Proximity and the Use of Public Science by Innovative European Firms

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Abstract

We use the results of a 1993 survey of Europe’s largest firms to explore the effect of proximity on knowledge flows from suppliers, customers, joint ventures, competitors and public research organisations to innovative firms. The focus is on the latter, since they are an essential component of National Innovation Systems. The importance of proximity for sourcing knowledge from public research increases with the quality and output of domestic public research organisations and declines with activity in the North American market, an increase in the firm’s R&D expenditures, and the importance of codified knowledge to the firm.

Keywords: Public research, knowledge flows, tacit knowledge, innovation.

JEL Subject Classification: H4, L3, O3

Introduction

Theories of National Innovation Systems (Nelson, 1993; Lundvall, 1992) and interactive and chain-link models of innovation stress the importance of flows of knowledge and information to the ability of firms to innovate (Kline and Rosenberg, 1986; Freeman, 1987). Within this framework, economic theory and empirical research have focused on knowledge flows between firms (Hagedoorn et al., 2001; Lundvall, 1992) and between firms and public research organisations such as universities, technical institutes, and government laboratories or research institutes (Mansfield, 1991; Mansfield and Lee, 1996; Pavitt, 1991). The empirical evidence shows that both types of knowledge flows make a substantial contribution to innovation and, consequently, to public welfare. Estimates of the rate of return to publicly funded research, for example, range between 20% and 60% (Salter and Martin, 2001).

With a few exceptions (Henderson et al., 1994), empirical research suggests that geographic proximity favours knowledge flows between knowledge producers and innovators. However, due to data limitations, most research in this area has been unable to provide direct evidence for the exchange of knowledge or to investigate why distance might matter. A National Innovation System approach suggests that there must be more to proximity than physical distance alone. Cultural and linguistic similarities could also influence knowledge flows, particularly if the value of proximity is due to the need for direct personal contacts to access tacit knowledge (Maskell and Malmberg, 1999; Leamer and Storper, 2001).

We use the results of the PACE survey of Europe's largest industrial firms to explore the effect of a broad definition of proximity, including cultural and linguistic factors, on knowledge flows. We define 'knowledge flows' to include both knowledge that is transferred via market mechanisms and true knowledge spillovers. Proximity is defined by the importance firms give to knowledge obtained from domestic versus foreign sources. In Europe, the latter will involve different cultures or languages. Due to its policy relevance, our primary focus is on knowledge obtained from public science, defined here as universities and public research institutes, although we compare the subjective importance of several knowledge sources outside the firm. We then develop an ordered logit model to evaluate the effect of several factors on the importance of proximity for the flow of knowledge from public science to firms. The independent variables include a measure of the importance of codified, basic research results to the firm as a substitute for a measure of tacit knowledge. In addition, the model includes a variable for the amount of relevant research output by public science in the same country as the firm.

This paper is organised into five sections. The theoretical and empirical background is presented in Section 1. Section 2 describes the data sources, while descriptive results are given in Section 3. Section 4 provides the econometric model of the importance of proximity for the transfer of knowledge from public science to firms. Conclusions and policy implications are discussed in Section 5.

1. Theoretical and empirical background

Empirical research on knowledge flows between public science and private firms has primarily addressed two issues, both of which are relevant to the design of public policies to support national research infrastructures. The first issue is the value of public science to the innovative activities of firms, particularly in comparison to alternative sources of knowledge. The second issue is the effect of proximity on the ability of firms to acquire knowledge from public science and other sources. A third issue, which has only been examined in a few studies, concerns the methods that firms use to access the results of research produced by public science and how these methods could mediate proximity effects.

1.1 Value of public science to innovation

The importance of public science to the innovative activities of firms has been explored through production function models that use patents or product announcements as the dependent variable, analyses of patent citations, case studies, and surveys of the subjective importance given by R&D managers to public science as a source of knowledge. These methods vary in their ability to identify the actual use of public research outputs by firms.

Two studies based on production function models, either using the number of patents as a proxy for innovative output (Jaffe, 1989) or the number of announcements of product innovations in newspapers and trade journals (Acs, et al, 1992), found that innovative outputs increase with university research expenditures in the United States. The cause of the relationship, however, is not known. It could be due to a positive correlation between university spending and the use of public research results by firms, or between spending and the supply of trained scientists and engineers.

Analyses of patent citations find that academic papers and university patents are more frequently cited than their equivalents from private firms, suggesting that public science is an important input for the innovative activities of firms (Jaffe *et al.*, 1993; Narin *et al.*, 1997; Malo and Geuna, 2000; Verspagen, 1999). However, the cited research or patent may not have contributed to the invention if the citation was only included to build the patent claim or added by the patent examiner. Conversely, patent citations could underestimate the contribution of public science to innovation if firms use other methods, such as interpersonal contacts, to source knowledge from public science.

