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Searching Low and High:
What Types of Firms use Universities as a Source of Innovation?

by

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Abstract
This paper examines the factors that influence whether firms draw from universities in their innovative activities. The link between the universities and industrial innovation, and the role of different search strategies in influencing the propensity of firms to use universities is explored. The results suggest that firms who adopt "open" search strategies and invest in R&D are more likely than other firms to draw from universities, indicating that managerial choice matters in shaping the propensity of firms to draw from universities.

Key words: University-industry links, innovation, external search strategies

JEL Codes: C25, C42, O31, O32

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INTRODUCTION

This paper explores factors that explain why firms draw from universities in their innovative activities. Industrial firms gain ideas for innovating from a wide variety of different sources and their innovative performance depends on how successful they are at appropriating knowledge from these sources (von Hippel, 1988; Cohen & Levinthal, 1990; Spencer, 2001). University research appears to offer a potential to improve national competitiveness and universities are often described as the "engines of growth", yet it has been difficult to empirically trace the direct effects of universities on industrial innovation because the relationship between universities and industrial firms is mediated by a complex set of overlapping interactions and institutions (Salter & Martin, 2001; Jacobsson, 2002). Research suggests that rarely does the work of universities directly translate into new products or services for industrial organizations (Pavitt, 2001). However, in some industrial sectors, this relationship between universities and industrial innovation appears to be a tight one, such as in biotechnology, while in others such as textiles, it appears to be distant and weak (Klevorick, Levin, Nelson, & Winter, 1995). In order to investigate the link between universities and industrial innovation, we build upon a number of studies exploring the factors that shape the propensity of firms to draw from universities in their innovative activities (for instance, Spencer, 2001; Cohen, Nelson, & Walsh, 2002). We extend these approaches by integrating two district research programs – one focusing on university-industry links and another focusing on search strategy. In doing so, we attempt to integrate the study of university-industry links into a framework of analysis that focuses on the role of innovative search in shaping innovative activities of industrial firms.

We examine the relationship between universities and innovation using a sample of 2655 manufacturing firms drawn from the UK Innovation Survey. Given that our dependent variable is discrete and inherently ordered, we apply an ordered logit model as the means of estimation. The dependent variable measures the degree to which firms draw from knowledge generated at universities in their innovative activities. First, we explore the effect of "structural" variables, such as firm size, age and R&D expenditures, on the propensity of firms to draw knowledge from universities. Second, we examine the role of search strategies in drawing on such knowledge.

The analysis shows that firm size and R&D expenditures are associated with the use of universities. In addition, we explore the implications of use of different search strategies at the firm level in influencing the propensity of these firms to use universities. In particular, we find that firms which use many other external sources of knowledge (sources such as competitors, suppliers and customers, private research institutes, fairs & trade associations, etc.) also tend to use university research more intensively. This finding suggests that firms with a more "open" search strategy will tend to draw from university research more intensively.

The remainder of the paper is organized into five sections. Section 2 focuses on theoretical and empirical background and examines debates about the role of universities in the innovation process. Section 3 describes the method and data used in the analysis. Section 4 gives descriptive results, while Section 5 contains an econometric analysis. Section 6 contains a discussion and a conclusion.

THEORETICAL AND EMPIRICAL BACKGROUND

University-industry Interactions

Many governments across the OECD have launched major new initiatives to "embrace the cause of technological commercialization" and to this end, they have supported increased interaction between universities and industry (Cohen et al., 2002). These initiatives are often premised on the expectation that university-industry interaction can increase the rate of innovation in the economy (Spencer, 2001). Although the traditional linear model of technology transfer, involving the movement of ideas from universities to the market, has been superseded by a number of rich, interactive models, policy-makers across the OECD have clung to the hope of opening up a pipeline from university research to industrial practice (OECD, 2002). For example, the UK government has supported a wide range of new programs designed to expand the commercial activities of universities (DTI, 2003b). Other OECD countries have adopted similar policy models, funding the development of "third steam" activities in universities (with research and teaching being the first and second stream respectively) (OECD, 2000).

Government interest in university-industry links has been complemented by a vast program of economic research (Jaffe, 1989; Mansfield, 1991; Stephan, 1996; Hicks & Katz, 1997;

Narin, Hamilton, & Olivastro, 1997; Cockburn & Henderson, 1998; Henderson, Jaffe, & Trajtenberg, 1998; Mansfield, 1998; Zucker, Darby, & Brewer, 1998; Hicks, Breitzman, Olivastro, & Hamilton, 2001; Mowery, Nelson, Sampat, & Ziedonis, 2001; Spencer, 2001; Agrawal & Henderson, 2002). Although extremely valuable, these studies of university linkages are hindered by a focus on a limited number of technological environments. For example, the vast majority of patent citations to academic research are located in health-related areas, such as the life-sciences, and patents only account for a small share of university-industry interaction (Hicks et al., 2001). Therefore, in order to understand differences between sectoral contexts, it is necessary to conduct large-scale cross-industry studies of university-industry links. Such studies provide the opportunity to examine what factors influence the propensity of firms to draw from public research (Klevorick et al., 1995).

