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University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry?

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Abstract

This paper examines the different channels through which academic researchers interact with industry and the factors that influence the researchers' engagement in a variety of interactions. This study is based on a large scale survey of UK academic researchers. The results show that university researchers interact with industry using a wide variety of channels, and engage more frequently in the majority of the channels examined – such as *consultancy & contract research, joint research, or training* – as compared to patenting or spin-out activities. In explaining the variety and frequency of interactions, we find that individual characteristics of researchers have a stronger impact than the characteristics of their departments or universities. Finally, we argue that by paying greater attention to the broad range of knowledge transfer mechanisms (in addition to patenting and spin-outs), policy initiatives could contribute to building the researchers' skills necessary to integrate the worlds of scientific research and application.

Keywords: University–industry interactions; Variety; Academic researchers; Integration skills

1. Introduction

Universities play a crucial role in society as producers and transmitters of knowledge. In recent years the discussion about whether universities can encompass a third mission of economic development, in addition to research and teaching, has received greater attention (Mansfield, 1995; Branscomb et al., 1999; Etzkowitz and Leydesdorff, 2000; Leydesdorff and Meyer, 2003). Many scholars have argued that within the remit of the third mission university–industry research collaborations are extremely important mechanisms for generating technological spillovers. Such collaborations contribute positively to address innovation market failures and help realise the full social returns of R&D investments (Martin and Scott, 2000; Siegel and Zervos, 2002). Moreover, there is a burgeoning empirical literature showing an increasing level of academic commercial activities, such as patenting and licensing, and generation of spin-out companies (Shane, 2004; Friedman and Silberman, 2003; Thursby and Kemp, 2002; Zucker et al., 1998). This has been accompanied by an increase in research joint ventures (Hall et al., 2001) and joint scientific publications (Calvert and Patel, 2003). At the same time many governments have introduced an increasing range of policies encouraging the involvement of universities in technology transfer.

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Despite this growing interest among academics and policy makers there are a number of gaps in the understanding of university-industry linkages. This paper aims to investigate two such gaps. The first is related to the variety of channels through which knowledge transfer occurs. Much of the literature on university–industry technology transfer has centred on the academic capacity to generate and exploit intellectual property rights (IPR) via patent ownership agreements, academic spin-offs and income streams from licences and royalties (Shane, 2004; Friedman and Silberman, 2003; Jensen et al., 2003; Link et al., 2003). In addition, many policy initiatives are aimed at encouraging university researchers to engage in patenting, licensing and creating new companies. However, systematic analysis of other forms of knowledge transfer, such as joint research projects, consultancy and training, has been largely neglected. The purpose of this paper is to focus on this wider variety of channels through which university researchers interact with industry.

The second neglected issue in the literature is related to the factors underlying the interactions of academic researchers with industry. Existing research shows that the distribution of science–technology interactions among academic researchers is highly skewed, with a few researchers engaged in a large number of interactions (Balconi et al., 2004; Agrawal and Henderson, 2002). However, we know little about the distinctive role of individual characteristics versus institutional characteristics (i.e. the institutional affiliation of university researchers) in explaining such heterogeneity of behaviour.

The paper is organised as follows. Section 2 sets out the conceptual framework highlighting why variety of interactions matters within the context of knowledge transfer between university and industry. Section 3 sets out the main research questions addressed in the paper and examines the main factors underlying the engagement of academic staff with industry, through a review of the literature. A description of the data used in the analysis is contained in Section 4, and Sections 5 and 6 present the main empirical results. Section 7 presents our conclusions.

2. Why variety of university–industry interactions matters

2.1. *Emphasising variety rather than focusing solely on patenting and spin-offs*

Many earlier studies of knowledge transfer have concentrated on patenting, licensing and formation of start-up companies as the main contributions of universities to technology diffusion. However, as several authors have noted, university–industry links embrace a much broader spectrum of activities than commercialisation of IPR (Agrawal and Henderson, 2002; Mowery and Sampat, 2005; Cohen et al., 2002; Mansfield and Lee, 1996; Schartinger et al., 2001). In particular, Cohen et al. (2002), using data from the Carnegie Mellon Survey of R&D performing firms in the US, highlighted that for most industries patents and licences were of lesser importance as channels for conveying public research than publications, conferences, informal interactions and consulting. In addition, Schartinger et al. (2001) and Roessner (1993) showed that patenting and licensing account for a small proportion of public–private interactions when compared to other formal arrangements such as contract research or joint research agreements. Agrawal and Henderson (2002), using data on academics in departments of mechanical and electrical engineering at MIT, confirm these findings, showing that patents account for only around 10% of all knowledge transfer activities.[1]

Thus there is abundant empirical evidence to suggest that the process of knowledge transfer between university and industry occurs through multiple channels such as personnel mobility, informal contacts, consulting relationships and joint research projects, and that patenting and spin-offs play a comparatively small part in this process (Faulkner and Senker, 1995; Arundel and Geuna, 2004; Sequeira and Martin, 1997). This is partly because only a minority of university–industry interactions are motivated by the prospect of directly realised commercial products. As Mansfield and Lee (1996) argue, academic R&D supported by industry seldom yields specific inventions or products. Such R&D is generally aimed at getting up-to-date knowledge, obtaining access to students and faculty, and finding solutions to specific problems.