Case studies and surveys provide a direct, albeit subjective measure of the contribution of public science to innovation. Mansfield (1991) interviewed the R&D managers of 76 large American firms in seven manufacturing industries. Only about 10% of new products and processes introduced between 1975 and 1985 could not have been developed, without a delay of over a year, in the absence of academic research within 15 years of commercialisation. These results were confirmed in an update covering innovations introduced between 1986 and 1994 (Mansfield, 1998). Beise and Stahl (1999), using 1997 survey results for 2,300 firms in Germany, estimated that 5% of new product sales in manufacturing were for products developed with the assistance of public research. The Yale survey of large R&D performing firms in the United States in the early 1980s found that university-based research was less important than other sources of scientific output (Klevorick *et al.*, 1995). The largest and most representative innovation surveys to date are the 1993 and 1997 European CIS surveys. Both found that public research is one of the least important sources of information for the innovative activities of firms (Arundel and Steinmueller, 1998; Arundel et al 2000).

1.2 Geographical proximity

In recent years, academic research has revisited some of the issues raised by Marshall (1920) on the geography of economic activity, including the effect of location on knowledge flows from public science to innovative firms. Studies using either the production function method (Acts *et al.* 1992; Audretsch and Feldman, 1996) or patent citations (Jaffe et al, 1993) found that knowledge spillovers from academic research to private firms were highly localised at the regional or state level. Similar results are found in detailed case studies of high technology clusters in the United States, such as Saxenian's (1994) study of Silicon Valley.

Several studies have used surveys to explore the effect of distance on knowledge flows between public science and firms. Mansfield and Lee (1996) report that firms prefer to work with local university researchers within 100 miles of the firm's R&D laboratory. Firms are reluctant to support research at universities 1000 or more miles away. Beise and Stahl (1999) explore the effect of distance using the survey results for 2,300 German firms. Their main result is that geographical distance did not influence the sourcing of outputs from public science, but this could have been due to much shorter distances in Germany than in the United States.

In contrast to most of the available research, Adams (2001) investigated the relationship between distance and how firms acquire external knowledge from both public and private sources, using the results of a 1997 survey of 208 private R&D

laboratories in the United States. The survey obtained data on four methods for obtaining knowledge from academic research (outsourcing research, faculty consulting, licensing university patents, and hiring engineering graduates) and four methods for obtaining knowledge from private research (outsourcing research, joint research, publications, and patents). Adams correlated a subjective measure of the importance of knowledge obtained via each method with a localisation indicator; the ratio between the log of the amount spent on learning about local (less than 200 miles) versus distant results of academic or private research. Two of the four methods for learning about private research, publications and patents, were negatively correlated with the localisation indicator, while all four methods for learning about academic research were positively correlated with the localisation indicator. Adams concludes that university-firm interactions tend to be more localised than interactions with other private firms.

1.3 Why should proximity matter?

The empirical evidence in support of localised knowledge flows requires an explanation for why such flows are encouraged by geographical, cultural, or linguistic proximity. The explanation offered in most of the literature focuses on the value of direct, inter-personal contacts, primarily in order to acquire tacit knowledge (Quintas, 1992; Faulkner *et al.*, 1995; von Hippel, 1987; Maskell and Malmberg, 1999). Therefore, the value of proximity should decline when useful knowledge is in a codified form, such as in patents and publications, and increase when useful knowledge is only available in tacit form, requiring personal contacts. Though distinct, these two forms of accessing knowledge are not complete substitutes. Some degree of personal contact might be necessary even when information is available in publications and patents since both these sources could omit information that is crucial to the full understanding of research results. Conversely, for someone ‘skilled in the art’, it may not matter if a sizeable portion of the necessary knowledge is not codified, since the codified information may provide enough information to pursue the research.

Imai (1991), Antonelli (1999), and Roberts (2000) argue that modern information and communication technologies, lower costs for codifying knowledge, and stronger intellectual property rights, are reducing the need for proximity while simultaneously increasing the ability of firms to obtain knowledge from outside the firm. These developments suggest that knowledge production and use are becoming increasingly globalised, resulting in a decline in the importance of proximity to access tacit knowledge. Perhaps the best example of innovation via completely codified knowledge is the collective development of Linux software, where problems, software code and information are shared almost entirely by email (Cowan and Jonard, 2000). Conversely, Senker (1995) proposes that most rapidly developing and complex technologies will always depend on tacit knowledge and, consequently, on inter-personal mechanisms for knowledge flows. This proposal is supported by Saviotti’s (1998) model in which the degree of knowledge codification is inversely correlated with the distance from the technological frontier. High technology firms active on the frontier are able to create temporary monopolies due to the low rate of dissemination of tacit knowledge to other firms. The economic benefits that flow from the appropriation of tacit knowledge - by firms that are capable of innovating at the frontier - should ensure that these firms invest in knowledge gathering methods that permit the transfer of tacit knowledge.

There are two main criticisms of the 'tacit' knowledge explanation for proximity effects. Breschi and Lissoni (2001) note that other factors such as labour markets could explain the importance of proximity. The second criticism comes from Cowan, David and Foray's (2000) theoretical evaluation of 'tacit' versus codified knowledge. They suggest that very little knowledge is intrinsically tacit in the sense that it is impossible to codify. Instead, much of what is believed to be 'tacit' could be codified if economically worthwhile, while other knowledge appears to be tacit only to the uninitiated. However, the latter criticism, although raising doubts about the role of tacit knowledge *per se,* does not counter a need for direct, personal contact in order to effectively transfer knowledge. This is because proximity could be advantageous even when knowledge is not intrinsically tacit. When knowledge is neither codified nor publicly accessible to a firm's researchers, it becomes crucial to understand who knows what – where the new knowledge is. In this context, proximity could matter because direct, personal contacts allow a company faster and more successful access to knowledge gatekeepers to discover where and how to access new knowledge. At the same time, codified research outputs, such as papers and patents, can 'signal' the location of academics conducting research of value to firms.