The recent paper by Cohen et al. (2002) attempts to provide a cross-industry analysis of university-industry interaction. It takes up the challenge of exploring the factors that influence the propensity of firms to draw from universities. The Cohen et al. study demonstrates the variety of mechanisms used by firms to access and interact with the university system. The study indicates that public research is used not just to help generate new ideas, but also to help in completing existing R&D projects. However, the analysis contained in the Cohen et al. (2002) study is circumspect in several important areas. The sample is drawn from firms with industrial R&D facilities and is therefore heavily biased towards large-scale, technologically-intensive firms, despite the inclusion of a limited number of 22 start-ups. Moreover, while the study contains a statistical test of the factors that influence the propensity of firms to draw upon public research, it examines two key explanatory variables only; firm size and whether or not the firm is a start-up.

Cohen et al. and other attempts to examine university-industry linkages have also tended to focus on the role of "structural factors", such as size, industrial context and R&D expenditures in shaping the use of universities by industrial firms. Most of this research is conducted by economists and in their models, they provide little scope for managerial choice and for firm strategy. By setting aside a description of how managers search for new ideas for innovation, the "structural" approach can lead to under-emphasis of the choices firms

make in how best to organize their innovative activities. In this respect, the "structural" perspective appears incomplete and partial.

Innovative search

Alongside the research program on university-industry links, there is a second research program, led by researchers operating in the management tradition, focusing on innovative search. The research focuses on the nature of innovative search and its role in shaping organizational learning, investigating how firms organize and manage their search processes. Search processes include the search for new product ideas, new forms of organization and/or solutions to existing problems (Stuart & Podolny, 1996; Koput, 1997; Katila, 2002; Katila & Ahuja, 2002; Mahdi, 2003). These search processes can be seen as a dynamic capability that allows firms to sustain their competitive advantage over time (Eisenhardt & Martin, 2000). Within these search processes, firms need to find an appropriate balance between knowledge exploration and exploitation, shifting resources between search and implementation in order to achieve and sustain successful product development (March, 1991).

At the center of the search strategy research program is an investigation of changes in the way in which private organizations have reorganized, outsourced and shifted their knowledge creation and capture activities, including R&D, into alliances that span across a wide range of different organizations. Chesbrough refers to this process as the shift from "closed" to "open" innovation. In part, these new models of "open" innovation seem to provide industrial firms with the opportunity to draw in expertise and experience from outside the organization (Valentin & Jensen, 2002; Christensen & Maskell, 2003). In theory, a wider and more diverse search strategy is seen to be able to create more opportunities to access and integrate highly specific knowledge sets (Nelson & Winter, 1982; Teece, 1986; March, 1991; Helfat, 1994; Katila, 2002).

The search strategy of a firm can be defined as "the problem-solving activities that involve the creation and re-combination of technological ideas" (Katila & Ahuja, 2002: 1184). Both the degree of scope (the degree to which it entails the exploration of new knowledge) and depth (the degree to which existing knowledge is reused or exploited) of search processes can play an important role in shaping success in product innovation (Katila & Ahuja, 2002). Exploring both the depth and scope of an external search strategy can provide a mechanism

for assessing the openness of a firm's search activities, i.e. the degree to which the firm seeks to draw in new knowledge and to reuse existing knowledge from external sources. It suggests that different strategies for search can yield different innovative performance outcomes.

The literature on search strategy is, however, largely based on single sector studies and patent analyses. Although some studies introduce a number of structural variables to control for size and R&D expenditures, much of the research in the search strategy tradition relies on small samples of particular industries. Since most of the research is based on patent analysis, it provides limited perspective on industrial innovation. Patents vary in economic importance across different sectors and many patents do not lead to commercially successful products (Levin, Klevorick, Nelson, & Winter, 1987). Accordingly, there is a need to extend the search strategy approach to account for a wider number of industrial contexts and to cut across a range of different issues, such as university-industry links, to determine the saliency of this perspective for understanding a range of different economic phenomena.

Hypotheses from the literature

As yet, few attempts have been made to theoretically and empirically link a firm's search strategy to its use of universities in its innovative activities. In order to integrate these two approaches described above, it is necessary to treat the use of universities as part of a firm's overall strategy for searching for new knowledge as well as investigating the effect of structural variables on the propensity of firms to use universities in their innovative activities. It is possible to draw several hypotheses to examine the link between universities and search strategy. We begin first with the "structural" variables. The first variable relates to the role of size in shaping the propensity of firms to draw from universities. In almost all studies of university-industry links, researchers have examined the impact of firm size on university-industry linkages (Link & Rees, 1990; Arundel & Geuna, 2000; Schartinger, Schibany, & Gassler, 2001; Cohen et al., 2002; Mohnen & Hoareau, 2003). The argument contained in previous research is that larger firms are more likely to have the capability to exploit external knowledge sources and to manage interactions with universities.[1] This is because large firms are able to dedicate greater resources and time to building links with universities than small firms who may operate in a more resource-constrained environment. Large firms also are also more likely to employ staff with a professional training in science

and engineering. With such a professional background, these employees are able to draw from their relationships with universities to support the work of the organization. Therefore and consistent with previous research, the hypothesis can be stated as:

> Hypothesis 1. The capability of firms to draw from university research increases with the size of the organization.

