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PROXIMITY AND THE USE OF PUBLIC SCIENCE BY INNOVATIVE EUROPEAN FIRMS

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We use the results of the policies, appropriation and competitiveness in Europe (PACE) 1993 survey of Europe's largest firms to explore the effect of proximity on knowledge flows from affiliated firms, suppliers, customers, joint ventures, competitors and public research organisations to innovative firms. The focus is on the last. First, we find that public science is among the most important sources of technical knowledge for the innovative activities of Europe's largest industrial firms. Then, after comparing the PACE results with the Community Innovation Survey II (1997) and the Carnegie Mellon Survey (1994), we use the unique information from the PACE survey on the geographic location of knowledge sources and the methods used to access them to develop an econometric analysis of proximity and location. The importance of proximity for sourcing knowledge from public research increases with the quality and output of domestic public research organisations and the importance given to public science by the respondents. It declines with an increase in the firm's R&D expenditure, activity in the North American market and the importance to the firm of codified basic research results. Surprisingly, firms that find informal contacts to be an important method for acquiring public research results are more likely to find proximity less important, even though proximity allows firms to access tacit knowledge. This effect is primarily limited to European countries, suggesting the development of a 'European Research Area'.

Keywords: Public research; Knowledge flows; Proximity; Innovation

JEL classification: H4, L3, O3

1 INTRODUCTION

In an innovation environment where 'no firm is an island', successful innovation partly depends on the ability of firms to acquire technical knowledge from external sources and effectively include this knowledge in their innovation activities (Kline and Rosenberg, 1986; Freeman, 1987). Where firms go to obtain technical knowledge and how they obtain it will be influenced by firm-specific characteristics, such as their internal competences and sector of activity, and by the national innovation system of the country in which they are located (Lundvall, 1992; Nelson, 1993). The latter includes the availability and quality of knowledge produced by other private firms and by the 'public science' infrastructure, consisting of universities and public research institutes. In this article we focus on knowledge flows from public science

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to firms. We define 'knowledge flows' to include both knowledge that is transferred via market mechanisms and true knowledge spillovers.

The flow of knowledge between public science and firms is of current interest to public policy, particularly in Europe where there is a widespread belief that European firms are at a competitive disadvantage compared to American firms because of a failure to commercialise discoveries made by public science (EC, 2001). Two empirically-verifiable issues are of particular relevance here. The first is the importance of public science to the innovative activities of firms, particularly in comparison to other sources of external knowledge, such as suppliers and customers. This is of relevance to policy decisions about the level of support to public science and about the fields of science that deserve support. The second issue concerns where and how firms source knowledge from public science. If firms can go anywhere to obtain the outputs of public science, then a reduction in the national public science infrastructure may not damage the innovative capabilities of a country, as long as public science continues to be supported in other countries and steps are taken to ensure that other essential outputs of public science, such as a supply of trained researchers, are met through other means.

1.1 Importance of Public Science

Several empirical approaches have been used to explore the first issue on the value of public science to innovation. The main methodological problem is ensuring that the outputs of public science, such as inventions and ideas, are actually used as an input into the innovation activities of firms. The simplest approach, using a production function model, essentially correlates university research spending and innovative outputs, as measured by patents or product announcements (Jaffe, 1989; Acs *et al.*, 1992). A more direct method is to analyse patent citations. Several studies find that academic papers and university patents are more frequently cited than their equivalents from private firms suggesting that public science outputs are an important input to private invention (Jaffe *et al.*, 1993; Narin *et al.*, 1997; Verspagen, 1999; Malo and Geuna, 2000). This method is not entirely accurate because the cited research or patent may not have contributed to the invention, with the citation only included to build the patent claim or added by the patent examiner. Furthermore, this method underestimates the value of public science because many innovations are not patented (Arundel and Kabla, 1998).

Case studies and surveys have been used to directly ask managers about their firms' use of public science outputs. The results generally show that public science is a minor input into private innovation. Mansfield (1991, 1998) and Beise and Stahl (1999) used this method to estimate that less than 10% of innovations in the United States and 5% of new product sales in Germany depended, in some way, on public science. 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 Community Innovation Surveys (CIS) in Europe. They found that public research is one of the least important external sources of information for the innovative activities of firms (Arundel and Steinmueller, 1998; Monjon and Waelbroeck, 2003).

1.2 The Importance of Proximity for Sourcing Public Knowledge

The second issue, concerning where firms source public science outputs, has largely been studied in the United States and framed in terms of geographical distance. With a few exceptions (Henderson *et al.*, 1994; Beise and Stahl, 1999), empirical research suggests that knowledge flows from public science to firms decline with geographical distance. Studies using either the production function method (Acs *et al.*, 1992; Audretsch and Feldman, 1996) or patent citations

(Jaffe *et al*., 1993) find that knowledge spillovers from academic research to private firms are highly localised at the regional or state level. Agrawal and Cockburn (2003) report that high levels of university publishing in metropolitan areas in the United States and Canada tend to be matched by high levels of firm patenting in the same technology field and metropolitan area, suggesting co-location of research activities. Mansfield and Lee (1996), using survey results, report that firms prefer to work with local university researchers within a hundred miles of the firm's R&D laboratory. Beise and Stahl (1999) report that geographical distance did not influence the sourcing of outputs from public science by German firms, but this could have been due to much shorter distances applying in Germany than in the United States. Adams (2001) survey of 208 private R&D laboratories in the United States finds that distance is a greater barrier to sourcing knowledge from public science than from firms. Finally, Siegal *et al*. (2003) find that the research productivity of UK firms in science parks (all near a university) is higher than that of a matched sample of firms outside science parks, suggesting real benefits from close physical proximity to universities.

Due to data limitations, most research in this area has been unable to investigate why distance appears to matter.[1] The explanation offered in the theoretical literature and in most of the empirical studies, although untested, focuses on the value of direct, inter-personal contacts in order to acquire tacit knowledge (Quintas, 1992; Faulkner *et al*., 1995; Hippel, 1987; Maskell and Malmberg, 1999; Agrawal and Cockburn, 2003). The importance of being physically close to public science 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.