To conclude, research to date has identified the importance of public science to innovation and the role of proximity to the transfer of knowledge from public science to firms. However, there are several limitations to this research. First, evidence for the transfer of knowledge from public science to firms is often indirect or circumstantial.

Furthermore, only a few studies could compare the value of public science to alternative knowledge sources. Second, proximity is usually defined by geographical distance, excluding linguistic or cultural factors that could form an important component of national innovation systems. This is partly because most of the available research is from the United States. Third, very few studies have been able to explore the methods firms use to acquire the results of public science and how these methods might mediate the influence of proximity. Of particular importance are methods based on codified and tacit (or non-codified) knowledge. Each of these three limitations are addressed through an analysis of the PACE survey.

2. Data Sources

The 1993 PACE survey of Europe's largest R&D-performing industrial and manufacturing firms (outside of France[1]) covers innovative activities between 1990 and 1992. The response rate was 55.6%, with a maximum of 615 useable responses. Almost all responses were from R&D managers, who were asked to complete the questionnaire for their 'area of responsibility'. For firms active in more than one product area, PACE sampled at the business line level. For simplicity, we refer to each 'business unit' or 'division' as a firm. Thirty responses were excluded because the respondent gave results for the entire firm rather than for his or her area of responsibility. All firms were assigned to low, medium and high technology classes

[1] The French section of the PACE survey was conducted by SESSI and used question formats for knowledge sources that are not comparable to those for other European countries.

following the OECD's definition.[2] Further details on the PACE survey are available in Arundel et al. (1995).

Most of the results presented here are limited to 473 firms that answered a question on R&D expenditures and which were active in manufacturing or utilities. These firms account for an estimated 60% of all R&D spending by firms in the European Union in 1992.

Two sections of the PACE questionnaire ask about knowledge flows. The first question asks "How important to the innovative activities of your unit is technical knowledge obtained from the following sources?" Six sources are listed: public research institutes and universities, affiliated firms, joint or cooperative ventures, suppliers, customers, and 'technical analysis' (reverse engineering) of competitor's products. The second question asks "How important to the innovative activities of your unit is technical knowledge obtained from each of the above six sources by region? Four regions are given: the European country in which the firm is located (the

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[2] The technology class definitions are as follows, with the ISIC (3rd revision) code given in parentheses. The low technology class includes food & beverages (15), tobacco (16), textiles and leather (17 - 19), wood products (20), paper and printing (21), petroleum products (23), ferrous metals (27), fabricated metal products (28), other manufacturing (36) and utilities (40). The medium technology class includes automobiles (34), chemicals other than pharmaceuticals (24), plastic and rubber products (25), non-ferrous mineral products (26), and machinery (29). The high technology class includes pharmaceuticals (2423), office equipment and computers (30), electrical equipment (31), telecom equipment (32), precision instruments (33), aerospace (35.3), and trains (35.2). In Europe, train manufacturers more closely resemble high technology than medium technology firms.

‘domestic’ country), other European countries, North America, and Japan[3]. PACE also includes a question on the importance of four different outputs of public research and a question on seven different methods for learning about public research results.

Responses to all four of these question groups are measured on a five-point ordinal scale, ranging from 1 or ‘not important’ to 5 or ‘extremely important’. The descriptive statistic that we use to evaluate these questions is the percentage of firms that give their *highest* score to each variable. The distribution of the highest scores is preferred to the means or the percentage of firms that rate each source as ‘very’ or ‘extremely’ important because the highest score avoids problems of inter-rater differences in the meaning of the ordinal importance scale. Instead, we make a reasonable assumption that respondents give internally consistent responses. For instance, we assume that a respondent that gives a score of 4 to public research and a score of 3 to the five other knowledge sources finds public research to be the most important of these six sources. Unless stated otherwise, tied high scores are equally distributed among the relevant sources, so that the percentages across all questions in a group sum to 100%. This provides an easy to interpret measure of the relative importance of each knowledge source or other variable.

Most of the descriptive results are weighted by the R&D expenditures of each firm, in order to adjust for a proxy of innovative output, assuming a positive correlation between the expected economic value of innovations and R&D expenditures. For

[3] Firms can also source information from countries outside of these four regions, such as South-East Asia or Latin America, but the CIS results show that less than 2% of firms are involved in research cooperation outside of the four main areas covered by PACE.

example, R&D weighting gives a firm that spends 20 million Euros on R&D twice as much weight in the calculation of the distribution of the highest scores as a firm that spends 10 million Euros on R&D.

Some of the PACE results are compared to two other surveys. First, we use the 1997 CIS to verify the PACE estimates of the general importance of public research as a source of knowledge for the firm's innovative activities. Second, the PACE questions on public research are similar to questions in the 1994 Carnegie Mellon Survey (CMS) of R&D-performing firms in the United States (Cohen et al., 2002). Although minor differences in the PACE and CMS questions prevent direct comparisons, we compare the PACE and CMS results for the methods that firms use to acquire the results of public science.