Moreover, as Howell et al. (1998), Meyer-Krahmer and Schmock (1998) and D'Este et al. (2005) showed, university researchers choose to interact with industry for a diverse set of reasons. These include access to additional research income, applicability of research, access to industry skills and facilities, and keeping abreast of industry problems. It is unlikely that any single form of

[1] Many authors have noted the inherent risks involved in concentrating on IPR commercialisation and formation of spin-offs, given the highly skewed nature of licensing income, with only a very small proportion of inventions yielding commercial success (Lee, 1996; Lerner, 2005). Moreover increasing university patenting and licensing may pose serious challenges to the culture of open science within academia (Mowery and Sampat, 2005).

interaction satisfies such a wide range of motivations. For instance, consultancies might raise additional income, but might have little effect on the need to access industry skills and facilities. On the other hand, joint research agreements will enable researchers to access these skills and facilities. This implies that researchers motivated to interact with industry are likely to do so through a variety of forms rather than via a single mechanism. Such variety enables them to reap both larger pecuniary (e.g. research income) and non-pecuniary (e.g. satisfaction from seeing research brought into application) returns.

In the light of this discussion, too much attention on patenting and spin-off activities may obscure the presence of other types of university–industry interactions that have a much less visible economic pay-off, but can be equally as (or even more) important both in terms of their frequency and economic impact.

2.2. Variety and 'integration' skills

In addition there are conceptual reasons for paying attention to variety. The concept of 'technology integration' in the knowledge management literature provides a theoretical framework for understanding the underlying rationale for academic engagement in a variety of interaction channels with industry. As stated by Iansiti (1998), technology integration can be defined as the capacity to successfully interrelate the worlds of research and the worlds of manufacturing and product application. While Iansiti introduces the concept within the context of organisational capabilities, we propose to apply it at the individual level to refer to individual skills, arguing that academic researchers who interact with industry through a wider set of mechanisms are more likely to build the capabilities necessary to bridge the gap between scientific research and application. The researcher's exposure to frequent and varied types of interactions with industry provides the basis on which such integration capabilities can be built, since, as Vincenti (1990) argues in the context of engineering knowledge, the capacity to successfully integrate science and technology can only grow through a complex interplay of experimentation and theory.[2]

Drawing on this concept of technology integration, we contend that the variety of interactions with industry positively contributes to the creation and development of academic researchers' 'integration' skills (i.e. the individual 'capabilities' necessary to integrate the worlds of scientific research and the worlds of manufacturing and product application), in the sense that it provides the university researcher with the opportunity to learn about the research and development worlds, and the most effective ways to facilitate interaction between the two. The reinforcing interplay between engagement in a varied range of interactions and the building of integration skills comes about for two reasons.

The first is related to the idiosyncratic nature of knowledge transfer processes (Bonaccorsi and Piccaluga, 1994). The context-specific nature of the knowledge transfer process – the degree to which knowledge can be codified, the extent to which problem solving is related to early stage or close-to-market research, the degree of explorative learning required, etc. – vary from one process to another. Consequently, different types of knowledge transfer processes will require different forms of inter-organisational arrangements between university and industry in order to make the transmission and dissemination processes more effective. These different arrangements include the necessity for frequent/intense information exchange (e.g. transfer of personnel versus one-off interaction), the length and involvement of resources (e.g. setting up a laboratory versus no commitment of industry funding), and the necessity for clear rules on knowledge appropriation (e.g. IPR agreements).

Based on the above, we would argue that the greater the engagement of a particular researcher in a wider variety of knowledge transfer activities with industry, and thus the greater the participation in a variety of inter-organisational arrangements, the more likely it is that the individual will build the skills necessary to integrate science and technology. These science and technology integration skills refer not only to the capacity to command a wide range of bodies of knowledge (i.e. fundamental and applied areas of research), but also to the capacity to balance and align conflicting interests arising from the distinct system of incentives between academia (governed by 'open science' norms) and industry (governed by 'proprietary technology' norms).

The second reason is related to the bi-directional knowledge flow that is often neglected in the analysis of university–industry interactions; in particular, the knowledge flow from industry to university. Interaction with industry practitioners exposes university researchers to a wide range of technological problems identified by industry, opening an array of research avenues that would not have emerged had researchers remained within the boundaries of university research. At the same time greater engagement in a variety

[2] The authors are particularly grateful to Finn Valentin for suggesting the concept of 'integration skills' within this context.

of interactions with industry is conducive to a better understanding of the application context by the university researcher, since industry practitioners are likely to be much better informed (compared to academic researchers) about technology and user needs as a consequence of proximity to users and downstream research (Siegel et al., 2003).

