0.022						
	(2.06)*	(0.09)						
No. medicine 5,5* ≤ 10km	0.125							0.165
	(1.23)							(3.69)**
No. material science 5,5* ≤ 10km		0.155	-0.004		0.128	0.018	-0.118	
		(0.84)	(0.03)		(0.51)	(0.08)	(0.27)	
No. elec. engineering 5,5* ≤ 10km				0.003	-0.244			-0.367
				(0.02)	(0.80)			(2.49)*
No. mech. engineering 5,5* ≤ 10km			-0.022		0.179	0.020	-0.486	
			(0.18)		(0.63)	(0.09)	(1.48)	
No. computer science 5,5* ≤ 10km					-0.226		-0.363	0.081
					(0.73)		(0.71)	(0.39)
No. physics 5,5* ≤ 10km					-0.067			
					(0.21)			
Pseudo R^2	0.05	0.06	0.07	0.06	0.08	0.07	0.10	0.06

Note, controls and number of observations as for Table 4. IRRs minus 1, (z-statistics). +, *, ** significant at the 10%, 5%, 1% level.
Source: Authors' calculations using BERD, ARD-ABI (Source: ONS), RAE, NSPD and NOMIS data.

Table 7. Location of establishments conducting intramural R&D, controlling for the presence of science parks

	Pharma	Chemicals	Machinery	Elec. machinery	TV, radio equip.	Vehicles	Aerospace	Instruments
No. biology ≤ 10km	0.284							
	(1.50)							
No. chemistry ≤ 10km	0.097	-0.132						
	(0.42)	(1.11)						
No. medicine ≤ 10km	-0.050							-0.017
	(1.49)							(0.74)
No. material science ≤ 10km		0.181	-0.004		0.053	0.018	-0.419	
		(2.39)*	(0.06)		(0.40)	(0.17)	(2.23)*	
No. computer science ≤ 10km					0.017		-0.288	-0.104
					(0.12)		(1.21)	(1.36)
No. electrical engineering ≤ 10km				-0.110	-0.230			-0.241
				(1.08)	(0.82)			(2.23)*
No. mechanical engineering ≤ 10km			-0.089		-0.042	-0.065	-0.225	
			(1.10)		(0.16)	(0.50)	(0.94)	
No. physics ≤ 10km					-0.186			
					(1.00)			
No. science parks ≤ 10km	0.895	0.074	0.080	-0.091	0.201	0.278	0.443	0.369
	(5.42)**	(0.69)	(1.18)	(1.13)	(2.06)*	(2.29)*	(1.63)	(4.00)**
Observations	2,269	2,273	2,280	2,271	2,271	2,268	2,268	2,274
Pseudo R^2	0.07	0.05	0.07	0.06	0.08	0.08	0.10	0.06

Note, controls as for Table 4. IRRs minus 1, (z-statistics). +, *, ** significant at the 10%, 5%, 1% level.
Source: Authors' calculations using BERD, ARD-ABI (Source: ONS), RAE, NSPD, NOMIS and UKSPA data.

In Table 7 we replicate the regressions in Table 4 but also control for the number of science parks within 10km. For half of the product groups we find a positive and significant relationship between the presence of science parks and the number of R&D establishments in a postcode district. The relationship is strongest for pharmaceuticals where an additional science park is associated with 90% increase in R&D establishments. Interestingly, the coefficient on the number of chemistry departments now becomes much smaller and insignificant. However, this does not necessarily imply that (highly-rated) chemistry departments are not a relevant factor driving these location decisions. As discussed above the location of science parks is itself endogenous, for example, if science parks arise because of a demand for space in proximity to frontier chemistry departments. Instead these findings suggest that science parks located close to chemistry departments are positively correlated with the location of pharmaceuticals R&D labs.[19] Co-location with science parks may also capture access to specialised infrastructure, or knowledge spillovers from other technology-intensive businesses. For the other seven product groups the coefficients on the research departments generally remain similar to those in Table 4. Finally, the coefficient on science parks is not significant for chemicals or machinery, consistent with the findings in Tables 4 and 5, and suggesting that the co-location of R&D with production may be more important in these industries.