3. Descriptive results

3.1 The relative importance of public science

Table 1 shows the distribution of the highest scores, by technology class, for public science plus five other external sources of technical knowledge. The pattern of the results is similar when not weighted by R&D, although the value of public science compared to several other sources decreases.

[Insert Table 1 here]

The results show that 24.2% of the R&D-weighted firms give their highest score to public science, with all other sources cited less frequently. The value of public science as a knowledge source is particularly marked among high technology firms, with

36.9% of these firms giving their highest score to public science. More low than medium technology firms give their highest score to public science, which corroborates some of the results of Beise and Stahl (1999) for Germany.

These results contrast sharply with the findings of the CIS. Less than 5% of respondents to the second CIS, covering innovative activities between 1994 and 1996, gave their highest score to public science (Arundel *et al*., 2000). The results of the CIS and similar innovation surveys have been widely cited to show that public science is of little importance to the innovative activities of firms. For example, the 1998 OECD report, *The University in Transition*, concludes that firms "rely little on university (and public) laboratories as a source of information and stimulus for their innovative efforts". Similar conclusions are drawn in a report sponsored by the European Commission on industry-science relations (EC, 2001).

There are two main explanations for the large differences between the importance of public science in PACE and the published research based on the CIS. First, PACE is limited to Europe's largest firms, which are more likely than smaller firms to use knowledge obtained from public science (Mohnen and Hoareau, 2002). Second, the published results from the CIS are not weighted by a proxy for innovation outputs, which means that the results largely measure the importance of public science to smaller and less innovative firms, which make up the vast majority of CIS respondents.

We investigated the differences in the PACE and CIS results by applying the same analysis to a similar group of firms from three sectors with more than 50 PACE respondents: food, chemicals, and machinery.[4] The CIS respondents were limited to R&D performers with over 500 employees in order to match the PACE respondents, although the PACE firms were still substantially larger. All results are weighted by R&D expenditures. In the food sector, 24% of PACE respondents versus only 3% of CIS respondents gave their highest score to public science ($p < .001$). However, the results are similar in chemicals (34% for CIS and 30% for PACE) and in machinery (20% for PACE and 17% for CIS). These results show that analytical methods that do not take account of firm size effects and which do not weight by a proxy for innovative output can underestimate the contribution of public science to innovation.

3.2 Proximity and the use of knowledge from public science

For each of five external knowledge sources (excluding affiliated firms), we constructed a proximity variable that measures the relative importance of domestic sources of technical knowledge over foreign sources. For example, the variable PROXPR for public research is defined as follows:

[4] The CIS results are based on 106 food, 152 chemical, and 193 machinery firms from six countries: Germany, France, Italy, Ireland, Norway and Sweden. The PACE results are for 56 food, 134 chemical, and 54 machinery firms. For comparability with PACE, the analyses were limited to four sources covered in both surveys: affiliated firms, suppliers, customers, and public science. The latter group includes the CIS questions on 'universities' and 'government laboratories'. Since the CIS used a three-point scale versus PACE's five-point scale, we assumed that a score of either 4 (very important) or 5 (extremely important) in PACE was equal to the CIS score of 3 (very important). The percentages given in the text distribute tied scores equally among the relevant external sources.

PROXPR = 0 if the importance of public research in the domestic country is *lower* than its importance in *at least* one foreign location.

PROXPR = 1 if the importance of public research in *any* other country is *equal* to its importance in the domestic country but never exceeds the domestic score.

PROXPR = 2 if the importance of public research in the domestic country is *greater* than its importance in *any* other country.

Table 2 gives equivalent results for the five external sources of technical knowledge (weighted by R&D expenditures). The sourcing of technical knowledge from public science is the most affected by proximity: 46.6% of firms rate domestic public research as more important than foreign, while only 5.1% consider domestic public research to be less important than foreign research. Proximity also affects the importance of the four other knowledge sources, but to a lesser degree. Only 4% of the firms give greater importance to domestic sources for the technical analysis of competitor's products. This result confirms the reliability of the data, as this mechanism for acquiring new knowledge should be largely unaffected by geographical, cultural or linguistic proximity.

[Insert Table 2 here]

3.3 Methods of accessing public science

The PACE questionnaire asks firms about the importance to innovation of four public research outputs and seven methods for learning about public research. The most important output is ‘specialised or applied knowledge’, ranked highest by 44.8% of the R&D weighted firms, followed by ‘general knowledge obtained from basic research’ (25.5%), ‘new instrumentation and techniques’ (20.4%), and lastly ‘early versions of prototypes of new product designs’ (9.3%). The unweighted results are very similar. The high value attributed to applied knowledge confirms the results of the Yale survey from the early 1980s (Klevorick *et al*., 1995).

The seven methods for learning about public research outputs include both codified sources, such as reading publications and technical reports and attending public conferences and meetings, and methods based on direct contacts that could permit access to non-codified knowledge. The latter include hiring trained scientists and engineers, informal personal contacts, and personnel exchange programmes. Two additional questions enquire about contract research (the public research organisation conducts the research) and joint research projects. Both of these methods could exchange non-codified information, although joint research would conceivably be more productive in this respect.