The second hypothesis relates to R&D expenditures. Previous research has found that the level of a firm's scientific and technological capability is directly related to its use of public research (Cohen & Levinthal, 1989). Investments in R&D provide the firm with the capability both to develop new products and processes, and to absorb knowledge developed outside of the firm (Cohen & Levinthal, 1990). A common indicator of scientific and technological capability is R&D expenditure. Therefore, it can be expected that the level of R&D intensity of the individual firm will strongly influence the likelihood that they will draw from universities (Mohnen & Hoareau, 2003). Hence, hypothesis can be stated as:

> Hypothesis 2. The higher the level of R&D intensity of the individual firm, the more likely it will be that the firm will draw from universities.

The third structural variable is related to the age of the firm. Start-ups are often viewed as a key vehicle for transferring university research into commercial innovation, especially in science-based sectors, such as biotechnology and software. By creating new knowledge and training problem solvers, universities support the formation of start-ups. In fact, numerous government policies and universities have sought to use support start-up activity by supplying "seed corn" funding or incubator sites. Yet, few studies investigate the link between firm age and the use of universities in the innovative activities of manufacturing firms. Existing research suggests that start-ups are more likely to draw from universities (Cohen et al., 2002). Yet much of this evidence is based on small samples of start-ups and focused on the experiences of particular spin-offs from few leading US universities and from a small number of science-based sectors, such as biotechnology (Shane, 2002; Di Gregorio & Shane, 2003; Nerkar & Shane, 2003). With our database, we are able to expand previous treatments of this question. Since most start-ups tend to be small (and therefore are unlikely to use universities as suggested by H1), we would expect that only science-based start-ups and those who spend resources on R&D are likely to use universities. The hypothesis can be stated as:

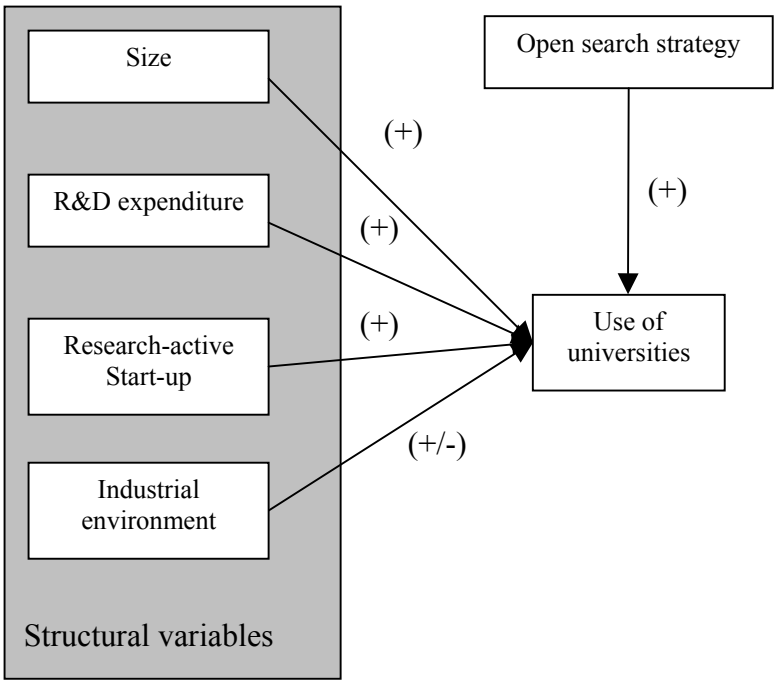
Hypothesis 3. The propensity of a firm to draw from universities will be influenced by the age of the firm, with young research-active organizations drawing more heavily from university research.

Outside the structural variables listed above as possible factors influencing the propensity of a firm to draw from universities, there is a more general question about whether different search strategies shape the propensity to use universities. A variety of studies have found search strategies play an important role in shaping innovative performance (Katila & Ahuja, 2002). As suggested earlier in this section, exploring the search strategies of firms can provide a mechanism for assessing the openness of a firm's search activities, i.e. the degree to which the firm seeks to draw in new knowledge and to reuse existing knowledge from external sources. In order to examine this question, we develop a proxy variable for "openness" of a firm's innovation search strategy. The variable is based on the number of different sources of external knowledge that each firm draws upon in its innovative activities. The assumption is that the higher the number of external knowledge sources that a firm draws upon in its innovation activities; the more "open" its search strategy will be. This variable introduces a degree of managerial choice into the debate about university-industry links. The hypothesis can be stated as:

Hypothesis 4. Firms who choose "open" search strategies are more likely to draw from universities in their innovative activities.

Figure 1 represents the main variables in the analysis and their predicted relationships. Hypotheses 1, 2 and 3 relate to the structural variables and the expected sign is based on previous research. Hypothesis 4 highlights the role of search strategy and therefore managerial choice in shaping the use of universities in innovative activities.

FIGURE 1
Factors influencing the use of universities in innovative activities



*Predicted relationship – represented by line and sign.