An academic debate has been growing over the last decade on how tacit and codified knowledge can mediate the effect of distance on knowledge sourcing. Antonelli (1999) and Roberts (2000) argue that modern information and communication technologies (ICTs), which lower the costs of codifying knowledge, and stronger intellectual property rights, are reducing the importance of short distances to access tacit knowledge, while simultaneously increasing the ability of firms to obtain knowledge from outside the firm. Conversely, Senker (1995) proposes that most rapidly developing and complex technologies will always depend on tacit knowledge and, consequently, on close, inter-personal interactions to share knowledge. This will hold even when knowledge can be codified, as long as there is a delay between its discovery and its codification. Under these conditions, it becomes crucial to understand who knows what and where the new knowledge is. In this context, distance could maffer because local, direct, personal contacts allow a company faster and more successful access to knowledge gatekeepers to discover where and how to access new knowledge.

At first sight, distance should be neutral in relation to the use of codified research outputs, such as papers and patents, which can be sourced from anywhere in the world at little cost. However, most codified outputs of public science will not be available domestically within Europe because of the comparatively small share of global public science that is produced within each European country. Therefore, European firms that seek codified outputs from public science should source much of this knowledge from outside their domestic country, although the amount of external sourcing should be negatively correlated with the share of public science that is produced domestically.

1.3 Using the PACE Survey to Explore Public Science and Proximity

We use the results of the policies, appropriation and competitiveness in Europe (PACE) survey of Europe's largest industrial firms to evaluate both the importance of public science to

[1] Breschi and Lissoni (2001) note that other factors such as labour markets partly explain why knowledge activities tend to cluster geographically.

innovation and the role of distance in accessing public science outputs. The PACE survey has two main advantages for addressing these issues compared to other European surveys such as the CIS, or comparable surveys in the United States. First, PACE asks firms about the importance of public science results obtained from four main regions (their own country, other Europe, the United States and Japan). Second, PACE includes a series of questions on the methods that firms use to learn about public science results. These methods differ in the degree to which they offer access to tacit and codified knowledge.

Research on the localisation of knowledge sourcing is largely framed in terms of physical distance because most of the relevant research is from the United States. However, a National Innovation System approach to innovation suggests that 'distance' encompasses more than kilometres. Cultural and linguistic similarities will also play a role, particularly if direct personal contacts are required to access tacit knowledge (Maskell and Malmberg, 1999; Leamer and Storper, 2001). This would be particularly important in Europe, where firms in border regions can be geographically close to a public science institution but separated by a different language and culture. We use the PACE results on the sourcing of public science by location to develop an index for *proximity* that is defined by the importance firms give to knowledge obtained from domestic versus foreign sources. Proximity is thus primarily characterised by differences in cultures or languages between European countries and with the United States, and secondarily by physical distance.

We develop two sets of econometric models to evaluate the effect of firm and country specific factors on the effect of proximity for sourcing knowledge from public science. The independent variables include the importance to the firm of several methods of obtaining the results of public science. This permits a first step towards an evaluation of the effect of tacit or codified knowledge on proximity, since the methods of learning about public science differ in terms of the type of knowledge that they can acquire. In addition, the model includes a variable for the amount of relevant research output by public science in the same country as the firm and a variable for investment in the public science infrastructure. This allows evaluation of the effect of domestic investment in public science on the location of knowledge sourcing.

The first set of models uses ordered logit and binary logit equations to assess the effect of the independent variables on the proximity index. The model does not differentiate between the specific domestic and foreign sources. To address these effects, the second set of models develops a location analysis that compares the relative importance of domestic public research against foreign public research sourced from two defined regions: other European countries and North America.

2 DATA SOURCES AND METHODOLOGY

The 1993 PACE survey of Europe's largest R&D-performing firms (outside of France[2]) covers innovative activities between 1990 and 1992. The overall response rate was 55.6%. The respondent firms account for a minimum estimated 60% of all private R&D spending in the European Union in 1992. 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. Further details on the PACE survey are available in Arundel *et al*. (1995).

Our analyses are limited to a maximum of 588 responses from manufacturing (ISIC third revision classes 15–36 inclusive) and industrial (mining, oil and gas extraction, utilities,

[2] 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.

and civil engineering) firms. Of these, 493 respondents (83.8%) provided data on R&D expenditures. It should be noted that, due to item non-response, the maximum number of available firms varies slightly with each question.

Two sections in the PACE questionnaire ask about knowledge flows. The first 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 competitors' 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 '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 mean 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. Many respondents give their highest score to more than one sub-question. In these cases, the 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, although it is not possible to calculate standard errors with this technique.

A major concern of innovation policy in respect to public science is to maximise the economic impact of public investment in research, for example, by providing inputs to as much private R&D as possible. On average, the impact of public science will be greater if it influences large or numerous innovation projects than if its influence is confined to small or only a few innovation projects. We adjust for this possible effect by weighting the descriptive results by the R&D expenditures of each firm. These expenditures provide a proxy for innovative output, assuming a positive correlation between the expected economic value of innovations and R&D expenditures. For example, we assume that a firm that spends 20 million Euros on R&D will, on average, develop innovations of an economic value that is twice that of 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 (covering innovation activities between 1994 and 1996 inclusive) to verify the PACE estimates of the general importance of public research as a source of knowledge for firms' 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 provide an indirect comparison between the PACE and CMS results for the methods that firms use to acquire the results of public science.

[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.

3 DESCRIPTIVE RESULTS

3.1 The Importance of Public Science Relative to Other External Sources

Table I gives the average R&D intensity for each sector and the distribution of the R&D weighted highest scores for public science plus five other external sources of technical knowledge. The sector results are listed first for the low technology sectors (food through low technology nec), second for medium technology sectors (chemicals through medium technology nec) and last for high technology sectors (office equipment through pharmaceuticals). For comparison, the last line of Table I gives unweighted results for all respondent firms. The sector R&D intensities are in line with other research. The seven low technology sectors all have R&D intensities below 2%, the five medium technology sectors have R&D intensities between 2.5% and 5% and R&D intensities for the five high technology sectors exceeds 5%.