Only 1% of the R&D weighted firms give their highest score to personnel exchanges. The most important methods are hiring (26.0%), informal contacts (22.1%), and contracted out research (19.1%). As shown in Table 3, there are notable differences by technology class, with firms active in high technology sectors preferring methods that allow the transfer of tacit knowledge, such as informal personal contacts and hiring, while a comparatively higher percentage of firms in low technology sectors prefer contract research and the two codified sources of conferences/meetings and publications. These results partially support Senker's (1995) conclusion that firms in high technology sectors are more likely than low technology firms to need to access non-codified knowledge (in her view the 'tacit' component) held by public science.

[Insert Table 3 here]

The CMS survey in the United States also investigated the importance of different methods of obtaining the results of public research, although it differs from PACE in asking about three additional methods, using a four-point scale, and limiting the responses to a 'recent major' innovation project. Cohen *et al.* (2002) give unweighted CMS results for the percentage of American R&D lab managers that scored each method 'moderately important' or 'very important'. We applied a similar method to the PACE data and then compared the rank order for the importance of each method. In both surveys, publications and technical reports are in first place (most frequently cited as important), informal contacts are ranked second, public conferences and meetings are ranked third, and temporary personnel exchanges are in last place. The rank order for hiring, contract research, and joint research differs between the two surveys. Cohen *et al.* conclude that the first, second and third place results for longstanding methods of information exchange point to the importance of 'open science', in contrast to the current policy emphasis on more formalised methods such as contract research. The PACE results concur with this conclusion.

The unweighted PACE results for the percentage of firms that gave their highest scores to each method of accessing information from public science were also compared with the relative importance of knowledge obtained from domestic and foreign public science (PROXPR). The percentage of firms that gave their highest score to publications does not differ significantly (p = .11) by the three categories of PROXPR[5]. Surprisingly, there are also no significant differences for informal personal contacts (p = .33), which we expected to be more important to firms that prefer domestic public science. However, 18% of firms that prefer foreign public science gave their highest rating to temporary personnel exchanges, compared to 7.5% of firms that prefer domestic public science (p = .03). This would be one method of obtaining tacit knowledge from afar. Conversely, a significantly lower percentage of firms that prefer foreign public science versus those that prefer domestic public science gave their highest score to hiring trained scientists and engineers (24% versus 37%, p = .05) and attending public conferences and meetings (18% versus 30%, p = .01). These results show that the relationship between the methods for sourcing non-codified knowledge from public science and the importance of proximity is complex. Firms can use one method to provide access to non-codified knowledge close to home and another method to provide access to culturally or geographically ‘distant’ expertise.

4. Econometric model of proximity

We use an ordered logit model to evaluate the effect of firm-specific, sector-specific and country-specific factors to the relevance of proximity for the transfer of

[5] Statistical significance calculated by chi-square, using each of the three options for PROXPR. The percentages in the text do not adjust for tied scores.

knowledge from public science. The dependent variable is PROXPR, as defined above.

4.1 Firm-specific independent variables

We expect larger firms to find it easier than smaller firms to access information from abroad, due to their greater financial resources. We capture this effect through the natural log of the firm's R&D expenditures (LNR&D). In addition, familiarity with foreign countries could increase awareness of the output of foreign public science and decrease the costs of accessing these outputs. Two groups of variables evaluate this effect. First, the dummy variable HOMEOFF is equal to 1 if the firm's head office is located in the domestic country and 0 otherwise. Second, firms that sell products in foreign markets are probably more familiar with local conditions. Three dummy variables account for presence in the North American (AMERICA), Other European (EUROPE) or Japanese (JAPAN) markets. They are equal to 1 when the firm is active in the foreign market and 0 otherwise.

R&D intensive firms could be more likely to go abroad for information because they are active at the technological frontier and must seek out expertise wherever it is available. Examples include firms active in pharmaceuticals, optics, and information technology. To test for this effect, we include a variable for the R&D intensity of the firm (RDINT), based on the ratio between R&D expenditures and sales.

Several attempts were made to construct a variable to measure the importance to the firm of accessing public research results via codified sources, such as publications, versus ‘tacit’ methods, such as informal contacts, hiring, or temporary exchanges of personnel. None of these relative measures of codified versus tacit sources had any effect in a series of preliminary analyses. We suspect that the explanation for this is that firms use different methods to access non-codified knowledge from distant versus proximal public science, as noted above. As an alternative, we constructed a variable, CODIFY, that equals the importance to the firm of publications as a method for accessing public research results times the importance of basic research carried out by public science. Since both variables are measured on a five-point scale, CODIFY can vary from 1 to 25. Firms with a high value of CODIFY are likely to give a high level of importance to published basic research.

4.2 Sector and country level variables

The descriptive results show that the firm’s technology class influences both proximity effects and the methods used to source knowledge from public science. One of the models, therefore, includes dummy variables for the firm’s sector of activity at either a two-digit or four digit ISIC level (DISIC), with pharmaceuticals as the reference category. Sectors with very few representative firms (less than 10) are excluded, which results in the loss of 40 firms, leaving up to 443 firms in 16 sectors[6].

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[6] The 16 sectors are telecom equipment (32), aerospace (35.3), pharmaceuticals (2423), office machinery and equipment (30), instruments (33), electrical equipment (31), automobiles (34), chemicals excluding pharmaceuticals (24), plastics and rubber products (25), machinery (29), non-ferrous mineral products (26), food (15), petroleum products (23), ferrous metals (27), fabricated metals (28), and utilities (40).