DATA AND METHODS

The data for the analysis is drawn from the UK innovation survey. The survey was implemented in 2001 and is based on the core Eurostat Community Innovation Survey (CIS) of innovation (Stockdale, 2002; DTI, 2003a). The method and types of questions used in innovation surveys are described in the Organization for Economic Co-operation and Development's (OECD) Olso Manual (OECD, 1997). CIS data are increasingly being as used as a key data source in the study of innovation at the firm level in Europe, Canada and Australia (for a recent prominent contribution using CIS data, see Mairesse & Mohnen, 2002). Within the Europe, CIS surveys are normally conducted every five years. CIS surveys of innovation often described as 'subject-oriented' because they ask individual firms directly whether they were able to produce an innovation. They are widely piloted and tested before implementation and, since it was first use in the early 1990s, the questionnaire has been continuously revised. The CIS questionnaire itself draws from previous generations of research on innovation, including the Yale survey and the SPRU innovation database. The CIS questionnaire asks firms indicate what sources of information and knowledge they draw upon in their innovative activities. It lists 18 different sources of information and knowledge

for innovation, including suppliers, customers and universities. CIS data provides an opportunity to investigate patterns of innovative strategy across a large number of industrial firms. It also enables researchers to explore the relationship between indicators of performance and different strategies for innovating. Although imperfect, CIS data does provide a useful complement to the traditional measures of innovation, such as patent statistics (Kaiser, 2002; Mairesse & Mohnen, 2002).

The UK innovation survey is 12 pages long and includes page of definitions. The sample of respondents was created by Office of National Statistics (ONS). It was sent to the firm's official representative for filling information on the firm's activities, such as surveys for calculating the UK Gross Domestic Product and R&D expenditures. On the survey, respondents were instructed to forward the survey to the department of the firm best able to respond to the different questions. The implementation of the survey was administered by the ONS and to guide respondents a help service was provided (Stockdale, 2002).

The survey was sent to 13,315 business units in the UK in April 2001 and a supplementary sample of 6,287 was posted the survey in November 2001. It received a response rate of 41.7% (Stockdale, 2002). The second mail out was designed to top-up the number of regional responses to the survey. The responses were voluntary and respondents were promised confidentiality and that the survey would be used to shape government policy. The sample was stratified by twelve Standard Industrial Classification classes and includes all main sectors of the UK economy, excluding public bodies, retail, and hotels and restaurants. The sample was also stratified by region and by size to reflect the total demographic characteristics of the UK economy. The response rates for different sectors, regions and size were largely consistent with the overall response pattern (Stockdale, 2002).

DESCRIPTIVE RESULTS

We begin by exploring the information and knowledge sources for innovation in the UK, focusing on industry-university relations. The question we focus upon is how important are universities as a source of information and knowledge in comparison to other possible sources of innovation. Table 1 lists all 17 sources listed in the UK innovation survey. Each firm is asked to indicate on a 0-1-2-3 scale the degree of importance for each source of

TABLE 1
Sources of information and knowledge for innovation activities in UK manufacturing firms, year 2000 (n=2655).

Type	Knowledge source	Not used	Low	Medium	High
		Percentages			
Internal	Within the enterprise	32	14	27	28
Market	Suppliers of equipment, materials, components or software	32	20	32	16
	Clients or customers	34	22	28	16
	Competitors	46	27	20	6
	Consultants	62	22	13	3
	Commercial laboratories/ R&D enterprises	73	18	7	2
Institutional	Universities or other higher education institutes	73	17	9	2
	Government research organizations	82	14	4	0
	Other public sector e.g. Business links, Government Offices	76	16	6	1
	Private research institutes	82	14	4	1
Other	Professional conferences, meetings	58	27	12	2
	Trade associations	52	28	17	3
	Technical/trade press, computer databases	47	27	22	4
	Fairs, exhibitions	42	29	23	7
Specialized	Technical standards	43	23	23	11
	Health and safety standards and regulations	37	24	27	12
	Environmental standards and regulations	40	26	24	10
Average		54	22	18	7

knowledge or information for their innovative activities. On the survey, the sources are grouped together under six different headings (internal, market, institutional, other and specialized). Table 1 presents the results for the entire range of sources for UK manufacturing firms. Overall, the results indicate that sources within the enterprise are the most important for innovation. The second most important source is suppliers of equipment, materials and components, followed closely by clients and customers. Alongside customers and suppliers, a range of standards, such as health and safety standards, are among key sources of innovation. As might be expected (see von Hippel, 1988), the results indicate that UK firms' innovation activities are strongly determined by relations between themselves and their suppliers and customers as well as the way they go about organizing their internal activities to support innovation.

The number of firms who draw from universities in their innovative activities is, however, modest and well below the scores for "market-related" and "specialized" sources. Only 27% of UK firms indicate that they draw from UK universities and fewer than 2% indicate that

the knowledge they draw from universities is highly important. The relatively low scores for universities suggest that university-industry relations are a concern of a minority of UK firms only. The results are consistent with the results the previous Community Innovation Surveys in Europe conducted in 1996 (OECD, 1999). Although there is some degree of national variation in these cross-country comparisons, the pattern is fairly consistent across EU countries. Both our data and past results therefore suggest that universities play a modest role in shaping innovation activities inside European firms. These results may indicate some support for Owen-Smith *et al.* view that industry-university relations in Europe may lag behind the US, yet differences in the data on university-industry interaction between Europe and the US make comparisons extremely difficult (Owen-Smith, Riccaboni, Pammolli, & Powell, 2002).