In short, analysing the variety of channels through which university researchers interact with industry should not only contribute to a more comprehensive picture of knowledge transfer activities (as opposed to an approach mainly focused on academic patenting behaviour), but also should identify those individuals who are more likely to develop the necessary skills to integrate fundamental research and technology development.

3. Drivers of interaction with industry among university researchers

Empirical studies that have contributed to the debate on university–industry interactions have looked mainly at the determinants of university–industry linkages, either from the viewpoint of firms involved in the collaboration (Cohen et al., 2002; Fontana et al., 2006) or from the perspective of the university and/or the department (Di Gregorio and Shane, 2003; Friedman and Silberman, 2003; Schartinger et al., 2001; Tornquist and Kallsen, 1994). A few studies have looked at the determinants of university–industry interactions taking the individual academic researcher as the unit of analysis (Landry et al., 2005; Bercovitz and Feldman, 2003; Agrawal and Henderson, 2002; Louis et al., 2001, among others). As Bercovitz and Feldman (2003) argue, the main reason for focusing on university researchers and the factors influencing their interactions with industry is that we need to improve our understanding about *who* in academia interacts with industry, and *why*. This is particularly important for the design of public policies aimed at facilitating and fostering university knowledge transfer.

In this paper, we examine the relative impact of both institutional (i.e. department and university) and individual characteristics in explaining the likelihood of engagement in a wider variety of interactions with industry.

Drawing upon the sociological literature on embeddedness (Kenney and Goe, 2004), it is important to distinguish whether the efforts devoted to creating and/or nurturing a wider scope of linkages with industry are a function of individual attributes or the result of the individual's environment. The environment that is likely to have the greatest influence on university researchers' behaviour is the department routines and the university culture and policies.

3.1. Commercial orientation of universities

As pointed out by Di Gregorio and Shane (2003), universities differ in the degree to which their researchers engage with industry. This is largely a consequence of the commercial orientation of university research. Some of the factors most frequently associated in the literature with strong commercial orientation are the founding mission of the university and the technology transfer experience of the university—either measured by the age and resources of TTOs or by the amount of industrial support for research received by the university (Di Gregorio and Shane, 2003; Friedman and Silberman, 2003; Siegel et al., 2003; Feldman et al., 2002). In this paper we examine the impact of two university features: whether the university had a founding mission to support regional development (as captured by whether the university was a former polytechnic) and whether the university has a strong orientation towards technology transfer activities (as captured by the proportion of each university's research budget funded by industry).

3.2. Department characteristics

The practices established by university departments might strongly influence the disposition of researchers to set up networks with users of their research. The scale of research resources and the quality of research are among the department characteristics most frequently associated with more intensive interaction with industry. The scale of resources, in terms of either academic research personnel or research income, can be considered a necessary condition for attracting industry interest. Some authors have suggested a U-shaped relationship between the size of the university department and the volume of industry interactions, with medium-sized departments being disadvantaged relative to small and large ones (Schartinger et al., 2001).

As with the case of the university as a whole, a large accumulated volume of research income from industry at the departmental level may signal a research profile more closely connected to the needs of industry, and thus an institutional environment that favours interaction with industry. Moreover, in addition to the total volume of research income per staff, different sources of funding for research at university departments – i.e. from business and public authorities – may have a distinct impact on interactions with industry (Schartinger et al., 2001).

However, abundance (or scarcity) of resources is not all that matters; the quality of research is also important. Thus, a number of studies have shown that there is a positive relationship between quality of university research and likelihood of interaction with industry (Mansfield and Lee, 1996; Tornquist and Kallsen, 1994). However, such a positive relationship does not apply to all modes of interactions. For example, Schartinger et al. (2001) show that, with the exception of joint research, for all other interaction types, association between research quality and the probability of interaction is non-existent.

3.3. Individual characteristics

While institutional characteristics are likely to influence the motivations of academic researchers to interact with industry, it is also reasonable to propose that entrepreneurial behaviour may also be strongly shaped by the features of individual university researchers. Previous research has argued that the past behaviour of an individual researcher regarding participation in knowledge transfer generates a strong imprint, leading to an expectation regarding continuing knowledge transfer practices (Bercovitz and Feldman, 2003).

Moreover, we would expect that individuals who have raised funding for research are more likely to attract the interest from industry, since success in fund raising may facilitate the identification of those researchers that are more active in certain fields of research (Landry et al., 2005). Additionally, we examine whether there is a relationship between the academic career cycle and the inclination to engage in knowledge transfer activities, by considering individual features such as age and seniority (i.e. academic status) (see, for instance, Bercovitz and Feldman, 2003).