We expect the quantity and quality of a country's research output to positively affect the importance of domestic versus foreign public science. Two variables capture these effects.

PUBSHARE is based on the Institute for Scientific Information's (ISI) National Science Indicators (NSI) database of the number of science publications by field and country. The main problem is to limit PUBSHARE to papers of relevance to the firm's innovative activities. This problem was solved by creating a concordance table between the NSI's classification of papers into 102 scientific fields, corresponding to the ISI's *Current Contents* categories, and the 16 industrial sectors. Of the 102 scientific fields, 67 were considered relevant to these sectors. Several scientific fields were relevant to more than one of the 16 industrial sectors.[7] PUBSHARE equals the total number of relevant ISI-SCI papers between 1986-1990 by country and of relevance to the firm's industrial sector, divided by the total number of relevant papers in the world.

PUBSHARE measures the overall quantity of scientific research in each country that is of relevance to the firm's sector. It is also a proxy for the supply of domestic scientists and engineers that can provide access to non-published knowledge. Traditional bibliometric indicators based on citations are less relevant for an analysis of knowledge flows from public science to firms because they measure the academic impact of publications.

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[7] The concordance table is based on expert evaluations and is available from Dr Geuna of SPRU. Similar regression estimations were obtained when we used a second concordance table, based on the BESST database for the publication output of firms in each scientific field (Larsen and Salter, 2001).

A country level variable, HERDGDP, is a proxy for both the availability and quality of a country's public research base. HERDGDP equals the ratio between the total amount of higher education R&D expenditure (5 year average for the period 1986-1990) and the country GDP. Countries with a high value for HERDGDP invest a relatively larger share of resources in public research. Therefore, the importance of proximity should be positively correlated with HERDGDP.

4.3 The ordered logit model

We model the determinants of the effect of proximity on the use of public research with an ordered logit. The ordered logit model estimates the impact of a range of exogeneous variables on a dependent variable which takes a finite set of ordered values (1,2 .. n) (Liao, 1994). The method of estimation is maximum likelihood. The model assumes that the dependent variable y is generated by a continuous latent variable y* whose values are unobserved, in our case the relative value of proximity. The model assumes that there is a set of ordered values ($\mu_1, \mu_2, .. \mu_{n-1}$) and a variable y* such that:

$$
(1) \quad
\begin{aligned}
&y = 1 \text{ if } y^* < \mu_1 \\
&y = k \text{ if } \mu_{k-1} < y^* < \mu_k \text{ for } 1<k<n \\
&y = n \text{ if } \mu_{n-1} < y^*
\end{aligned}
$$

The unobserved variable y* is modelled as a linear function of the (N,k) vector of exogenous variables X:

$$(2) \quad y^*_i = \beta X_i + e_i \quad i = 1,...N$$

where e_i has a distribution function f derived from the logistic cumulative distribution function:

(3) $F(x) = 1/(1+ e^{-x})$

Given the characteristics X_i of individual i, the probability that y_i is found in category k is:

(4) $\text{Prob}(Y_i = 1/Xi) = F(\mu_1-\beta X_i)$
$\text{Prob}(Y_i = k/Xi) = F(\mu_k-\beta X_i) - F(\mu_{k-1} -\beta X_i)$
$\text{Prob}(Y_i = n/Xi) = 1- F(\mu_{n-1} -\beta X_i)$

with n number of categories. In our case, the dependent variable PROXPR has three categories 0, 1 and 2 with increasing importance of proximity.

The model estimates the effect of several firm, sector, and country specific characteristics on the importance to the firm of proximity for sourcing knowledge from public science. The model does not explain the importance to the firm of the knowledge obtained from public science. For this reason, the estimation is not affected by problems of endogeneity.

The ordered logit equation is estimated for the following three forms:[8]

(5) $PROXPR = 1- F(\mu-\beta_1 LNR\&D-\beta_2 AMERICA-\beta_3 CODIFY -\beta_4 PUBSHARE-\beta_5 HERDGDP)$

(6) $PROXPR = 1- F(\mu-\beta_1 LNR\&D-\beta_2 AMERICA-\beta_3 CODIFY -\beta_4 PUBSHARE-\beta_5 HERDGDP-\beta_6 RDINT-\beta_7 HOMEOFF- \beta_8 EUROPE-\beta_9 JAPAN)$

(7) $PROXPR = 1- F(\mu-\beta_1 LNR\&D-\beta_2 AMERICA-\beta_3 EUROPE -\beta_4 JAPAN -\beta_5 CODIFY-\beta_6 PUBSHARE-\beta_7 HERDGDP-\beta_8 HOMEOFF-\Sigma_j\beta_j DISIC_j)$

[8] We also estimated different versions of the model that included country dummies (only included in the model when country specific information such as HERDGDP are excluded).

There is only one μ estimate because for three categories n-2 = 3-2 = 1, with the first μ normalised to be zero and j=1…15, given 15 sector dummies (DISIC).