3.3.1 Robustness

We perform some robustness checks on our main results in Table 4. We focus on pharmaceuticals since the findings for this industry are the most consistent across the different specifications. The results are shown in Table A.4 in the Appendix where only the coefficients on the numbers of relevant departments are reported. The first column repeats the results in Table 4, except that 170 central London postcode districts (within postcode areas E, EC, N, NW, SE, SW, W and WC) dropped from the sample. The pattern of results is similar, but the coefficient on the number of chemistry departments within 10km loses statistical significance. The average number of chemistry departments located within 10km of a central London postcode district is 3, whereas outside this area it is 0.3, suggesting than London plays an important part in the co-location of pharmaceuticals R&D and chemistry departments. The second column includes a set of broad region dummies (Southern England,

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[19] The unconditional correlation between the number of science parks and the number of chemistry departments within 10km of the centre of a postcode district is 0.53, with 532 out of the 631 postcode districts with chemistry departments within 10km also having a science park within 10km.

Midlands, Northern England, Wales and Scotland), so that the results are identified from variation within regions. Some of the region dummies enter significantly, with negative coefficients on all regions relative to Southern England. The results are very similar to those in Table 4, although the coefficient on the number of chemistry departments within 10km is now only significant at the 10% level.

A further concern is that we have omitted a number of R&D establishments from the analysis for which product group information is not available, in particular for the pharmaceuticals industry. The final two columns of Table A.4 use a count of the number R&D establishments recorded as being in the R&D services industry as the dependent variable.[20] As discussed in Section 2.1 there are some small, specialised R&D services labs for which the data do not specify the product group for which they are conducting R&D, making it difficult to know which fields of academic research are likely to be relevant for their activities. Of the 1,696 labs recorded as being in R&D services in 2003, 112 do provide information about the product group for which they are doing R&D. Of these just over 50% report that they are performing R&D in pharmaceuticals, with about a further 25% spread across the other product groups that we consider, and the remaining 25% in other product groups. For this reason we first investigate whether the location of R&D services labs is related to the presence of research departments that are relevant to the pharmaceuticals industry. The results in column (3) suggest that postcode districts with an additional chemistry department within 10km are associated with 16% more R&D services labs, consistent with the results for pharmaceuticals, and we also find a positive relationship with the presence of biology departments. In the final column we include the full set of research fields from Table 4, given that some specialised labs will be performing R&D in other products. The coefficient on chemistry departments becomes higher and more significant and we also find a positive relationship with the presence of physics departments, but a negative relationship with mechanical engineering departments.

4 Are innovative firms near universities more likely to interact with them?

The previous section provided some evidence that firms may be locating their R&D to benefit from localised knowledge spillovers from university research. We now look for more direct evidence. We investigate whether innovative firms near universities are more likely to

[20] We only consider R&D labs in natural sciences and engineering, as opposed to social sciences and humanities.

conduct co-operative R&D with local universities and to source information from universities for their innovative activities. Research joint ventures provide a formal frame for interaction, so geographic proximity might not be as crucial as for more informal, non-market exchanges of knowledge.[21] Hence we investigate both of these modes of knowledge transfer. We begin with some descriptive evidence then outline our empirical approach and discuss our findings.

4.1 Descriptive statistics

Since the nature of firm-university interactions may vary across industries we focus on four manufacturing industries (chemicals excluding pharmaceuticals, machinery, vehicles and precision instruments) for which we can identify relevant research fields and for which sample sizes are large enough. These industries account for a substantial share of UK R&D (Table 1). Unfortunately sample sizes for pharmaceuticals in the CIS data are too small to investigate linkages with the science base for this industry.

Table 8. Descriptive statistics, research departments (mean)

	Chemicals				**Machinery**				**Vehicles**				**Precision Instruments**			
	C	**NC**	**S**	**NS**	**C**	**NC**	**S**	**NS**	**C**	**NC**	**S**	**NS**	**C**	**NC**	**S**	**NS**
No. observations	16	188	108	96	22	457	187	292	10	312	115	207	33	256	158	131
% of total obs.	8%	92%	53%	47%	5%	95%	39%	61%	3%	97%	36%	64%	11%	89%	55%	45%
No. chemistry ≤ 10km	0.38	0.40	0.36	0.48												
No. medicine ≤ 10km													5.35	3.63	4.01	3.54
No. materials science ≤ 10km	0.68	0.34	0.43	0.29	0.28	0.32	0.35	0.30	0.39	0.34	0.31	0.36				
No. mechanical engineering ≤ 10km					0.67	0.42	0.57	0.36	0.76	0.52	0.52	0.53				
No. electrical engineering ≤ 10km													0.98	0.53	0.62	0.52
No. computer ≤ 10km													1.58	0.93	1.07	0.90