Finally, as Owen-Smith and Powell (2001) showed in their comparison of life sciences and physical sciences faculties, cultural norms across scientific fields may also be critical in shaping faculty involvement in entrepreneurial activities. As Kenney and Goe (2004) argue, academic researchers from the same scientific discipline have a set of common perceptions and practices that are likely to influence their degree of engagement in knowledge transfer activities. In this paper we examine the extent to which patterns of collaboration differ across different disciplines.

In summary the aim of this paper is to investigate the factors that underlie the decision to interact with industry across a range of interaction channels using data collected from individual university researchers. In principle, this should allow us to disentangle the importance of factors associated with university–industry interactions at three levels of aggregation: the university, the department, and the university researcher.

4. Data description

This paper is based on a large-scale survey of university researchers in the UK aimed at obtaining information about their interactions with industrial partners (see D'Este et al., 2005). The sample of researchers was obtained from the records of principal investigators who had received research grants from the UK Engineering and Physical Sciences Research Council (EPSRC) in the period 1995–2003. The EPSRC distributes funds on the basis of research proposals, mainly from university-based investigators, in response to open calls for applications. It distributes some 23% of the total UK science budget and is responsible for funding research in the areas of engineering and physical sciences. The EPSRC actively encourages partnerships between researchers and the potential users and beneficiaries of research. Partners may include people working in industry, government agencies, local authorities, National Health Service (NHS) Trusts, non-profit organisations, research and technology organisations and the service sector. As a result, almost 45% of EPSRC funded research grants involve partnerships with industry or other stakeholders.

In order to ensure that the list of university researchers to be surveyed was representative of the overall population of active researchers, the range of scientific fields was restricted to 10, excluding those fields where researchers were likely to apply to other research councils in their search for research funding. The 10 scientific fields included in our study are chemical engineering; chemistry; civil engineering; computer science; electrical and electronic engineering; general engineering; mathematics; mechanical, aeronautics and manufacturing engineering; metallurgy and materials; and physics. In order to minimise the risks that addresses were not up to date, the sample was restricted to individuals who received grants between 1999 and 2003. This resulted in a list of 4337 university researchers.

The main problem with this sampling strategy is that it only captures scientific disciplines within the remit of the EPSRC, and excludes disciplines related to biology and medicine. Moreover, even for disciplines within the EPSRC remit, generalisation of the results to the whole population of university researchers should be made with care since we do not capture those researchers relying solely on other forms of funding (e.g. from industry).

Table 1 reports the distribution of researchers across the 10 scientific disciplines and the proportion that they

Table 1
Proportion of population surveyed relative to total academic staff

	Population surveyed	Academic staff (average in 1999–2003: HESA)	Proportion of population surveyed in total population of academic staff (%)
Chemical engineering	174	655	26.5
Chemistry	754	3230	23.3
Civil engineering	242	1433	16.9
Computer science	536	3493	15.3
Electrical & electronic engineering	496	3428	14.5
General engineering	292	2844	10.3
Mathematics	563	2855	19.7
Mechanical, aero. & manuf. engineering	484	3040	15.9
Metallurgy & Materials	201	1063	18.9
Physics	595	3333	17.8
Total	4337	25379	17.1

Note: HESA defines academic staff into three categories according to their primary employment function: teaching only, teaching and research, and research only. In addition, note that HESA classification of departments in the 10 categories in the list may slightly differ from the criteria used by EPSRC to classify university researchers across scientific disciplines. In this sense, the final percentages in column 3 must be taken as approximations.

represent of total academic staff in those disciplines (i.e. the average number of academic staff between 1999/2000 and 2002/2003 as measured by the UK Higher Education Statistical Agency, HESA). There are some differences across disciplines with chemical engineering and chemistry being over-sampled, and general engineering being under-sampled (the sampling proportions of each of these three scientific fields significantly depart from those of all other fields combined).

However, it is important to note that HESA academic staff includes non-research active academic staff, and thus, the proportions shown in column 3 of Table 1 represent a lower bound. Ideally we would have preferred to include only research active staff, rather than total academic staff, to compute the proportions. Indeed, if we consider the figures from the Research Assessment Exercise (RAE) (2001),[3] which report the number of full-time-equivalent staff that submitted to the RAE (and therefore can be considered as our reference population of research active staff), the proportion of the population surveyed relative to the RAE records of active researchers in the 10 fields considered is 44%, ranging from 29% for general engineering to a 59% for chemical engineering.[4]

Our survey was conducted in the first half of 2004, and resulted in 1528 valid returned questionnaires, a response rate of 35.2%. There were no statistical differences in the response rates across scientific disciplines, which ranged from 30.2% for computer science to 39.7% for general engineering.