Overall, the results from the UK Innovation Survey strongly contrast with the results of the Cohen et al. (2002) study. In their study, close to 60% of industrial R&D labs indicate that they either draw research findings, prototypes, and instruments and techniques from university research. Drawing on these results, they suggest that "university is critical to industrial R&D in a small number of industries and importantly effects industrial R&D across much of the manufacturing sector". Nevertheless, the analysis of the UK innovation survey suggests that among a larger and more diverse sample of firms (i.e. those with and without R&D labs), the salience of universities and public research to innovation and industrial R&D appears to be limited. However, a methodological caveat should be added here, since some of the differences between Cohen et al. and our study may be a result of the application of alternative methods, such as when firms receive a survey focused on university-industry links it may yield more evidence of links than a survey focused on more general issues relating to innovation.

In Table 2, we explore inter-industry variation in the importance of universities to innovation. The results are organized in 13 industrial sectors, spanning the entire UK manufacturing sector. For each industry, we report the percentage of firms indicating the degree that firms draw from universities in their innovation activities. The results confirm the findings of Klevorick et al. (1995), indicating that there is considerable inter-industry variation in the propensity of firms to draw from universities. In the sample, chemical industries draw most heavily on universities in their innovative activities, with over 49% of

TABLE 2

How important do firms (within 13 manufacturing industries) indicate universities or other higher education institutes to be as information and knowledge sources for technological innovation during the period 1998-2000?

	No use	Low use	Medium use	High use	Row per cent	No. of firms
			Per cent			
Food, drink & tobacco	78.5	16.3	4.8	0.5	7.9	209
Textiles	75.7	19.1	5.3	0.0	5.7	152
Wood	82.6	11.0	5.8	0.7	5.8	155
Paper and printing	87.5	7.5	3.3	1.7	9.0	240
Chemicals	50.5	27.9	16.2	5.4	4.2	111
Plastics	79.6	12.1	5.3	3.0	5.0	132
Non-metallic minerals	71.6	17.9	10.5	0.0	2.5	67
Basic metals	70.9	14.6	12.7	1.8	2.1	55
Fabric. metal products	79.7	11.2	6.6	2.5	10.8	286
Machinery	57.4	23.0	16.8	2.9	7.9	209
Electrical	62.4	23.4	11.9	2.3	16.4	436
Transport	67.6	19.6	11.3	1.5	10.4	275
Other	82.0	12.2	4.6	1.2	12.4	328
Column per cent	73.1	16.6	8.5	1.8	100.0	
No. of firms	1940	441	226	48		2655

firms indicating that they draw from universities. In the machinery and electrical/electronic products sectors, around 40% of firms draw from universities, while the sector reporting the lowest share of firms drawing from universities is paper and printing.

The results suggest that firms in sectors characterized by high levels of investment in R&D and other scientific and technological activities have a higher propensity to draw from universities, indicating the average level of absorptive capacity within the sector can influence the propensity of firms to draw from university sources (Cohen & Levinthal, 1989). The degree of inter-industry variation in the use of universities is, however, relatively modest in comparison to the Cohen et al. (2002) study. In the Cohen et al. study, some industries report an extremely high percentage of firms drawing from universities, such as TV/Radio and Glass, whereas others such as Electrical Equipment draw little or no research, prototypes and instruments from public research. However, it must be said that the level of industrial aggregation is greater in our study than in the Cohen et al. study and this might explain some of the differences between the two samples.

ECONOMETRIC ANALYSIS

Measures

Dependent variable. Since we are interested in the use of university knowledge by manufacturing firms, our dependent variable is the degree of importance of universities and other research institutions as sources of knowledge or information in innovation activities of firms. If the firm in question replied that it does not use university knowledge as a source, the variable takes the value of 0, if firms responded "low use", the value is 1, if they responded "medium use" the value is 2, and the variable takes the value of 3 if the firms responded "high use". This variable is not a direct measure of interaction and it should be seen as a proxy for the importance of universities to the firm's innovative activities, reflecting the judgment of members of the firm concerning the value of universities to its activities.

Independent variables. We use the number of employees (expressed in logarithms) as the measure of size. This variable is similar to the one used by Cohen et al. (2002) and Mohnen & Hoareau (2003). Second, we include a measure of R&D intensity, measured as firm R&D expenditure divided by firm sales. The numerator is taken from the CIS survey, while the denominator firm sales is based on register data, supplied with the survey data by the Office of National Statistics. This variable is similar to the one used by Mohnen & Hoareau (2003). A second variable aimed at reflecting more radical innovative activities concerns whether or not the firm in question indicated that they have other innovation activities not directly aimed at imminent new products or processes in terms of basic R&D, technology watch, etc. (long-term R&D). Moreover, like Cohen et al. (2002) we include a variable expressing whether or not the firm was a start-up in the period 1998-2000.

Apart from variables reflecting structural characteristics of the firms, such as size and R&D intensity, we include a variable reflecting firms' search strategies. Despite the fact search strategy is seen to be important in shaping how firms acquire, absorb and capture knowledge from outside the organization, there is no consensus on how to measure firms' search processes. Several studies have focused on patent citations whereas others focus on direct questions on firm-level surveys. We follow the latter approach, examining the responses of managers to questions about information and knowledge sources for innovation.

Our indicator is new and to our knowledge it has not been used before. The variable attempts to reflect the "openness" of a firm to the external knowledge environment. It is constructed by treating all 15 sources of knowledge or information for innovation listed in Table 1 of this paper (that is, excluding "within the firm" and "university knowledge and information") as a pool of sources that firms may or may not draw upon as they innovate. In order to construct the variable, each of the 15 sources are coded as a binary variable, "0" being no use and "1" being use of the given knowledge source. Subsequently, 15 sources are simply added up so that each firm gets a 0 if no knowledge sources are used, while the firm gets the value of 15, if all knowledge sources are used. It is assumed that firms who use higher numbers of sources will be more "open" than firms to who do not. In other words, the variable is a proxy for the openness of a firm's innovative search strategy.