Note: Excluding first two rows, calculations are weighted using inverse sampling weights. C = co-operates with, NC = does not co-operate with local universities located within 50 miles (CIS3) or 100 miles (CIS4). S = sources information, NS = does not source information from HEIs.
Source: Authors' calculations using CIS3, CIS4, RAE, and NSPD data.

[21] Firms are also asked about co-operation with universities located in the rest of the UK and abroad. Pond et al. (2007) show that co-operating with non-local universities is also important and in our sample, for example, 8% of firms in chemicals co-operate with local universities and 13% with non-local UK universities.

Table 8 shows mean values for the variables measuring proximity to research departments (number within 10km) for co-operating (C), non-co-operating (NC), knowledge sourcing (S) and non-sourcing (NS) firms for each industry. In line with Table 2, the second row shows that for each industry more firms source information from universities than co-operate formally with them. There is some variation across industries, with a higher proportion of firms interacting with universities in chemicals and precision instruments. Overall there is some indication that firms that interact with universities are located in postcode districts with a similar or higher number of university research departments within 10km. For example, chemicals firms that interact with universities typically have a higher number of materials science departments located within 10km relative to firms that do not interact, and firms interacting with universities in machinery have a higher number of mechanical engineering departments in close proximity than non-cooperating, non-sourcing firms.

4.2 Empirical Approach

To investigate how the probability of interacting with universities relates to geographic proximity and the research quality of relevant departments we run a probit model as follows:

$$\Pr(Y_{fij} = 1) = \Phi(\mathbf{DEP}'_{\mathbf{ij}}\boldsymbol{\alpha}_{\mathbf{i}} + \mathbf{X}'_{\mathbf{f}}\boldsymbol{\beta}_{\mathbf{i}} + \mathbf{Z}'_{\mathbf{j}}\boldsymbol{\delta}_{\mathbf{i}} + \mathbf{W}'_{\mathbf{r}}\boldsymbol{\gamma}_{\mathbf{i}}) \qquad (2)$$

where *f* refers to a firm, *i* to industry, *j* to postcode district and *r* to postcode area. The main explanatory variables are the measures of the presence of research departments, DEP_{ij}, X_f is a vector of firm characteristics (Table 2) that may affect the probability that a firm engages with universities, Z_j includes measures of general university presence (number of universities and log of the number of research students within 10km) and a measure the density of economic activity (log of the number of postal addresses) and W_r includes the percentage of the economically active population with degree-level qualifications. We weight regressions using inverse sampling weights and since some firms appear in both the CIS3 and CIS4 we cluster standard errors at the firm level.

We estimate for each industry separately and for each of the two dependent variables described in Section 2.2 - the indicator of co-operation with local/regional universities, and the indicator of whether the firm sources information from universities. It is worth noting that although one of our dependent variables relates specifically to local co-operation and hence the presence of a local HEI is a pre-requisite for a positive response, the definition of local/regional is within 80km in CIS3 and within 160km in CIS4 and hence covers a much wider geographic area than our measures of university activity. These cross-section results should be interpreted as a descriptive exercise rather than evidence of the causal determinants of firms' engagement with universities. If firms choose to locate near universities in order to interact with them, or if firms choose such a location for other reasons but the presence of a university induces them to interact, then we would expect a positive relationship reflecting the importance of geographic proximity for firm-university linkages. However, there may be unobserved characteristics of firms or areas that drive any observed correlations between firms' locations and their interactions with universities. The firm characteristics we include may also be endogenous.

4.3 Results

Before presenting our main results we first took two broad groups of firms, those in manufacturing and those in other industries, and looked for evidence that firms located near to universities were more likely to interact with HEIs. We ran a probit as in equation (2), but omitted the DEP_{ij} variables and looked only at proximity to universities in general (results are not displayed). We find that firms that engage with universities are larger, employ a higher fraction of scientists and engineers and are more likely to receive financial public support for their innovative activities. Conditional on this we find little evidence that geographic proximity to universities is correlated with firms' propensity to interact, except for a positive correlation between the number of research students located within 10km (indicating the scale of university research activity) and the probability of non-manufacturing firms sourcing information from universities. Since pooling firms across industries may be masking heterogeneity we now turn to our results for four specific manufacturing industries.