5. Patterns of university–industry interaction

This section provides a description of the data collected in the survey, addressing a number of issues. First, we describe the range of university–industry interactions included in the survey, and the rationale for grouping interaction channels into non-overlapping categories. Second, drawing upon the survey data, we assess the extent to which university researchers interact with industry, the most common types of interaction, and whether these interactions are evenly spread across the academic community or are concentrated in certain scientific fields, universities or regions.

5.1. Classification of university–industry interactions in distinct categories

The survey asked about the importance of a variety of interactions in the period 2002–2003, including formal agreements (involving contracts between university and industry researchers) and informal networks (such as meetings and conferences). As many authors have noted (Bonaccorsi and Piccaluga, 1994; Faulkner and Senker, 1995; Schartinger et al., 2001) interactions can be categorised according to resource deployment, and length and formalisation of agreements. Building on this

[3] This information is available at www.hero.ac.uk.

[4] The proportions of the population surveyed relative to RAE 2001 records of research active staff for the remaining disciplines are as follows: chemistry, 58%; civil engineering, 47%; computer science, 34%; electrical & electronic engineering, 57%; mathematics, 45%; mechanical, aero. & manufacturing engineering, 47%; metallurgy & materials, 50%; and physics, 36%.

Table 2
Grouping interaction types in five categories

Groups	Interaction activities included in the questionnaire
Meetings and conferences	Attendance at *Industry sponsored meetings* Attendance at *Conferences* with industry and university participation
Consultancy and contract research	*Consultancy work* (commissioned by industry, non involving original research) *Contract research agreements* (commissioned by industry and undertaken only by university researchers)
Creation of physical facilities	Setting up *spin-off companies* *Creation of physical facilities* with industry funding (including campus laboratories, incubators and cooperative research centres)
Training	*Postgraduate training in company* (e.g. joint supervision of PhDs) *Training company employees* (through course enrolment or personnel exchanges)
Joint research	*Joint Research agreements* (involving research undertaken by both parties)

Table 3
Correlation matrix for the five categories of interaction

Type of interaction	Category 2	Category 3	Category 4	Category 5
Category 1	0.443	0.249	0.366	0.316
Category 2		0.235	0.341	0.266
Category 3			0.191	0.316
Category 4				0.306

Notes: Category 1: meetings and conferences; Category 2: consultancy and contract research; Category 3: creation of physical facilities; Category 4: training; and Category 5: joint research. All Pearson correlations are significant at the 0.01 level. The number of observations for the correlation analysis ranges between 1064 (e.g. Category 3 vs. Category 5) and1071 (e.g. Category 1 vs. Category 4).

literature we asked respondents about the frequency of interactions across nine different activities and classified them into five groups (see Table 2).[5] Appendix A presents the question as framed in the survey questionnaire.

We grouped the nine types of interaction according to their intrinsic characteristics. The first category was *industry sponsored meetings and conferences*, which are grouped together as representing personal informal relationships (those interactions between university researchers and industrial practitioners that do not involve any formal, signed agreement). The second group was *consultancy and contract research*, representing commissioned and targeted-research agreements between industry and academic researchers involving formal agreements and the definition of specific objectives at the start of the contract. The third category includes creation of *new companies* and new *physical facilities* involving industry funding, representing establishment of focused structures generally involving a heavy organisational commitment by the university.[6] The fourth group focuses on *training* relationships, either joint training by university and industry of PhD students or training for company employees enrolled in university courses. The fifth group was *joint research*, which we consider as to be a category on its own since it involves formal research agreements under which original research is conducted in university–industry collaborations.

The data from the survey provide empirical support for the conceptually driven criteria underlying the five categories presented in Table 2. Using the survey data, and considering respondents who reported having been involved in at least one interaction (regardless of channel) with industry, we computed the number of times (using interval mid-points) that respondents reported having interacted within each of the five categories in Table 2. It can be seen that there is only a weak correla-

[5] The questionnaire included also two other types of interaction (secondments to industry and creation of electronic networks). However, because they proved to be extremely infrequent among respondents, we have not included them further in the analysis.

[6] While we realise that *spin-offs* and *creation of physical facilities that involve industry funding* are different species, we have grouped them together to reflect structures created with a mission towards commercialisation or to conduct application-oriented research.