Although the list of sources on the questionnaire is not fully comprehensive, it is extensive and not mutually exclusive. It reflects a wide range of sources of innovation, including suppliers, clients and competitors as well as general institutions operating inside the innovation system, such as regulations and standards. The sources listed in the survey overlap with the resources and institutions that are considered part of the national innovation system (Lundvall, 1992; Nelson, 1993; Spencer, 2001). Like previous literature on search strategy, we assume that firms have a degree of choice in how "open" they wish their innovative search processes to be. This assumption is consistent with the literature on innovation search and managerial strategy in that it ascribes an important role to managerial choice in shaping the outlook of the firm to its external environment. Although the introduction of any variable into a well-established area of research is always contentious, the introduction of the "openness" variable does enable researchers to better explore the link between innovative search and university-industry links. The variable itself appears to have a high degree of statistical validity (Cronbach's Alpha Coefficient = 0.93).

In addition to the ten explanatory variables discussed above, we include 13 industry controls to control for different propensities to apply university knowledge and information across industries.

Statistical Method and Results

Since the dependent variable is a discrete and inherently ordered multinomial-choice variable (the dependent variable, the use of university knowledge and information takes

TABLE 3
Descriptive statistics

	Mean	Std. Dev.	Min.	Max.	1	2	3	4	5
1.Use of university knowledge	0.39	0.72	0	3.0					
2. Log firm size	4.14	1.42	0	8.9	0.26***				
3. R&D intensity	0.01	0.04	0	0.9	0.14***	0.07***			
4. Long-term R&D	0.20	0.40	0	1.0	0.28***	0.21***	0.13***		
5. Start-up	0.06	0.24	0	1.0	-0.04†	-0.08***	0.01	-0.04†	
6. Openness	6.93	5.02	0	15.0	0.53***	0.35***	0.09***	0.31***	-0.03

† $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

values from 0 to 3), an ordered logit model is applied as the means of estimation (for an exposition of ordered logit models, see Greene, 1997: 926-931).

Table 3 gives descriptive statistics for our variables. From the table, it can be seen that 6% of the firms in the sample were start-ups over the period 1998-2000. Moreover, R&D intensity is on average quite low, but varies quite a lot — the standard deviation is four times larger than the mean. It can also be seen that firms use on average about 7 external knowledge sources out of the total of 15.

Table 4 contains the results of the estimation, while the Appendix Table A1 gives the marginal effects at the mean corresponding to the coefficients from Table 4. With respect to the hypothesized positive relationship between the use of universities as a knowledge source and firm size suggested in Hypothesis 1, it can be seen from Table 4 that being a large firm increases the probability of using university knowledge and information. This conclusion can be made based on the fact that the parameter for the size of the firm is positive and significant and moreover, the marginal effect for the size variable is negative (see the Appendix) only in the case of no use (use of university knowledge=0), while the marginal effects are positive in the case of all levels of use of university knowledge (use of university knowledge=1,2,3). It can also be noted that the marginal effect is particularly large in the case of the use of university knowledge =1.[2] In other words, a one percent increase in size increases the probability of using university knowledge to a low degree by 1.4%, while the

TABLE 4

Ordered logit regression, explaining the use of knowledge created in universities for technological innovation activities, 1998-2000

	Model (1)		Model (2)		Model (3)	
Variable	Estimate	t-value	Estimate	t-value	Estimate	t-value
Intercept	-5.29	-19.46***	-5.28	-19.34***	-2.54	-9.69***
Log firm size	0.15	3.51***	0.15	3.50***	0.15	3.41***
R&D intensity	3.63	3.46***	3.61	3.45***	3.59	3.60***
Long-term R&D	0.48	4.05***	0.47	3.94***	0.48	4.09***
Start-up	-0.17	-0.65	-0.20	-0.62	-0.20	-0.74
Start-up x long-term R&D			0.09	0.17		
Openness	0.35	22.17***	0.35	22.15***		
Openness factor 1					0.90	10.29***
Openness factor 2					1.22	21.61***
Industry dummies (12)		Yes		Yes		Yes
Number of observations		2655		2655		2655
Log likelihood		-1548.23		-1548.21		-1506.59
Restricted log likelihood		-2149.76		-2149.76		-2149.76
Log likelihood test		1203.07		1203.10		1286.34
Pseudo R2		0.28		0.28		0.30

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

probability of using university knowledge to a medium degree increases by 0.35% and the probability of using university knowledge to a high degree increases by 0.05%. In sum, our findings are consistent with Hypothesis 1 of this paper ("the capability of firms to draw from university research increases with the size of the organization"). Therefore, our findings concerning the importance of firm size in the use of university knowledge corresponds to those of Cohen et al. (2002) and Mohnen & Hoareau (2003).