Table 9 shows results for the relationship between the two measures of business-university interaction and the presence of relevant research departments within 10km. The table reports marginal effects with z-statistics in parentheses. Conditional on firm and area characteristics, for innovative chemicals firms we find that the probability of co-operating or sourcing knowledge is positively correlated with the number of materials science departments within 10km. An additional materials science department is associated with a 1.6 percentage point increase in the probability of co-operating with local universities and a 19 percentage point increase in the probability of sourcing information. These are large increases given that in the weighted data around 5.4% and 47% of innovative chemicals firms co-operate and source knowledge respectively (as shown in the last row of Table 9). We find a positive relationship between proximity to mechanical engineering departments and the probability of co-operation for innovative firms in the vehicles industry – an increase of one mechanical engineering department being associated with a 0.7 percentage point increase in the probability of co-operation. However we also find some negative and significant marginal effects at the 10% level - chemicals firms located within 10km of chemistry departments and precision instruments firms located within 10km of medical departments are less likely to engage in co-operative R&D with universities.

In Table 10 we add in variables for relevant research departments located between 10km and 50km (only the marginal effects for relevant departments are displayed). For the chemicals industry for both interaction measures the marginal effect for materials science departments within 10km remains positive and significant, whereas that for materials science departments between 10km and 50km is smaller and insignificant. In the analysis of co-location in Section 3 we found that R&D labs in chemicals are more likely to locate in postcode districts with a higher number of materials science departments between 10km and 50km and in areas with higher manufacturing employment density. However, here, conditional on location we find that those chemicals firms that *are* located in closer proximity to materials science departments are more likely to engage with universities, both through formal co-operation and through knowledge exchange. For R&D co-operation in the vehicles industry the marginal effect for mechanical engineering departments is still positive and significant but now only at the 10% level.

Compared with Table 9 we find some further significant relationships at the 10% level. The marginal effect on materials science departments within 10km is now significant for firms in the machinery industry for the co-operation dependent variable, and we find a number of significant relationships for innovative firms in the precision instruments industry. These point to a positive relationship between the probability of engaging in co-operative R&D and the presence of electrical engineering departments, which strengthens with geographic proximity, and some evidence of a negative relationship between engagement with HEIs and the presence of medical departments.

Table 9. Co-operation with local/regional universities and sourcing information from universities, by industry

	Chemicals		Machinery		Vehicles		Precision instruments	
	Co-operate	*Information*	*Co-operate*	*Information*	*Co-operate*	*Information*	*Co-operate*	*Information*
No. chemistry ≤ 10km	-0.018	-0.080						
	(1.72)+	(0.71)						
No. medicine ≤ 10km							-0.003	0.004
							(1.86)+	(0.42)
No. materials science ≤ 10km	0.016	0.193	-0.029	-0.064	0.000	-0.053		
	(2.72)**	(2.84)**	(1.60)	(1.25)	(0.06)	(0.80)		
No. mech. engineering ≤ 10km			0.004	0.065	0.007	0.070		
			(0.32)	(1.03)	(2.38)*	(0.84)		
No. elec. engineering ≤ 10km							0.014	0.028
							(1.59)	(0.67)
No. computer science ≤ 10km							0.004	0.007
							(0.76)	(0.26)
Log employees	0.006	0.062	0.007	0.096	-0.001	0.070	0.009	0.054
	(2.03)*	(1.87)+	(1.37)	(4.31)**	(0.63)	(2.44)*	(3.82)**	(4.32)**
Share employees science/engineering	0.000	0.005	0.001	0.003	0.000	0.008	0.000	0.002
	(1.64)	(1.79)+	(2.96)**	(1.28)	(1.14)	(1.53)	(1.98)*	(2.36)*
Financial public support for innovation	0.105	0.244	0.037	0.179	0.126	0.191	0.047	0.072
	(3.13)**	(2.08)*	(1.67)+	(2.35)*	(4.01)**	(2.20)*	(4.16)**	(2.45)*
R&D intensity	0.066	0.313	0.234	-0.051	0.004	1.073	-0.055	0.729
	(1.78)+	(0.32)	(1.91)+	(0.06)	(0.21)	(1.28)	(1.11)	(1.50)
Proportion of population with L4+ skills	-0.092	-0.937	-0.232	-0.593	-0.040	-1.571	0.062	-0.042
	(1.34)	(1.03)	(1.40)	(1.24)	(1.40)	(2.58)*	(1.27)	(0.15)
Log number of postal addresses	-0.011	-0.058	-0.006	-0.072	0.000	0.029	0.004	0.004
	(2.32)*	(0.80)	(0.56)	(1.61)	(0.16)	(0.56)	(1.03)	(0.20)
Number of universities within 10km	-0.004	-0.015	0.004	0.010	-0.003	0.003	-0.000	-0.009
	(1.30)	(1.09)	(1.49)	(0.94)	(1.29)	(0.21)	(0.25)	(0.95)
Log of research students within 10km	0.002	-0.006	0.004	-0.008	0.001	-0.004	0.001	-0.002
	(1.23)	(0.29)	(1.31)	(0.70)	(0.86)	(0.29)	(0.62)	(0.30)
Observations	204	204	479	479	322	322	289	289
Dependent variable weighted mean	0.054	0.472	0.040	0.342	0.026	0.317	0.080	0.486
R^2	0.36	0.10	0.15	0.08	0.38	0.12	0.21	0.13