The R&D weighted results show that affiliated firms receive the largest percentage of high scores at 23.7%, followed by customers at 17.4% and public science at 17.3%. There are large differences by sector in the importance of different knowledge sources. In five sectors at the two-digit or finer level, less than 5% of respondents gave their highest score to public science, compared to over 50% of respondents from utilities and aerospace and between 20% and 30% of respondents in the food, plastic and rubber products, medium technology (nec) and pharmaceutical sectors. After R&D weighting, 26.4% of the 183 low technology sector respondents gave their highest score to public research, compared to 12.1% of the 190 medium technology sector respondents and 21.9% of the 120 firms in high technology sectors. The greater importance of public science to low technology firms corroborates some of Beise and Stahl's (1999) results for Germany.

Substantially more PACE than CIS respondents gave their highest score to public science – 17.3% versus an equivalent rate of 5% for the second CIS (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 in the PACE and CIS surveys in the importance attributed to public science. 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 R&D spending as 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 four sectors with over 40 PACE respondents: food, chemicals, machinery and automobiles.[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. The analysis is limited to

[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 44 food, 113 chemical (including pharmaceutical firms), 48 machinery and 46 automobile firms. The public science category for the CIS equals the highest score given to separate 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).

TABLE I Percent of Firms by Sector Giving Their Highest Score to Six External Sources of Technical Knowledge for Innovation (Weighted by R&D Expenditures).

Sector (ISIC class, 3rd revision)	*N*	*R&D intensity* (%)*	*Public research*	*Affiliated firms*	*Customers*	*Reverse engineering*	*Joint ventures*	*Suppliers*	*Total (%)*
Food (15)	44	0.60	23.5	38.1	11.8	19.1	2.3	5.2	100
Petroleum prod (23)	17	1.07	18.0	24.4	25.9	10.6	3.2	18.0	100
Non-metallic minerals (26)	24	1.51	16.9	40.5	4.7	18.4	11.4	8.1	100
Basic metals (27)	18	1.45	3.3	7.3	31.2	33.3	13.0	11.9	100
Fabricated metal products (28)	14	1.73	1.9	53.8	3.1	3.0	9.4	28.8	100
Utilities (40)	25	1.33	55.9	7.8	10.6	1.9	20.6	3.3	100
Low technology sectors (nec)	41	1.09	13.1	31.0	32.6	10.0	6.7	6.5	100
Chemicals (24 excl. 2423)	77	3.19	16.6	29.4	0.8	17.3	7.0	28.9	100
Plastic and rubber products (25)	11	4.20	21.7	0.4	46.7	22.4	0.1	8.8	100
Machinery (29)	48	2.66	10.5	8.3	33.4	25.0	3.0	19.7	100
Automobiles (34)	46	3.95	9.4	24.7	32.8	14.7	10.0	9.0	100
Medium technology sectors (nec)	8	2.97	29.8	8.6	14.1	25.9	20.5	1.2	100
Office equipment and computers (30)	13	5.97	5.4	22.7	28.1	18.2	4.8	20.9	100
Electrical equipment (31)	17	7.41	0.5	52.2	7.7	3.5	30.3	5.9	100
Telecom equipment (32)	18	8.80	3.8	20.0	10.7	18.4	31.5	15.6	100
Instruments (33)	17	8.96	4.0	12.2	10.4	35.4	9.9	28.3	100
Aerospace (3530)	19	21.35	57.4	3.9	2.3	19.2	13.5	3.8	100
Pharmaceuticals (2423)	36	12.82	23.1	18.1	7.3	14.5	34.3	2.7	100
All sectors; weighted by R&D	493	3.49	17.3	23.7	17.4	15.1	14.7	11.9	100
All sectors; unweighted	588	–	16.4	18.9	16.3	19.9	9.5	18.9	100

*For each sector, the total R&D expenditures are summed across all firms and divided by total sales across all firms.

four external sources that were queried in both the PACE and the CIS questionnaires: affiliated firms, suppliers, customers and public science.[5]

In the food sector, 30.6% of PACE respondents versus only 3.4% of CIS respondents gave their highest score to public science ($p < 0.001$). However, the results are similar in chemicals (34.2% for PACE and 33.5% for CIS), machinery (13.5% for PACE and 16.7% for CIS) and automobiles (13.5% for CIS and 14.7% for PACE). These results suggest 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 External Knowledge Sources

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. The variable PROXPR for public research is defined as follows:

PROXPR = 0 if the importance of public research in the domestic country is *lower* than the importance of public research in *at least* one foreign location.
PROXPR = 1 if the importance of public research in the domestic country equals the *highest* importance given public research in any other country.
PROXPR = 2 if the importance of public research in the domestic country is *greater* than the importance of public research in *all* other countries.

The variable is built in this way to increase its robustness. Our measure of proximity is constructed on the basis of the importance given by the *same* respondent to knowledge sources in different countries. In this respect, PROXPR does not create inter-rater comparability problems across respondents as a result of the question using a subjective, ordinal scale. Nor does PROXPR assume an interval level of measurement. PROXPR is a useful metric to the extent that proximity is inherently an internal measure of how each firm values public research in different locations. However, its one main drawback is that it does not account for differences in the value of public research between firms. This problem is overcome in the econometric analysis by including a separate indicator for the relative value of public science compared to other external knowledge sources.

Table II gives equivalent results for the five external sources of technical knowledge (weighted by R&D expenditures). A striking result is that the sourcing of technical knowledge from public science is the most affected by proximity: 46.6% of R&D weighted firms rate domestic public research as more important than foreign public research, 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 competitors' 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.

3.3 Sourcing of Public Science by Location

Although Table II shows that proximity is more important for public science than for any of the five other external knowledge sources, we expect differences by sector in the importance

[5] The use of only four external sources versus six sources, as in Table I, alters the distribution of high scores, which must sum to 100% over either four or six sources. For this reason, the results for the PACE respondents in the following paragraphs is not comparable to those in Table I.