As expected, we find R&D intensity significant in explaining the use of university knowledge in innovation activities since the parameter is significant for this variable (and given that the non-zero marginal effects are all positive). It further highlights the importance of the "two faces of R&D" – absorbing knowledge from outside the organization is closely related to the generation of new knowledge within the firm (Cohen & Levinthal, 1989). In this case and as expected from Hypothesis 2, expenditures on R&D encourage firms to seek knowledge from universities ("the higher the level of R&D intensity of the individual firm, the more likely it will be that the firm will draw from universities").

Our results confirm the importance of controlling for R&D intensity when dealing with the commercial use of university knowledge. It should be noted, however, that R&D expenditure and drawing from knowledge from universities are not synonymous. There are many firms in our sample who perform R&D, but do not draw directly from universities in their innovative activities. Of course, these firms may indirectly draw from universities, such as through the employment of trained scientists and engineers. Yet managers in these organizations do not appear to use universities directly in their innovative activities. Moreover, since our measure of R&D is a percentage of sales, it suggests, as might be expected, that the propensity to use universities increases with the degree of sales devoted to R&D. The significant parameter for long-term R&D activities was expected because the variable reflects innovation activities related to basic R&D and the like, activities in which universities are generally believed to play an important role as a source of knowledge.

However, we cannot confirm the finding of Cohen et al., showing that being a start-up raises the probability of using university knowledge, since we find an insignificant parameter for the start-up variable, and moreover, the parameter has the wrong sign. Since university knowledge may be of central importance in high-research intensive firms only, as suggested

in Hypothesis 3, we interacted the start-up variable with the long-tern R&D variable, R&D intensity and with some of the industry dummies, and although the signs changed, the variable did not become significant in any case. In model (2) we have shown the result for the interaction between start-up and long-term R&D, since long-term R&D may be a good proxy for whether or not the firm is a research-active organization. Accordingly, it may be concluded that we do not find support for Hypothesis 3 ("the propensity of a firm to draw from universities will be influenced by the age of the firm, with young research-active organizations drawing more heavily from university research"). The reason for the difference in results may lie in the fact that we use firms (with or without an R&D lab) use of university knowledge, while the Cohen et al. results are based on the use of university knowledge in R&D labs, and not in firms as such. However, there are a number of advantages of using a broader sample of organizations. It is possible to gain fuller understanding of general features of firms who draw from universities in their innovation activities rather than focusing on a specific subset of organizations. Moreover, it should also be noted that the effect of the start-up variable in the Cohen et al. study appears to be relatively weak.

Our firm-strategy variable is positive and strongly significant. Hence, we find a strong effect of the degree of openness in the external knowledge search strategy of firms on the probability of using university knowledge in innovation activities, given the fact that the parameter for the openness variable is highly significant, and again, all the non-zero marginal effects are positive. In sum, we find very strong support for Hypothesis 4 of this paper ("firms who choose "open" search strategies are more likely to draw from universities in their innovative activities"). This suggests that search strategy plays an important role in shaping the orientation of firms to universities. Firms who are more open in the way they search for new ideas for innovation are more likely to draw from universities. The decision whether or not to use universities in a firm's innovative activities is not pre-determined by the environment or structure of the firm, but it is also shaped by that firms' strategy for searching for innovative ideas, indicating that there is a strong degree of managerial choice in the use of universities by industrial firms.

We also conduct a factor analysis of the list of sources, using principal components analysis with Varimax rotation. The factor analysis reveals two major factors with Eigenvalues above one that (jointly) explain 62% of the variation in the original 15 source-variables. The factor

loadings from the factor analysis are reported in Appendix Table A2. We call the first variable the "broad search" factor as it relates closely to 10 of our 15 source-variables – accordingly this factor (openness factor 1) resembles the openness variable the most. We also identify another factor (openness factor 2), which we term the "research assistance" factor, since it is closely related to private and public source-variables mainly aimed at directly assisting firms in conducting innovative activities. In order to determine whether the use of the factors alters the results of our study, we introduce the factors into the regression and rerun the analysis using the factors instead of the "openness" variable. The results are shown in model (3), and show that both factors are significant and positive (and the corresponding marginal effects are positive for the use of university knowledge=1,2,3) in explaining the use of university knowledge, further strengthening the view that firm strategies matter in this context.

The findings concerning the industry controls (not shown for reasons of space) correspond broadly to previous findings in the field (e.g. Klevorick et al., 1995; Cohen et al., 2002) in showing that while controlling for other relevant factors – such as R&D intensity and size – firms in machinery and chemical industries use universities more than firms affiliated to other industries. Firms from the paper & printing and food industries appear to use universities less, when controlling for other factors.

DISCUSSION AND CONCLUSION

This paper began by observing the recent expansion of both academic and government interest in the role of universities in shaping and enhancing industrial practice. Despite the enthusiasm for university-industry links, we found that only a limited number of firms draw directly on university research when conducting their innovative activities. The results do not imply that universities make little or no contribution to industrial innovation, rather they suggest that the contribution of universities to industrial practice is likely to be highly concentrated in a small number of industrial sectors, among those firms who have existing capability in R&D and among those firms who have adopted an "open" approach to innovative search. These findings suggest that research examining the relationship between university research and R&D labs (such as Cohen et al., 2002) may tend to overestimate universities as knowledge sources, when making conclusions on the wider economic impact of universities. When analyzing a broader sample of firms, including both firms with and

without an R&D lab, more "conventional" knowledge sources such as firm-internal R&D, suppliers and customers continue to be the prime knowledge sources in manufacturing firms' innovation activities.