4.4 Model results

Table 4 gives the three ordered logit results. The first model correctly predicts the dependent variable for 56% of the firms, while the third model correctly predicts 60%. The highly significant, positive μ (M) estimate indicates that the three categories in the responses are indeed ordered.

[Insert Table 4 here]

In all three models, the importance of proximity declines with absolute R&D expenditures (LNR&D), showing that firms with large financial resources for R&D are less constrained by proximity than other firms. Conversely, neither R&D intensity (RDINT) nor the location of the home office (HOMEOFF) influences the importance of proximity. R&D intensity was also included in a version of the third model with sector dummies, but it did not have a statistically significant effect. R&D intensity is not included in the final version of model 3 because its inclusion results in a loss of 53 firms, due to missing sales data.

Activity in the European (EUROPE) or Japanese (JAPAN) markets also does not influence the probability that the firm will find proximity of importance, but activity in the North American market (AMERICA) significantly reduces proximity effects. One possibility is that the results for AMERICA are distorted by UK firms, which are culturally and linguistically closer to North America than firms based in other countries, or by pharmaceuticals firms, which are more likely than other firms to go to the United States for new knowledge, particularly in biotechnology (Senker et al, 1996; Patel and Pavitt, 2000). To check for these possibilities, the regressions were rerun after 1) excluding the pharmaceutical sector and 2) excluding the UK. In both of these regressions the coefficient for AMERICA was statistically significant and negative, showing that activity in the North American market has a robust effect in reducing the importance of proximity.

The measure of the importance to the firm of codified outputs of public research (CODIFY) is negative and statistically significant in the first model. This indicates that firms that seek codified basic research outputs are less likely to find proximity of importance. One explanation for this effect is that codified knowledge can be obtained at low cost from distant locations. Of interest, the effect of CODIFY is no longer statistically significant once sector dummies are included, suggesting that the importance of codified outputs from public science varies by sector. This should not come as a surprise, since the importance of basic research to firms and the availability of useful results in publications varies by sector. For example, the highest mean value of CODIFY (which can vary from 1 to 25) is 18.1 for the pharmaceuticals sector, while the lowest mean values are 8.5 in fabricated metals and 8.9 in aerospace.

Both PUBSHARE and HERDGDP have a positive and significant effect on the importance given to proximity. This shows that the scientific "competencies" of a country’s research output affects the relative importance of domestic and foreign sources of public research outputs. It is important to note that PUBSHARE partially reflects the economic and population size of each country, insofar as larger countries produce more publications.

An alternative version of each model replaced the country level variable HERDGDP with the geographical size (in hectares) of each country. Country size could influence the importance of proximity if firms based in small countries find it less costly to go abroad because the average distance from domestic firms to foreign public science is lower than for large countries. Or, firms based in small countries might need to go abroad because small countries lack the funds to support public research in all fields. However, country size had no effect in any of the models. There are two possible explanations for this; either the measure is too crude to adequately capture the effect of geographical distance or cultural or social effects are more important than geographical distance.

Table 5 gives the marginal effects at mean values for the first model estimation. A one unit change in LNR&D, equal to 16.7 million Euros, results in a 2.6% decrease in the proximity effect (the probability that the firm finds domestic public research to be more important than public research in any other location). Firms that are active in the North American market are 14.8% less likely than other firms to find domestic public science to be of greater value than public science in other countries.

[Insert Table 5 here]

The two variables for output and investment in domestic public science have a comparatively large impact on the proximity effect. For instance, a relatively small increase of about 70 million Euros in national expenditures on higher education R&D (equal to a 1% change in the average HERD for all countries in the regression) results in an increase of 1.1% in the probability that the firm finds domestic public research to be more important than public research in any other location. An analysis of the marginal effects for the variable PUBSHARE for the food sector shows that an increase of about 5,000 papers over the five years preceding the survey increases the proximity effect by 3.2%.

5. Conclusions

Two essential questions for innovation policy are first, whether proximity matters to knowledge flows, and if yes, how these knowledge flows occur and the conditions necessary for their success. Answers to these two questions are relevant to a range of policies that have been introduced by governments, particularly in Europe, to support close linkages between firms and public science. These policies include subsidies to encourage the regional development of clusters of innovative firms, subsidies for firms to collaborate with public science, and the establishment of science parks close to universities.

The descriptive results presented above provide direct evidence, although based on the subjective judgement of R&D managers, that public science is not only an important source of technical knowledge for the innovative activities of Europe's largest industrial firms, but the most important of five external knowledge sources, after adjusting for a proxy measure of innovative output. Other sources of knowledge, such as suppliers and customers, are of less importance overall, although suppliers are a more important source of knowledge for firms active in medium technology sectors.

These results on the general importance of public science are relevant to science and technology policy, particularly because proximity effects are more pronounced for public science than for the four other external knowledge sources. Only about 5% of R&D weighted firms find knowledge obtained from foreign public science to be of greater value to their innovative activities than knowledge from domestic public science, while almost half find the output of domestic public science to be more valuable than the output of foreign public science. The ordered logit models show that proximity effects decline with an increase in the firm's R&D expenditures and with experience in the North American market, but increase with the quality and availability of outputs from public science in the firm's domestic country. These results point to the need for a well-funded national public research base. This could be particularly important for firms that lack the financial resources or capabilities to source knowledge abroad.