Table 4
Involvement of university researchers in the five interaction categories according to scientific discipline (% of university researchers engaged at least once over the period 2002–2003 in any of the interaction activities included in each of the five interaction categories)

Discipline	Meetings and conferences	Consultancy and contract research	Joint research	Training	Creation of physical facilities
Chemical engineering	85.5	75.4	59.0	56.5	26.2
Chemistry	67.4	58.9	46.8	45.2	17.3
Civil engineering	81.4	74.4	47.7	44.2	26.7
Computer science	59.9	42.0	42.6	31.5	17.9
Electrical and electronic engineering	81.4	69.8	54.7	53.5	32.0
General engineering	79.3	71.6	55.3	52.6	31.0
Mathematics	24.1	20.4	12.0	15.3	2.8
Mechanic. aero. and manuf. engineering	86.0	81.0	62.9	62.0	34.8
Metallurgy and materials	89.9	82.6	61.8	64.7	31.9
Physics	46.7	37.4	35.9	31.8	11.3
All disciplines combined	65.0	56.3	44.6	42.5	20.8
Number of valid observations	1527	1526	1519	1526	1526

Note: There are significant differences in percentages across the 10 disciplines (chi-square, $p < 0.01$) within each interaction category.

tion among the five categories, supporting the argument that these categories are largely non-overlapping. As Table 3 shows, while correlation coefficients are significant at standard levels, the correlation coefficients themselves are relatively low.[7] Therefore, conceptually these five categories represent distinct forms of interaction, and empirically the five categories are weakly correlated forms of interaction.

5.2. Modes of university researchers' engagement with industry: wide-ranging and frequent or limited and rare?

In order to assess the extent to which university–industry interactions are spread among university researchers, we examined the results along three dimensions highlighted in the literature: scientific disciplines (Klevorick et al., 1995); regions (Audretsch and Feldman, 1996; Zucker et al., 1998); and university departments (Schartinger et al., 2001; Mansfield and Lee, 1996).

5.2.1. Differences according to disciplines

Here we examine whether the proportion of respondents that report having involvement in an interaction type at least once varies across scientific disciplines. The underlying hypothesis in the literature is that scientific disciplines play an important role in influencing the type of interactions with industry. The results reported in Table 4 highlight two issues. First, as could be expected, the most widespread form of interaction with industry is *meetings and conferences*, which is a reflection of the extent to which university researchers are involved in any of these two informal interactions with industry. A rather more surprising result is the extent of involvement in *consultancy and contract research.* About 56% of university researchers in our study had engaged in consultancy or contract research at least once over the period 2002–2003. *Creation of physical facilities* (i.e. spin-offs and new laboratories) was the least frequent form of interaction, and *joint research* and *training* were moderately important. In summary, for four out of the five interaction types, over 40% of university researchers have been involved in some form of interaction with industry.

Second, within each of the five interaction categories there are significant differences in the level of involvement across disciplines, with mathematics (and to a lesser extent physics) researchers showing much lower levels than those engaged in research in most fields of engineering. While it is tempting to conclude that there is a stark distinction between basic and applied fields in terms of participation in university–industry interactions, this distinction is not clear-cut, as chemistry researchers seem to resemble their counterparts in engineering fields rather than those in physics or mathematics, and the pattern for computer science researchers resembles that of physics.

Our survey also asked whether university researchers had been involved in any sort of patenting activity between 2002 and 2003 (i.e. in patent applications or

[7] This grouping was largely confirmed by factor analysis; data reduction by means of factor analysis leads to identification of four groups. The only discrepancy with our five categories is that the factor analysis groups together: *industry sponsored meetings and conferences* and *consultancy and contract research*.

Table 5
Involvement of university researchers in the five categories of interaction according to regions (% of university researchers engaged at least once over the period 2002–2003 in any of the interaction activities included in each of the five interaction categories)

UK RDA regions	Meetings and conferences	Consultancy and contract research	Joint research	Training	Creation of physical facilities
East Midlands	65.6	59.5	47.3	38.9	23.7
East of England	69.2	58.7	49.3	46.2	23.1
London	63.4	51.9	43.3	39.9	17.5
North east	61.2	50.0	40.8	34.7	16.3
North west	69.8	59.7	46.9	45.7	25.6
Northern Ireland	64.9	56.8	43.2	37.8	29.7
Scotland	62.8	55.9	42.0	38.8	17.6
South east	65.2	54.2	41.6	38.3	16.7
South west	60.2	52.4	45.1	44.7	23.3
Wales	74.2	66.1	45.2	54.8	24.2
West Midlands	58.2	52.7	42.2	48.9	18.7
Yorkshire & Humberside	65.8	59.2	47.3	46.2	23.4
All regions combined	65.0	56.3	44.6	42.5	20.8
No. of valid observations	1527	1526	1519	1526	1526

Notes: There are no significant differences in percentages across the 10 disciplines (chi-square, $p < 0.5$) within each interaction category.