Note: Table shows marginal effects and robust z-statistics in parentheses with standard errors clustered at the firm level. +, *, and ** significant at 10%, 5% and 1% levels.
Source: Authors' calculations using CIS3, CIS4, RAE, NSPD and NOMIS.

Table 10. Co-operation with local/regional universities and sourcing information from universities, by industry

	Chemicals		Machinery		Vehicles		Precision instruments	
	Co-operate	*Information*	*Co-operate*	*Information*	*Co-operate*	*Information*	*Co-operate*	*Information*
No. chemistry ≤ 10km	-0.010	-0.039						
	(1.67)+	(0.32)						
No. medicine ≤ 10km							-0.002	-0.001
							(1.84)+	(0.10)
No. materials science ≤ 10km	0.011	0.177	-0.027	-0.053	0.000	-0.054		
	(2.79)**	(2.68)**	(1.68)+	(1.00)	(0.05)	(0.78)		
No. mech. engineering ≤ 10km			-0.003	0.049	0.004	0.080		
			(0.27)	(0.75)	(1.92)+	(0.92)		
No. elec. engineering ≤ 10km							0.013	0.021
							(1.90)+	(0.48)
No. computer science ≤ 10km							0.002	0.009
							(0.51)	(0.31)
No. chemistry 10km – 50km	0.001	-0.046						
	(0.49)	(0.97)						
No. medicine 10km – 50km							0.000	-0.008
							(0.81)	(1.89)+
No. materials science 10km – 50km	-0.003	0.004	-0.000	-0.019	0.000	0.002		
	(1.36)	(0.13)	(0.06)	(1.08)	(0.04)	(0.11)		
No. mech. engineering 10km – 50km			0.003	0.035	-0.001	0.000		
			(0.49)	(1.41)	(0.94)	(0.01)		
No. elec. engineering 10km – 50km							0.005	-0.011
							(1.80)+	(0.53)
No. computer science 10km – 50km							-0.003	0.018
							(0.94)	(1.00)
Observations	204	204	479	479	322	322	289	289
R^2	0.40	0.12	0.18	0.09	0.40	0.12	0.23	0.16

Note: Table shows marginal effects and robust z-statistics in parentheses with standard errors clustered at the firm level. +, *, and ** significant at 10%, 5% and 1% levels. Dependent variable weighted mean as for Table 9. Controls as in Table 9 plus no. universities and log no. research students 10km – 50km.
Source: Authors' calculations using CIS3, CIS4, RAE, NSPD and NOMIS.