The most frequently cited explanation for proximity effects is the need to acquire tacit knowledge, or at least knowledge that is not yet codified. Firms use a variety of methods to acquire different types of knowledge from public science, including some that provide access to codified knowledge, such as reading publications or attending conferences, and methods that provide the opportunity to access non-codified knowledge, such as informal personal contacts, joint research, and hiring trained scientists and engineers. In general, firms prefer methods that provide the opportunity for accessing non-codified knowledge. However, exploratory econometric analyses did not find that these methods increased the importance of proximity to public science. In part, this is due to the complexity of the methods available to firms for accessing non-codified research. Firms can use one method for foreign public science and a separate method for domestic public science. In contrast, firms that attach a high importance to basic research results in publications (CODIFY) are less likely than other firms to give a higher importance to knowledge sourced from domestic versus foreign public science. This is partly due to sectoral differences in the importance to firms of this type of codified knowledge. Nevertheless, the role of proximity declines when useful knowledge is available in a codified form. This suggests that new information technologies that increase the amount of codified knowledge produced by public science, and decrease the time between discovery and codification, could reduce the importance of proximity.

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Table 1

Percent of firms giving their highest score to six external sources of technical knowledge for innovation

	Technology sector			
	Low (160 firms)	**Medium (187 firms)**	**High (126 firms)**	**All firms**
Public research	30.7	11.9	36.9	24.2
Affiliated firms	19.0	24.7	18.0	21.3
Customers	16.6	23.5	6.2	15.6
Reverse engineering	13.6	16.0	12.4	14.2
Joint ventures	13.1	8.3	20.1	13.8
Suppliers	7.0	15.6	6.4	10.9
Total	*100*	*100*	*100*	*100*

Note: Weighted by R&D expenditures. Tied scores are distributed equally among the relevant knowledge sources.

Table 2

Percent of firms rating domestic sources of technical knowledge as less important, of equal importance, and of more importance than foreign sources

	Domestic less important	Domestic and foreign equal	Domestic more important	Total
Public research	5.1 (1.0)	48.3 (2.3)	46.6 (2.3)	100
Customers	15.5 (1.7)	64.3 (2.2)	20.2 (1.9)	100
Reverse engineering	31.2 (2.2)	65.2 (2.2)	3.6 (0.9)	100
Joint ventures	37.5 (2.3)	43.3 (2.3)	19.2 (1.8)	100
Suppliers	22.6 (1.9)	38.4 (2.3)	39.0 (2.3)	100

Note: Weighted by R&D expenditures. Standard errors in parentheses.

Table 3

Percent of firms giving their highest score to seven methods for learning about public research outputs

	Technology sector			
	Low (159 firms)	**Medium (188 firms)**	**High (127 firms)**	**All firms**
Hiring trained scientists/engineers	15.2	28.2	36.2	26.0
Informal personal contacts	20.8	17.0	31.4	22.1
Contracted-out research	25.9	23.1	4.7	19.1
Joint research projects	11.0	13.5	9.8	11.7
Publications	13.3	10.0	9.1	10.9
Attending conferences & meetings	11.9	8.1	7.9	9.3
Temporary personnel exchanges	2.0	0.1	0.9	1.0
Total	*100*	*100*	*100*	*100*

Note: Weighted by R&D expenditures. Tied scores are distributed equally among the relevant methods.

Table 4

Ordered Logit Model Estimates for Proximity

	1 ß (t ratio)	2 ß (t ratio)	3 ß (t ratio)
LNR&D	-0.106 (-2.284)**	-0.153 (-2.792)***	-0.108 (-2.008)**
RDINT		-0.004 (-1.550)	
AMERICA	-0.596 (-2.837)***	-0.768 (-2.599)***	-0.740 (-2.430)**
EUROPE		-0.063 (-0.171)	0.100 (.291)
JAPAN		0.384 (1.493)	0.359 (1.333)
CODIFY	-0.033 (-2.148)**	-0.027 (-1.659)*	-0.024 (-1.398)
PUBSHARE	0.130 (3.933)***	0.133 (3.797)***	0.164 (4.538)***
HERDGDP	0.046 (3.642)***	0.048 (3.521)***	0.051 (3.542)***
HOMEOFF		0.400 (1.097)	0.250 (.679)
SECTOR DUMMIES[1]	No	No	Yes
Constant	1.779 (3.251)***	1.746 (2.173)**	0.065 (0.072)
?	2.594 (14.179)***	2.639 (12.940)***	2.771 (13.937)***
LL	-389.83	-339.61	-370.64
Model significance	P < .000	P < .000	P < .000
No. of firms	443	390	443

*** statistically significant at p. <.01;
** statistically significant at p. <.05;
* statistically significant at p. <.10.
1: Pharmaceuticals is the reference category.

Table 5

Marginal Effects for the first model estimation

	Foreign > domestic (PROXPR=0)	Domestic = foreign (PROXPR=1)	Domestic > foreign (PROXPR=2)
LNR&D	0.0078	0.0187	-0.0264
AMERICA	0.0436	0.1048	-0.1484
CODIFY	0.0024	0.0058	-0.0083
PUBSHARE	-0.0095	-0.0229	0.0324
HERDGDP	-0.0034	-0.0082	0.0116
CONST	-0.1300	-0.3127	0.4427