Table 6
Involvement of university researchers in the five interaction categories according to departmental research income (% of university researchers engaged at least once over the period 2002–2003 in any of the interaction activities included in each of the five interaction categories)

Department categories in terms of total research income per staff	Meetings and conferences	Consultancy and contract research	Joint research	Training	Creation of physical facilities
Below £10 k	45.5	36.6	27.7	25.9	9.9
Between £10 k and £25 k	59.2	53.5	40.0	37.0	18.7
Between £25 k and £40 k	70.1	60.2	49.3	46.3	23.8
Above £40 k	74.5	64.1	52.3	52.6	24.9
Total	65.0	56.2	44.7	42.5	20.9
No. of valid observations[a]	1524	1523	1516	1523	1523

[a] There are three cases for which we could not match the institutions reported in EPSRC and HESA. There are significant differences in percentages across the four department categories of research income per staff (chi-square, $p < 0.01$) within each interaction category.

patents granted). While patenting is not an interaction with industry, it is an indication of the commitment of university researchers towards proprietary knowledge and commercialisation activities. Overall, 25% of respondents indicated that they had been involved in patenting activities at least once, with electrical & electronics engineering showing the highest percentage (38%) and mathematics and computer science (4% and 11%, respectively) the lowest. These results show that patenting activity occurs at similar frequency to *Creation of physical facilities*, and thus are events of comparatively lower frequency relative to the other four types of interaction.

5.2.2. *Differences according to regions*

We also investigated the extent to which university–industry interactions were spread across regions in the UK. From Table 5 it can be seen that there are no significant differences across regions in terms of percentages of researchers involved in each of the five types of interaction considered.[8] The results in Table 5 do not take account of the geographical location of the interaction – i.e. whether the interaction took place within the region – but simply show the proportion of university researchers in each region that report having been engaged in interactions with industry (wherever industrial partners are located).

[8] The proportion of university researchers surveyed relative to total academic staff (as measured by HESA) is largely similar across UK regions, ranging from 12.2% for the north east to 19.5% for the south west.

5.2.3. Differences according to university departments

Here we analyse the extent to which university–industry interactions vary according to the department in which a researcher is located. In particular, we examine whether the department's research income level has an influence on the proportion of researchers engaged in each of our five types of interactions. The results in Table 6 show that the probability of interacting with industry for the five categories of interaction considered, increases with departmental research income per staff.

In summary, our survey results show that a significant proportion of university researchers take part in interactions with industry, and that these interactions take a wide variety of forms. The degree of engagement with industry, among university researchers varies according to scientific discipline, but this cannot be simply related to a distinction between basic and applied disciplines. Moreover, university researchers in all UK regions engage with industry (regardless of location) to similar degrees. Finally, we found that the degree of engagement in interactions with an industrial partner increases with the research income of the university department, indicating that university–industry interactions may be strongly influenced by institutional characteristics. In the next section we formally examine the relative roles of institutional and individual characteristics in such interactions.

6. Factors influencing the variety of university researchers' interaction with industry

In this section we investigate the factors that influence the variety of university researchers' interactions with industry. We discuss the construction of the variables used, and report the results of the empirical analysis.

6.1. Measure of 'Variety'

Our dependent variable is constructed to reflect the variety of interactions discussed in Section 5.1. However, measuring variety is not a simple matter. As Stirling (1998) argues,[9] the concept of variety comprises three basic properties: (a) the category count, or the number of categories into which the system elements are apportioned (i.e. how many categories do we have?); (b) the balance, or the relative weight of the different categories (i.e. how much of each type do we have?); and (c) the disparity, or the degree to which the categories differ (how different from each other are our categories?).

Any measure of variety focused only on a sub-set of the above three properties would produce an incomplete picture of the extent of variety (Stirling, 1998). For instance, looking only at the number of different categories can be an inadequate measure of variety if categories are very similar in nature or if one category is very frequent and the rest extremely infrequent.

In order to deal with the problem of measurement, we propose using two complementary indicators – variety 1 and variety 2 – to capture, as comprehensively as possible, the three properties of variety mentioned above. It is important to note that in terms of the third property, 'disparity', we limit our assessment to the discussion in Section 5.1, where we showed that the five categories of interaction we identified are essentially distinct, and show no substantial overlap. The two indicators of variety that we applied are explained below.

6.1.1. Variety 1

'Variety 1' measures the extent to which researchers are involved in a broad or narrow range of interactions by examining the number of distinct categories of interaction in which the researcher has engaged. If a researcher responds as having no interaction with industry in any of the five categories listed in Table 2, then the dependent variable takes the value 0; if a researcher reports interaction in just one type of interaction (say, joint research agreements), the value is 1; if a researcher was active in two categories of interaction, the value is 2, and so on. Thus, our dependent variable reaches a maximum value of 5 if researchers interacted in all five modes.[10]

By defining our dependent variable in this way, we consider two of the properties of variety mentioned above: the category count and the disparity. In this sense, we can argue that 'Variety 1' measures *how many distinct* forms of interaction the individual researcher is engaged in. The advantage of this indicator is that it is compatible with the use of our survey data to obtain a measure of the breadth of interactions, and overcomes the problem of having to aggregate or balance interactions that are very different in nature (i.e. formal versus informal, interactions involving a diverse time span or a different commitment of resources, etc.). However, this indicator does not provide any information regarding the frequency of interaction (the relative weight across categories).

[9] Note that we use a different terminology to that used by A. Stirling (1998); we refer to variety while he uses the term diversity.