TABLE II Percent of Firms Rating Domestic Sources of Technical Knowledge as Less Important, of Equal Importance, and of More Importance than Foreign Sources.

	*N**	*Domestic less important*	*Domestic and foreign equal*	*Domestic more important*	*Total (%)*
Public research	485	4.7 (0.96)	44.4 (2.26)	50.9 (2.27)	100
Customers	456	17.1 (1.76)	61.4 (2.28)	21.5 (1.92)	100
Reverse engineering	473	34.5 (2.22)	61.7 (2.24)	3.8 (0.88)	100
Joint ventures	400	40.7 (2.46)	38.3 (2.43)	21.1 (2.04)	100
Suppliers	472	25.0 (1.99)	40.6 (2.26)	34.5 (2.19)	100
Affiliated firms	400	27.9 (2.24)	50.9 (2.50)	21.2 (2.04)	100

Note: Weighted by R&D expenditures. Standard errors are in parentheses. The unweighted results for public research are 9.7% (domestic less important), 41.2% (domestic and foreign equal) and 49.1% (domestic more important).
**N* varies because of firms that reported no experience with the source in all four regions. For example, eight firms report that they had no experience sourcing knowledge from public research institutes in all four regions and are therefore excluded from the analysis.

of knowledge sourced from public science in different locations. For example, firms active in the pharmaceutical sector should be more likely to source knowledge from universities in the United States – the world leader in this technology – than firms in the automobile and chemical sectors, where Europe has a long history of highly competitive firms and active public sector involvement in allied fields. Relevant results are given in Table III for the percentage of firms that give their highest score to public research obtained from four locations: their country of location (Domestic), other European countries, North America, and Japan.

TABLE III Percent of Firms by Sector Giving Their Highest Score to the Importance of Public Research Results from Four Locations (R&D Weighted).

Sector	*N*	*Domestic*	*Other Europe*	*North America*	*Japan*	*Total (%)*
Food (15)	44	56.1	27.9	14.9	1.1	100
Petroleum prod (23)	17	54.8	26.7	10.0	8.5	100
Non-metallic minerals (26)	22	75.1	15.0	2.8	7.2	100
Basic metals (27)	18	76.2	21.6	1.1	1.1	100
Fabricated metal products (28)	13	59.4	18.3	13.6	8.8	100
Utilities (40)	25	75.2	21.7	2.7	0.6	100
Low technology sectors (nec)	40	77.0	9.6	13.0	0.4	100
Chemicals (24 excl. 2423)	76	71.0	12.5	14.4	2.1	100
Plastic and rubber products (25)	11	51.5	40.7	7.8	0.0	100
Machinery (29)	48	73.0	14.2	8.8	4.0	100
Automobiles (34)	45	84.7	12.8	1.2	1.3	100
Medium technology sectors (nec)	8	70.0	16.9	5.9	7.2	100
Office equipment and computers (30)	12	60.2	13.7	22.1	4.0	100
Electrical equipment (31)	17	36.2	27.5	32.2	4.1	100
Telecom equipment (32)	18	60.7	9.7	28.5	1.1	100
Instruments (33)	17	59.9	15.3	24.3	0.5	100
Aerospace (3530)	18	74.6	18.9	6.6	0.0	100
Pharmaceuticals (2423)	36	48.4	23.0	22.2	6.5	100
All sectors; weighted by R&D	485	69.0	16.9	11.7	2.5	100
All sectors; unweighted	577	67.7	17.4	11.8	3.2	100

With two exceptions, over 50% of the highest scores in each sector are for domestic sources of public science. The exceptions are electrical equipment (36.2%) and pharmaceuticals (48.4%). Conversely, less than 10% of the highest scores are given to public science in Japan. The greatest variation is between other European sources and North America. The percentages for almost all low and medium technology sectors are higher for other Europe than for North America, and often substantially so. Only 1.1% and 1.2% of the highest scores, in basic metals and automobiles, respectively, are for North America, compared to 15.2% and 12.8%, respectively, for other Europe. Conversely, firms active in all high technology sectors except aerospace and pharmaceuticals give a larger percentage of their highest scores to North America than to other Europe. The distribution for pharmaceuticals is almost evenly balanced between the two, at 23% for other Europe and 22.2% for North America.

3.4 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 46.2% of the R&D weighted firms, followed by 'general knowledge obtained from basic research' (24.3%), 'new instrumentation and techniques' (19.6%) and, lastly, 'early versions of prototypes of new product designs' (9.9%). The unweighted results are very similar. The high value attributed to applied knowledge confirms the Yale survey results for the United States 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 facilitate the exchange of non-codified information, although joint research would conceivably be more productive in this respect.

As shown in Table IV, only 0.7% of the R&D weighted firms give their highest score to personnel exchanges. The methods seen as most important are hiring (29.1%), informal contacts (20.8%) and contracted out research (17.0%). There are notable differences by sector, 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 either contract research or joint research projects 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.

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 (via patents, licensing and consulting), using a four-point scale, and limiting the responses to a 'recent major' innovation project. Cohen *et al.* (2002) gave unweighted CMS results for the percentage of American R&D laboratory 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 of the seven comparable methods. 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 third and temporary personnel exchanges come last. Cohen *et al.* (2002) conclude that the first,

TABLE IV Percent of Firms by Sector Giving Their Highest Score to Seven Methods for Learning About Public Research Outputs.