Table 11. Co-operation with local/regional universities and sourcing information from universities, by industry

	Chemicals		Machinery		Vehicles		Precision instruments	
	Co-operate	*Information*	*Co-operate*	*Information*	*Co-operate*	*Information*	*Co-operate*	*Information*
No. chemistry 4 or below ≤ 10km	-0.014	-0.080						
	(1.57)	(0.70)						
No. medicine 4 or below ≤ 10km							-0.003	-0.002
							(1.33)	(0.15)
No. materials science 4 or below ≤ 10km	-0.000	0.149	-0.017	-0.010	0.000	-0.012		
	(0.11)	(1.26)	(0.86)	(0.12)	(0.05)	(0.15)		
No. mech. engineering 4 or below ≤ 10km			-0.002	0.121	0.008	0.038		
			(0.10)	(1.63)+	(2.24)*	(0.43)		
No. elec. engineering 4 or below ≤ 10km							-0.001	0.014
							(0.12)	(0.22)
No. computer science 4 or below ≤ 10km							0.009	0.015
							(1.82)+	(0.45)
No. chemistry 5, 5* ≤ 10km	-0.008	-0.134						
	(0.82)	(0.74)						
No. medicine 5, 5* ≤ 10km							-0.005	0.008
							(1.77)+	(0.52)
No. materials science 5, 5* ≤ 10km	0.016	0.260	-0.049	-0.107	-0.001	-0.122		
	(2.32)*	(1.86)+	(2.42)*	(1.24)	(0.10)	(1.17)		
No. mech. engineering 5, 5* ≤ 10km			0.013	-0.005	0.007	0.093		
			(0.81)	(0.06)	(1.99)*	(0.92)		
No. elec. engineering 5, 5* ≤ 10km							0.021	0.032
							(2.14)*	(0.53)
No. computer science 5, 5* ≤ 10km							0.013	0.034
							(1.03)	(0.42)
Observations	204	204	479	479	322	322	289	289
R^2	0.45	0.11	0.15	0.08	0.38	0.11	0.22	0.14

Note: Table shows marginal effects and robust z-statistics in parentheses with standard errors clustered at the firm level. +, *, and ** significant at 10%, 5% and 1% levels. Dependent variable weighted mean as for Table 9. Controls as in Table 9.
Source: Authors' calculations using CIS3, CIS4, RAE, NSPD and NOMIS.

Table 11 looks at whether the research ratings of nearby departments are related to the probability that firms engage with universities. For chemicals firms it is proximity to higher RAE-rated, 5 and 5* materials science departments that seems to be driving the relationships in Tables 9 and 10. Also it appears that it is proximity to lower rated chemistry departments that was driving the negative relationship in Table 9. For vehicles, proximity to both 1-4 and 5 and 5* rated mechanical engineering departments is positively associated with the probability of co-operating with local universities. For machinery we find some evidence that firms located near to 5 and 5* materials science departments are less likely to engage in co-operative R&D and weaker evidence that firms located nearer to lower rated mechanical engineering departments are more likely to source knowledge for their innovative activity.

We also find some positive correlations for precision instruments when we split research departments by rating. The marginal effect on the presence of 5 and 5* electrical engineering departments is positive and significant, and we find weaker evidence of a positive association with the presence of lower rated computer science departments and a negative relationship with higher rated medical departments. Overall the results for this industry in Tables 9-11 point towards a positive relationship between the presence of electrical engineering departments and the likelihood of business-university linkages, but not the presence of medical departments. It is possible that innovative firms in measurement instruments are driving these results, whereas R&D labs specialised in medical equipment are driving the results in Section 3 on co-location with higher-rated medicine departments. Indeed of those firms that report to be engaged in co-operative R&D with universities and which are situated within 10km of an electrical engineering department, the majority are classified to industry 33201, manufacture of electronic instruments for measurement.[22]

As a final exercise we experimented with including measures of the extent to which universities themselves are engaging in knowledge transfer to businesses. We replicated the specifications in Table 9 including two alternative measures capturing the propensity of nearby universities to interact with business - the average proportion of academic staff, and the average proportion of total staff dedicated to third stream commercial activities in universities located within 10km. We found no clear pattern and only found a few instances of positive and significant coefficients. For

[22] There is also a very high correlation between the presence of medical departments and electrical engineering departments within 10km, with 95% of postcode districts in our sample with an electrical engineering department within 10km also having a medical department within 10km. Therefore the negative relationship with medical departments is likely to be driven by firms in areas with medical departments but not electrical engineering departments in close proximity being less likely to conduct co-operative R&D.

example, for the chemicals industry the coefficient on the proportion of academic staff devoted to third stream activity was positive and significant for the co-operation dependent variable, and the coefficient on the proportion of total staff devoted to third stream activity with commercial partners was significant for the sourcing information measure. The results on specific research departments remain similar, in particular the results for firms in the chemicals industry and proximity to materials science departments.