The present paper confirms the importance of "structural" factors in explaining why some firms use universities. It appears that R&D intensity, firm size and the industrial environment are important factors in explaining the propensity of firms to use universities in their innovative activities. We could not support the expectation that start-up firms are greater users of university knowledge in their innovative activities. It should be remembered that our sample of firms is drawn from the entire UK manufacturing industry and contains few firms in emerging science-based industries, such as biotechnology and nanotechnology. Other approaches that focus more directly on start-ups in these industries may be necessary in order to understand the relationship between universities and innovation in these rapidly emerging areas of the economy.

The key finding of the paper is that the search strategy adopted by a firm will strongly influence its propensity to use university knowledge and information. Previous attempts to explain why firms use universities have exclusively focused on structural factors. Yet our study demonstrates other factors are important as well. Managerial choice matters in determining whether a firm draws from universities. This finding has important implications for the literature on corporate strategy and contributes to the growing literature on the relationship between search strategies and innovation (Bowman & Helfat, 2001; Katila & Ahuja, 2002). It confirms Katila and Ahuja (2002) on the saliency of different search strategies in shaping the innovative activities of firms.

Despite government interest in supporting university-industry interaction as a key input to innovation, we find the innovation activities of firms are still shaped by their own internal strategies for knowledge exploration and exploitation (March, 1991), and their relationships with their customers and suppliers. In comparison to these sources of innovation, universities are of modest importance. In some respects, it could be argued that emphasizing university-industry interaction as a spur to innovation is like "pushing on string". That is, trying to stimulate relationships that may have only a faint impact on firm-level innovative performance. There is a possibility that our result reflects a deeper malaise in Europe about

university-industry interaction and that the findings of the study confirm Owen-Smith et al.'s (2002) suggestion that Europe (including the UK) "lags behind" the US. It is, however, extremely difficult to draw conclusions about national differences as the data used in the cross-industry comparisons in the UK and the US differ greatly. For example, our sample includes all firms, whereas Cohen et al. (2002) includes only those firms with R&D labs. This may explain some of the differences. However, it is also possible that differences in university-industry interaction between the US and the UK, as a result of dissimilar search strategies, may explain some of the difference. One possibility is that UK firms may have adopted narrower search strategies than US firms. Governments may need to place an increased emphasis in policy on broadening search strategies rather than promoting a particular knowledge source.

In the current literature on university-industry linkages more space needs to be given to managerial choice and search strategy. Along these lines, it would be useful to explore the characteristics of different search strategies, such as their depth and scope, and to link these properties to the propensity of firms to draw from universities. Such an approach would place the role of universities in innovation within the context of corporate strategies for exploitation and exploration of knowledge. We see this paper as a first step in this direction.

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APPENDIX A

TABLE A1

Marginal effects from the logit estimations in Table 2

	Uni. Know. =0	Uni. know. =1	Uni. know. =2	Uni. know. =3
Model (1)				
Log firm size	-0.018	0.0140	0.0035	0.0005
R&D intensity	-0.437	0.3401	0.0842	0.0126
Long-term R&D	-0.058	0.0448	0.0111	0.0017
Start-up	0.020	-0.0157	-0.0039	-0.0006
Openness	-0.043	0.0333	0.0082	0.0012
Model (2)				
Log firm size	-0.018	0.0139	0.0035	0.0005
R&D intensity	-0.435	0.3386	0.0838	0.0126
Long-term R&D	-0.057	0.0444	0.0110	0.0016
Start-up	0.024	-0.0183	-0.0045	-0.0007
Start-up x long-term R&D	-0.011	0.0084	0.0021	0.0003
Openness	-0.043	0.0333	0.0082	0.0012
Model (3)				
Log firm size	-0.021	0.0165	0.0037	0.0005
R&D intensity	-0.507	0.4039	0.0906	0.0126
Long-term R&D	-0.068	0.0544	0.0122	0.0017
Start-up	0.028	-0.0220	-0.0049	-0.0007
Openness factor 1	-0.127	0.1015	0.0228	0.0032
Openness factor 2	-0.173	0.1377	0.0309	0.0043

TABLE A2

Factor loadings from principal components analysis (Varimax rotation, n = 2665)

	Openness factor 1	Openness factor 2
Suppliers of equipment, materials, components or software	**0.77**	0.19
Clients or customers	**0.78**	0.20
Competitors	**0.67**	0.30
Consultants	0.40	**0.57**
Commercial laboratories/ R&D enterprises	0.30	**0.72**
Government research organizations	0.16	**0.82**
Other public sector e.g. business links, Government Offices	0.22	**0.76**
Private research institutes	0.16	**0.80**
Professional conferences, meetings	**0.55**	0.50
Trade associations	**0.61**	0.40
Technical/trade press, computer databases	**0.70**	0.35
Fairs, exhibitions	**0.72**	0.27
Technical standards	**0.78**	0.26
Health and safety standards and regulations	**0.84**	0.15
Environmental standards and regulations	**0.83**	0.18

ENDNOTES

[1] However Acs et al. (1994) find that while large firms innovative activities are more responsive to industry R&D as compared to small firms, small firms' innovative activities are more responsive to university research as compared to the case of large firms.

[2] This is also the case for the rest of the marginal effects, reported in Appendix Table A1.