Sector	*N*	*Publications*	*Conferences*	*Hiring trained staff*	*Informal contacts*	*Temp. personal exchanges*	*Contract research*	*Joint research projects*	*Total (%)*
Food (15)	43	15.2	10.3	37.6	15.6	4.8	8.5	8.0	100
Petroleum prod (23)	17	3.8	8.0	25.7	21.9	0.3	37.7	2.6	100
Non-metallic minerals (26)	22	19.0	23.5	1.4	30.1	11.5	10.3	4.2	100
Basic metals (27)	18	10.2	7.2	26.0	16.7	0.0	11.4	28.4	100
Fabricated metal products (28)	13	4.2	1.5	10.3	6.2	0.5	23.0	54.4	100
Utilities (40)	25	14.9	14.9	11.1	17.6	1.0	36.2	4.3	100
Low technology sectors (nec)	39	11.8	17.4	34.2	20.9	6.1	5.5	4.2	100
Chemicals (24 excl. 2423)	76	18.4	5.4	33.6	14.4	0.0	12.7	15.5	100
Plastic and rubber products (25)	11	1.9	1.6	76.8	2.4	1.5	2.2	13.6	100
Machinery (29)	48	30.3	12.6	22.1	26.1	1.4	4.7	2.8	100
Automobiles (34)	45	4.7	9.5	23.4	18.5	0.0	30.5	13.4	100
Medium technology sectors (nec)	8	16.2	9.7	31.4	14.5	0.0	6.5	21.8	100
Office equipment and computers (30)	12	11.4	24.9	20.9	9.5	8.1	14.0	11.1	100
Electrical equipment(31)	17	1.7	1.1	76.3	17.8	0.6	1.2	1.4	100
Telecom equipment (32)	18	34.7	16.3	26.0	10.9	2.2	2.3	7.6	100
Instruments (33)	17	15.2	16.9	12.9	39.2	0.1	9.7	6.0	100
Aerospace (3530)	18	7.7	7.9	18.0	23.0	0.0	16.0	27.5	100
Pharmaceuticals(2423)	36	11.3	12.3	20.0	41.4	1.0	1.7	12.4	100
All sectors; weighted by R&D	483	10.4	9.3	29.0	20.8	0.8	17.1	12.6	100
All sectors; unweighted	574	24.1	12.3	20.9	18.2	2.8	9.3	12.8	100

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.

4 ECONOMETRIC MODELS OF PROXIMITY

Our data provide information on both the relative importance of domestic versus foreign public science to the innovative activities of the firm, as captured by PROXPR, and on where firms source knowledge from public science, with one domestic location and three foreign locations (other Europe, North America and Japan). We expect the relative importance of domestic versus foreign sources and the specific location from which firms source knowledge from public science to be influenced by firm-specific and country-specific factors. As noted in the Introduction, we develop two sets of econometric models to evaluate the effect of these factors on knowledge sourcing. Both sets of models draw from the same group of independent variables, discussed below. We then describe each of the models and their estimations.

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. For research activities, the best measure of the ability of a firm to access information, no matter where it is located, is probably the firm’s total R&D budget.[6] We therefore use the natural log of the firm’s R&D expenditures (LNR&D) to capture size effects, in preference to alternative measures such as total sales.

In addition to the absolute size of the firm’s R&D budget, the firm’s R&D intensity could also influence knowledge sourcing strategies. 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, many of the regressions included a variable for the R&D intensity of the firm, based on the ratio between R&D expenditures and sales. However, R&D intensity was not significant in any of the regressions and is therefore not included in the final regression models.

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. We calculated three dummy variables for sales in the North American (AMERICA), other European (EUROPE) and Japanese (JAPAN) markets, with the variable equal to 1 when the firm has positive sales in the market and 0 otherwise. The variables HOMEOFF, EUROPE and JAPAN were never significant in any of the regressions and are therefore not included in the results given here. In contrast, activity in the American market has a significant effect in some of the regressions.

The dependent variable in all models measures the relative importance of public research in the domestic country compared to other countries. However, the value of proximity could also vary according to the absolute importance of public science to the firm, with firms that

[6] Previous analyses of the PACE data found that many of the innovation strategies of firms depend more on the absolute size of their research budget than on other factors such as a sales-based measures of size. A large research unit uses innovation strategies that are similar to other large research units, even if research is only a small fraction of the firm’s total activities (Arundel *et al*., 1995).

find public science of great importance to their innovation activities more likely to seek out relevant public science results wherever they can be found. Unfortunately, PACE does not obtain absolute measures of the importance of public science, since all variables are based on subjective responses along an ordered scale.

We used the question set on the importance of each of six external knowledge sources, including public science, to calculate four indicators for the value of public science that are independent from the data used to calculate the dependent variables. Of note is that each question provides five response options, ranging from 1 or not important to 5 or extremely important. The four indicators are (1) using the results for public science as an interval measure, (2) using the results as a categorical variable, (3) applying a similar technique as for PROXPR and (4) using the difference in the score for public research and the mean score for the five other external sources. All options are statistically significant and positive when entered into many of the regressions, showing that the importance of public science has a robust effect on knowledge sourcing. For simplicity, we use option 4, termed IMPSCI (importance of public science). IMPSCI is approximately normally distributed, with a mean of −0.05 and a standard deviation of 1 .2.[7]

We expect that the importance of proximity for accessing public science will be influenced by the methods that firms use to access public science and the type of information that they are seeking. Five of the seven methods can act as a conduit for both codified and tacit knowledge (hiring, conferences, temporary exchanges, contract research and joint research ventures). In contrast, publications primarily act as a conduit for codified knowledge (publications can be used to identify individuals within universities for follow-up contacts), while we assume that firms that attach a high importance to informal contacts will be seeking tacit knowledge. The next issue is the relationship between the location of knowledge and the method used to access it. As noted in the Introduction, we expect firms that are interested in codified knowledge to be more likely to go abroad, simply because most of the codified outputs of public science will be located in other countries. Conversely, the literature on tacit knowledge implies that firms would primarily use informal contacts to access local tacit knowledge because they are based on personal contacts where cultural, social and linguistic factors probably matter.

We construct a relative variable (TACIT) that is the difference between the importance of informal contacts and publications for sourcing public science outputs. The variable INFORMAL equals the original response to the question on the importance of informal methods for obtaining the results of public research and varies between 1 (low importance) and 5 (high importance). We also entered INFORMAL into the regressions as a categorical variable or as a binary variable, but with no substantial difference in the results. For simplicity, we only give results for the interval version of INFORMAL.