5 Conclusions

This paper provides new evidence on the role of geographic proximity in firm-university innovation linkages for Great Britain. We first look at the extent to which business-sector R&D is located in the vicinity of university research departments, relative to other factors such as proximity to production facilities or the availability of skilled workers. We find some evidence of co-location of R&D facilities in pharmaceuticals with high research-rated chemistry departments, consistent with geographically localised knowledge spillovers and the importance of accessing academic knowledge for firms in this industry. London and the South East of England appear to play an important part in the story, as does the prevalence of science parks. While science parks may provide other localisation or infrastructure benefits, the occurrence of science parks is itself likely to be linked to university presence.

In other industries such as chemicals, vehicles and machinery co-location with production appears to play a more important role than immediate proximity to universities, potentially indicating that knowledge flows or other synergies exist between production activity and R&D activity in these sectors. But it may be that the scale of R&D and production facilities in these industries restricts location choices, leading firms to locate outside urban areas and hence further away from city centre university research. However, conditional on location, for innovative firms in the chemicals and vehicles sectors we do find evidence in line with geographic proximity to related research facilitating formal and informal knowledge flows from universities. Our results on firm-university interactions should be taken as indicative descriptive evidence rather than necessarily implying a causal relationship, nor do they shed light on the extent to which the underlying behaviour behind any causal relationship is driven by certain firms selecting to locate nearer to universities in order to interact with them, versus universities themselves being most visible to or actively targeting firms in their immediate area. However, we think that our findings are relevant to understanding whether geographic proximity matters in firm-university interactions, and the importance of other factors that might influence where firms locate their R&D in the wider context of regional policy.

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Appendix

Table A.1. Linking R&D product groups, industries and research fields

R&D product group	Corresponds to products in BERD	Corresponds to UK SIC92 codes	Corresponds to US industry codes in CMS Cohen et al. (2002)	Relevant fields from CMS, Cohen et al. (2002)[1]
Pharmaceuticals	15 (H) pharmaceuticals	24.4	2423	BIO CHEM MED
Chemicals	14 (G) chemicals	24 (excl. 24.4)	2400 2411 2413 2429	CHEM MATSCI
Machinery	21 (N) machinery	29	2910 2920 2922	MATSCI MECHE
Electrical Machinery	23 (P) electrical machinery	31	3100 3110	EE
TV, radio equipment	24 (Q) TV / radio	32	3210 3211 3220 3230	MATSCI COMPSCI EE MECHE PHYS
Vehicles	26 (S) motor vehicles	34	3410 3430	MATSCI EE MECHE
Precision instruments	(R) Precision instruments	33	3311 3312 3314	COMPSCI EE MED

[1] University sectors that over 50% respondents say are moderately or very important in this industry.

Table A.2. Importance of academic research in different fields of science for industrial R&D managers in the US

Percentage of respondents indicating research "moderately important" or "very important"