Proximity should be less important for firms that are seeking basic research results (traditionally codified and available in publications) than for firms seeking applied research results that may require tacit knowledge to be fully understood. Firms that are both seeking basic research results and also rely on publications as a knowledge source should be the least influenced by proximity. We therefore construct a variable, CODIFY, that equals the importance to the firm of publications as a method for accessing public research results times the importance to the firm of basic research. 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.

[7] We recognise that IMPSCI assumes that the difference between the score for public science and other external knowledge sources is an interval level measure. However, using the same method as for PROXPR produces similar results. Furthermore, we used IMPSCI to create a categorical variable (greater than average, approximately average and less than average) that was also statistically significant, but we chose not to use this variable because it depends on a subjective division of the three categories.

The descriptive results show that the firm's sector of activity influences both proximity effects (Tab. III) and the methods used to source knowledge from public science (Tab. IV). Therefore, the regressions include 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, leaving up to 435 firms in 16 sectors.[8]

4.2 Country Level Variables

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.[9] 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.

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 Regression Models for Proximity Analysis

We model the determinants of the effect of proximity on the use of public research with both an ordered and a binary logit model. Both models estimate the impact of a range of exogeneous variables on a dependent variable, which takes a finite set of values (Liao, 1994). The method of estimation is maximum likelihood. The models assume 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.

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[8] The 16 sectors (ISIC code in parentheses) 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).

[9] The concordance table is based on expert evaluations and is available from Dr. A. 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. See Laursen and Salter (2004) for the description and availability of this concordance table.

The ordered model assumes that there is a set of ordered values $(\mu_1, \mu_2, \ldots, \mu_{n-1})$ and a variable y^* such that:

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

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

$$y_i^* = \beta X_i + \varepsilon_i \quad i = 1, \ldots, N \tag{2}$$

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

$$F(x) = \frac{1}{(1 + \mathrm{e}^{-x})} \tag{3}$$

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

$$\begin{aligned} \text{Prob}\,(Y_i = 1/X_i) &= F(\mu_1 - \beta X_i) \\ \text{Prob}\,(Y_i = k/X_i) &= F(\mu_k - \beta X_i) - F(\mu_{k-1} - \beta X_i) \\ \text{Prob}\,(Y_i = n/X_i) &= 1 - F(\mu_{n-1} - \beta X_i) \end{aligned} \tag{4}$$

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

Only 9.7% of the unweighted firms report that domestic public science is of less importance than public science in any other country, which means that the ordered logit model results are largely determined by the factors influencing firms to report that domestic and foreign public science are of equal importance, versus those reporting domestic science to be of greater importance. For this reason, we also provide the results for the simpler binary logit model in which categories 0 and 1 of PROXPR are combined into the 0 category.[10] The dependent variable equals 1 when the importance of public science in the domestic country is greater than its importance in all other countries. As shown in Table V, the coefficients in the ordered and binary logit models are very similar, although the ordered logit provides a slightly better model fit.

The full ordered logit equation is estimated as follows:[11]

$$\begin{aligned} \text{PROXPR} = 1 - F(\mu - \beta_1 \ln \text{R\&D} - \beta_2\ \text{AMERICA} - \beta_5\ \text{CODIFY (or INFORMAL)} \\ - \beta_6\ \text{PUBSHARE} - \beta_7\ \text{HERDGDP} - \beta_8\ \text{IMPSCI} - \sum_j \beta_j\ \text{DISIC}_j) \end{aligned} \tag{5}$$

For DISIC, there are 15 sector dummies with $j = 1, \ldots, 15$.

The binary logit version uses an identical set of explanatory variables. However, we give the odds ratio (the exponent of the coefficient) rather than the coefficient. The odds ratio gives the percentage change in the probability of the outcome (the dependent variable = 1) given a one unit change in the independent variable. An odds ratio of less than 1 occurs when the coefficient is negative, while an odds ratio greater than 1 occurs when the coefficient is positive.

[10] Combining these two categories is reasonable, given that the ordered logit regressions given in Table V accurately predict the category of only 5–7% of the firms that report foreign public science as more important than domestic science (PROXPR = 0), with 76% of these firms allotted to the mid category of 'domestic equals foreign public science' (PROXPR = 1).

[11] 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).

TABLE V Model Results for Proximity (Importance of Public Science in Any Other Country Relative to Domestic Public Science).

	Ordered logit models		*Binary logit models*	
	1, β (SE)	*2, β (SE)*	*3, e^{β}*	*4, e^{β}*
LN R&D	−0.264 (0.127)**	−0.282 (0.125)**	0.737**	0.721**
PUBSHARE	0.167 (0.035)*	0.165 (0.036)*	1.167*	1.164*
HERDGDP	0.052 (0.014)*	0.052 (0.014)*	1.041**	1.041**
IMPSCI	0.184 (0.092)**	0.183 (0.092)**	1.212***	1.203***
INFORMAL	−0.201 (0.100)**		0.811**	
CODIFY		−0.032 (0.017)***		0.966***
AMERICA	−0.429 (0.234)***	−0.401 (0.234)***	0.641***	0.668***
Sector dummies	Yes	Yes	Yes	Yes
μ_1	−0.734 (0.793)	−0.525 (0.775)		
μ_2	1.982 (0.801)*	2.183 (0.785)*		
Chi-square	89.8 $p < 0.000$	89.2 $p < 0.000$	76.4 $p < 0.000$	75.4 $p < 0.000$
Pseudo R^2	0.22	0.22	0.22	0.21
No. firms	435	433	435	435
Percentage correctly classified	59.5%	57.7%	67.1%	65.6%

Note: Pharmaceuticals is the reference category for sector in the two ordered logit models. There is no reference category in the binary logit because the intercept is set equal to 0. The binary logit results give the odds ratios for the probability that the dependent variable = 1 (domestic public science is more important than foreign public science). An odds ratio less than 1 reduces this probability, while an odds ratio over 1 increases this probability.
*Statistically significant at $p < 0.01$.
**Statistically significant at $0.01 > p < 0.05$.
***Statistically significant at $0.05 > p < 0.10$.

Both models estimate the effect of several firm and country specific characteristics on the importance to the firm of proximity for sourcing knowledge from public science. Neither model explains the importance to the firm of the knowledge obtained from public science. For this reason, the estimations are not affected by problems of endogeneity.

4.4 Regression Models for Location Analysis

We model the determinants of the importance of public science by location with an ordered logit model that compares the importance of domestic public science relative to sources in (1) other Europe and (2) North America. We use the same set of explanatory variables introduced in the proximity analysis. The dependent variable in the model for other Europe is equal to 0 when public science in other European countries is rated as more important than domestic public science, 1 when both are of equal importance and 2 when domestic public science is more important than public science in other European countries.[12] The same structure is used for North America.

For the other Europe model, 249 respondents find domestic public science more important, 155 find other Europe and domestic public science of equal importance, and 31 find domestic public science of less importance than sources in other Europe. For the North America model, 308 respondents find domestic public science more important, 100 find North American and

[12] We also used a multinomial logit model, with seven categories for the dependent variable, to examine the relative importance of the explanatory variables according to all possible combinations for the most important source of public science. Due to the large number of dependent categories, the full results are too complex to be presented here, but they are consistent with the simpler binary logistic models.

domestic public science of equal importance, and 27 find domestic public science of less importance than sources in North America.

4.5 Regression Results for the Proximity Analysis

Table V gives the results for the two ordered logit models and the binary versions. The difference between Models 1 and 2 is based on the choice of the variable for the method of acquiring the results of public science. Model 1 uses INFORMAL, or the importance to the firm of informal personal contacts for learning about research conducted by public science, while Model 2 uses CODIFY.

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 distance than other firms.

Sales activity in the North American market (AMERICA) reduces proximity effects in the two ordered logit models, but the effect is of borderline significance. 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 sales activity in the North American market also reduces the proximity effect in other sectors and other EU countries.

Firms that give a high value to public science, relative to other external knowledge sources (IMPSCI), are more likely to find domestic public science of greater importance than foreign public science. In addition, both PUBSHARE and HERDGDP have a positive and significant effect on the importance given to proximity. The odds ratios in Models 3 and 4 show that a 1% increase in the domestic country's world publication share increases the probability that firms will find domestic public science more important than foreign public science by a little over 16%. These results show that the scientific 'competencies' of a country's research output affects the relative importance of domestic and foreign sources of public research. Other things being equal, the higher the 'scientific competencies' of a country in terms of both (1) the overall amount of the scientific research of relevance to the firm's sectors and (2) investment in the public science infrastructure, the higher the probability that the firm finds domestic public research to be more important than public research in any other location.

PUBSHARE partly 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.

Variables for the method used to obtain research results (INFORMAL, CODIFY and similar variables for publications, etc.) cannot be introduced in the same model due to collinearity. A variable for the importance of publications always decreases the proximity effect. As expected, this shows that publications are used to access distant codified knowledge. This variable is not of great interest here and therefore we do not present the relevant results in Table V.

Nor do we give results for TACIT (the score for informal personal contacts minus the score for publications) because it has no effect in any of the models. The lack of an effect for TACIT is probably due to the fact that both the importance of publications and INFORMAL *decrease* the proximity effect, in contrast to expectations from the literature on tacit knowledge.[13] The results for INFORMAL (Models 1 and 3) suggest that firms can develop informal, personal contacts with public science based in any location and that informal contacts are a useful method for acquiring knowledge (possibly both tacit and codified) outside of the firm's domestic country.[14]

Models 2 and 4 in Table V use CODIFY, which combines both the importance of publications and the value of basic research to the firm. Many basic results are expected to be available in publications, so CODIFY is a measure of both the value of basic research to the firm and the usefulness of publications as a method of acquiring this information. In both Models 2 and 4, CODIFY is negative and statistically significant. The negative coefficient for CODIFY suggests that proximity is not an advantage for accessing published basic research results. Globally, such results are probably not available domestically, which would explain why the coefficient is negative – firms that are interested in this type of output must go abroad.

4.6 Regression Results for Location Analysis

Table VI gives the results for two ordered logit models for the location analysis. As in Table V, a statistically significant negative coefficient shows that the variable decreases the probability that domestic public science is more important than foreign public science.

Table VI only presents results using the variable INFORMAL for the methods of acquiring public science results. Replacing INFORMAL with CODIFY produces similar results, except that CODIFY is negative and statistically significant for both locations, showing that the firms that value basic published research results were more likely to seek this information in either other Europe or in North America. The results for other Europe using INFORMAL are similar to the first model in Table V. In contrast, the domestic share of publications in the firm's field, the importance of public science to the firm and INFORMAL have no effect on the relative importance of public science obtained from North America compared to the domestic country. The difference in the results for INFORMAL between other Europe and North America suggests that informal contacts are more useful for acquiring public science from other European countries than from North America. This could possibly occur because the Atlantic simply presents too much of a barrier to informal contacts, whereas the distances within Europe are not enough to reduce the value of informal contacts for acquiring the results of public science.

One possibility is that European firms use more 'formal' methods of acquiring knowledge from American public science. This is supported by some of the results using the identical models as in Table VI, but where the variable INFORMAL is replaced by the importance of other methods of learning about public science: hiring, temporary personnel exchanges,

[13] We also ran separate models including an indicator for each of the seven methods of acquiring the outputs of public science. The importance of temporary personnel exchanges also decreased the proximity effect, while the importance of conferences, hiring, contract research and joint research had no effect.