Industry (ISIC code)	Description	Sample size	BIO	CHEM	PHYS	COMPSC	MATSC	MED	CHEME	EE	MECHE	MATH
2400	Chemicals	75	13.3	52.0	8.0	24.0	22.7	17.3	34.7	1.3	5.3	5.3
2411	Basic Chemicals	42	14.3	47.6	7.1	23.8	23.8	16.7	40.5	2.4	4.8	2.4
2413	Plastic Resins	30	13.3	56.7	13.3	30.0	50.0	6.7	46.7	3.3	3.3	6.7
2423	Drugs	70	64.3	74.3	7.1	30.0	26.5	75.7	22.9	5.7	5.7	4.3
2429	Miscellaneous Chemicals	32	12.5	62.5	9.4	31.3	46.9	12.5	37.5	3.1	12.5	9.4
2910	General Purpose Machinery	79	1.3	13.9	10.1	29.1	53.2	5.1	21.5	26.6	59.5	10.3
2920	Special Purpose Machinery	74	10.8	23.0	25.7	35.1	38.4	5.4	20.3	31.1	36.5	14.9
2922	Machine Tools	11	0.0	0.0	0.0	36.4	36.4	0.0	0.0	27.3	36.4	0.0
3100	Electrical Equipment	23	0.0	13.0	8.7	8.7	21.7	8.7	8.7	17.4	21.7	8.7
3110	Motor/Generators	24	0.0	4.2	12.5	29.2	41.7	0.0	4.2	58.3	33.3	8.3
3210	Electronic Components	28	3.6	25.0	28.6	32.1	53.6	7.1	10.7	63.0	50.0	28.6
3211	Semiconductors	26	11.5	46.2	61.5	46.2	76.9	11.5	30.8	65.4	42.3	26.9
3220	Comm equipment	37	2.7	8.1	29.7	54.1	27.0	2.7	5.4	70.3	37.8	24.3
3230	TV/radio	9	0.0	11.1	33.3	44.4	55.6	11.1	22.2	66.7	33.3	22.2
3311	Medical Equipment	76	35.5	34.2	21.1	30.3	47.4	76.3	18.4	29.0	29.0	15.8
3312	Precision Instruments	38	15.8	18.4	21.1	39.5	31.6	15.8	5.3	52.6	39.5	23.7
3314	Search/Navigational Equipment	41	2.4	12.2	34.2	53.7	41.5	4.9	12.5	68.3	43.9	36.6
3410	Car/Truck	9	11.1	22.2	33.3	44.4	55.6	11.1	22.2	33.3	44.4	22.2
3430	Auto Parts	34	2.9	14.7	23.5	41.2	54.6	2.9	20.6	50.0	58.8	23.5

Fields: Biology (BIO), Chemistry (CHEM), Physics (PHYS), Computer Science (COMPSC), Materials Science (MATSC), Medical and Health Science (MED), Chemical Engineering (CHEME), Electrical Engineering (EE), Mechanical Engineering (ME) and Mathematics (MATH).
Source: CMS survey reported in Cohen, Nelson and Walsh (2002).

Table A.3. Mapping between relevant research fields and UK university departments (RAE 2001)

Relevant fields (CMS, Cohen et al., 2002)	UK university departments (RAE 2001)
BIO (biology)	14 Biology
CHEM (chemistry)	18 Chemistry
MED (medicine)	1 to 5 Clinical medicine, 6 Anatomy, 7 Physiology, 8 Pharmacology, 9 Pharmacy, 10 to 11 Other medical
MATSCI (material science)	32 Metallurgy and materials
EE (electrical engineering)	29 Electrical and electronic engineering
MECHE (mechanical engineering)	30 Mechanical, aeronautical and manufacturing engineering
COMPSCI (computer science)	25 Computer Science
PHYS (physics)	19 Physics

Table A.4. Location of establishments conducting intramural R&D, robustness

	Pharmaceuticals		R&D services	
	Excluding London (1)	Regional dummies (2)	Departments relevant for pharmaceuticals (3)	All departments (4)
No. biology ≤ 10km	0.086	0.189	0.113	0.095
	(0.40)	(0.81)	(1.72)+	(1.27)
No. chemistry ≤ 10km	0.494	0.628	0.163	0.496
	(1.60)	(1.74)+	(2.14)*	(3.80)**
No. medicine ≤ 10km	-0.018	-0.027	-0.016	0.009
	(0.39)	(0.75)	(1.35)	(0.58)
No. materials science ≤ 10km				-0.051
				(1.02)
No. electrical engineering ≤ 10km				-0.129
				(1.33)
No. mechanical engineering ≤ 10km				-0.216
				(2.06)*
No. computer science ≤ 10km				-0.069
				(1.44)
No. physics ≤ 10km				0.162
				(1.69)+
Observations	2,099	2,269	2,306	2,306
Pseudo R^2	0.06	0.06	0.03	0.04

Note: Controls as for Table 4. Values shown are IRRs minus one, robust z-statistics in parentheses. +, *, ** significant at the 10%, 5%, 1% level.
Source: Authors' calculations using BERD, ARD-ABI (*Source*: ONS), RAE, NSPD and NOMIS data.