[14] Other survey data support this finding. An additional question with a 'yes' or 'no' response category asked respondents if their firm had obtained the results of public science from each region and by each method. The total number of 'hits' for each country (with a positive response for each method counting as a hit) is 3002 for the domestic country, 2065 for other Europe, 1554 for North America and 802 for Japan. This is not surprising and shows that firms source a lot more knowledge from proximate versus distant locations. However, we also calculated the percentage of hits that were due to each method of sourcing knowledge. Publications accounted for an increasing share of hits with distance: 17.5% for the domestic country, 23.2% for other Europe, 28.7% for North America and 39.4% for Japan. The share for informal contacts also increased with distance: 17.4% of all hits for the domestic country, 20.0% for other Europe, 21.8% for North America and 22.4% for Japan. Although the effect is not as pronounced as that for publications, we expected a decline with distance in the share of hits attributed to informal contacts.

TABLE VI Ordered Logit Model Results for Location (Importance of Public Science in Other Europe and North America Relative to Public Science in the Domestic Country).

	Other Europe B (SE)		*North America B (SE)*	
LN R&D	−0.382	(0.134)*	−0.373	(0.151)**
PUBSHARE	0.237	(0.037)*	0.580	(0.040)
HERDGDP	0.044	(0.014)*	0.076	(0.017)*
IMPSCI	0.218	(0.097)**	0.080	(0.104)
INFORMAL	−0.254	(0.106)**	−0.09	(0.115)
AMERICA			−0.594	(0.281)**
Sector dummies	Yes		Yes	
μ_1	−1.41	(0.830)***	−1.17	(0.889)
μ_2	1.31	(0.830)	0.913	(0.885)
Model chi-square	102.5	$p < 0.000$	76.8	$p < 0.000$
Pseudo R^2	0.25		0.21	
No. firms	435		435	
Percentage correctly classified	59.5%		51.7%	

Note: Pharmaceuticals is the reference category for sector.
*Statistically significant at $p < 0.01$.
**Statistically significant at $0.01 > p < 0.05$.
***Statistically significant at $0.05 > p < 0.10$.

contracting out research to a public science institution and joint R&D projects. Firms that gave a high importance to temporary personnel exchanges and joint R&D were significantly more likely to rank North American public science as more important than domestic public science ($p = 0.038$ and 0.080, respectively), while neither method had any effect in the model for other Europe. Hiring had no effect in either model, while the coefficient for contract research was negative and significant ($p = 0.078$) in the model for other Europe. As in the case of the proximity analysis, we verified the robustness of the results by the exclusion of the UK and the pharmaceuticals industry.

The fact that neither PUBSHARE nor IMPSCI increases the probability of finding local public science of greater importance than that in North America suggests that the latter may produce unique results that are of value no matter how large the domestic contribution to research or the general importance of public science to the firm. This could occur if public science in North America was far more technically advanced, or if access was easier, for example due to simpler licensing rules. However, PACE contains no data for exploring these possibilities.

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 European governments 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 among the most important of six external knowledge sources, after adjusting for a proxy measure of innovative output. Only knowledge sourced from affiliated firms is notably more important than public science for the firms' innovative activities. It is interesting that public science is most important to firms in low technology sectors, followed next by firms in high technology sectors and lastly by firms in medium technology sectors. These results differ considerably from aggregate results using the CIS surveys, where public science is one of the least important sources of technological knowledge. However, much of the difference between the CIS and PACE results vanishes once the CIS results are weighted to account for a proxy of innovation output (R&D expenditures) and limited to large firms that perform most of the R&D in Europe.

These results on the general importance of public science are relevant to science and technology policy, particularly because proximity effects are much more pronounced in the case of public science than the five other external knowledge sources. The sourcing of technical knowledge from public science is the most affected by proximity. 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 more than half find the output of domestic public science to be more valuable than that of foreign public science.

The domestic preference holds for most sectors, with the exception of electrical equipment and pharmaceuticals. Sectoral differences also occur in the importance of public science results from other Europe, North America and Japan. For example, about 30% of the R&D-weighted respondents in the telecom equipment sector said that public science in North America was more important than domestic sources, compared to only 1.1% of firms active in basic metals.

The econometric models identify firm and country specific factors that influence the probability of finding domestic public science more important than other sources. 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 own 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.

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. Our assumption that firms that seek codified knowledge are less likely to find proximity of importance (since most codified knowledge will not be in the firm's domestic country) is supported by the econometric results, although the need to go abroad to seek information also depends on the availability of knowledge in the domestic country.

The most frequently cited explanation for proximity effects is the need to acquire tacit knowledge, or at least knowledge that is not yet codified. Developing informal contacts is one method of acquiring tacit knowledge. However, our results do not find that firms that stress the value of informal contacts are more likely to find domestic public science more important than foreign public science. On the contrary, firms that stress the value of informal contacts consider domestic sources less important, and use their contacts to access knowledge outside the firm's domestic country. It is of note that while these results do not support the hypothesis that tacit knowledge is the cause of proximity effects, they do not refute it either. A full test of the tacit knowledge theory would require direct data, not available in PACE, on the type of knowledge obtained through the use of informal contacts in each location. It is possible that firms are using their informal contacts abroad to acquire both tacit and codified knowledge.

The regressions for the location of the most important source of public science suggest that the usefulness of informal contacts for acquiring public science results does not extend beyond other European countries to North America. This provides weak evidence for a link between proximity effects and informal contacts, although in this case other European countries are included within the proximate sphere, suggesting that geographical proximity is not necessary for the development of personal contacts. One possible explanation is the development of 'network proximity', based on a communication structure that allows successful repeated interactions within Europe. Network proximity would enable geographically distant, but personal contacts to share both useful knowledge and information about where such knowledge can be found. This could be especially true for public science, where supra-national European policies have been subsidising cross-country collaboration between firms and public researchers. In this respect, perhaps large European firms had already begun to create a 'European Research Area' in the early 1990s – the current goal of many European policies. These results also suggest that public science needs to be located somewhere in Europe, even if large firms can readily access public science outside of their home country.

Finally, neither the size of domestic public science outputs and the importance of public science to the firm have any effect on the relative importance of domestic versus North American public science. This suggests that large R&D intensive European firms access public science in North America, not as a substitute for domestic sources, but because North America offers unique advantages. Further research is needed to shed more light on this result.

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