[10] Cronbach's alpha coefficient, examining the reliability of a scale, shows that the variable 'Variety 1' has relatively high internal consistency: Cronbach's alpha coefficient is 0.80.

6.1.2. Variety 2

'Variety 2' measures the number of distinct forms of interaction in which a researcher has engaged more frequently than the average (relative to our overall sample of researchers). The indicator ranges between 0 (if interaction was below average in each of the five categories) to 5 (if interaction was above average in each of the five categories).[11]

By considering a measure of frequency (or intensity), 'Variety 2' includes the three properties mentioned above. The indicator tells us in how many categories a researcher is interacting more frequently than average. Therefore, if a researcher interacts in three types of interaction more frequently than the average this ranks as a higher level of variety, compared to engagement in all five forms of interaction but never above the average in terms of frequency.

Thus, while Variety 1 focuses on the breadth/range of interaction categories, Variety 2 focuses on the frequency (how much the individual interacts within each category of interaction). We consider that these two indicators are complementary in capturing the variety of interactions in which a researcher is engaged; and thus, the use of both of these indicators measures variety in a very comprehensive manner. For instance, out of the 1060 respondents who reported having been involved in at least one of the five types of interaction, 51% (almost 550 respondents) scored 3 or above for 'Variety 1', but only 2 or less for 'Variety 2', while only 21% respondents scored 3 or above both measures of variety. Finally, since our two dependent variables are discrete and ordered (ranging from 0 to 5), the estimation procedure chosen was an ordered logit model.[12]

6.2. Explanatory variables

As discussed in Section 3, the literature suggests a number of variables that are likely to affect university researchers' interactions with industry partners. We grouped these explanatory factors into three broad categories related to the *individual*, the *department* and the *university* characteristics.

In terms of the attributes of individual university researchers, we examine the following factors. First, we examine the extent to which previous experience of collaborative research with industry has an impact on the variety of interactions an individual engages in. We would expect a positive relationship as a large number of interactions in the past may point to the formation of a personal network of relationships with industry, which generally is built upon mutual trust and thus is likely to endure over time. We used two variables to account for previous involvement in interactions with industry: *number of joint publications with industry* in the period 1995–2000, and *average value of collaborative grants* (i.e. with industry) obtained by the university researcher from the EPSRC in the period 1995–2001. These two variables are not correlated with each other (see Appendix Table A2), indicating that they are capturing different channels of interaction.[13]

Second, we examine the amount of public funding for non-collaborative research obtained by an individual researcher as a measure of success in fund-raising. However, the sign of this relationship is unclear a priori. On the one hand, a negative relationship might be expected, as the higher the level of non-collaborative research funding obtained by the researchers, the less will be their dependence on other sources of income, such as industry. On the other hand, if being a fund-raiser is a proxy for quality of research, then the sign of the relationship would be positive, since high quality research is likely to attract the attention of industry. Our proxy for non-collaborative research funding is the *average value of non-collaborative grants* obtained by the researcher from the EPSRC over the period 1995–2001.

Third, we examine whether the incentives to engage in interactions with industry vary according to the

[11] The questionnaire asked about the number of times the respondent had participated in each type of interaction over the period 2002–2003, and to indicate the number in a set of five possible intervals. We assigned each response to the corresponding interval mid-point and calculate an average number of interactions within each interaction category. We then compared the records of each individual in each single category of interaction with the average value for the corresponding category of interaction. If the number of a respondent's interaction fell into a category above that for the average, we codified this as 1 (otherwise the value given was 0). Finally, we summed each respondent's scores across the five categories of interaction. The Cronbach alpha coefficient for 'variety 2' is 0.67.

[12] The proportion of questionnaire respondents in each of the six categories of our dependent variable 'Variety 1' was: Category 1 'no interaction': 29%; Category 2 '1 type of interaction': 5%; Category 3: '2 types of interaction': 15%; Category 4 '3 types of interaction': 20%; Category 5 '4 types of interaction': 20%; Category 6 '5 types of interaction': 11%. For 'Variety 2' the proportion of respondents across the six categories is as follows: Category 1, 49%; Category 2, 21%; Category 3, 16%; Category 4, 8%; Category 5, 5%; and Category 6, 2%. Because of the small proportion of cases in some categories, we conducted the analysis using both the above defined dependent variables as well as alternative indicators in which certain categories were aggregated. The estimated results were similar to those reported in the text.

[13] Data on EPSRC grants and names of Principal Investigators were provided by EPSRC; we drew the sample population for the survey from this information. The value of grants is measured in £ thousands.

researcher's *age* and *academic status* (measured as a dummy variable, indicating whether the researcher is a professor or not). The direction of the relationship is unclear a priori. On the one hand, drawing upon the human capital argument (Levin and Stephan, 1991), it could be expected that researchers who are well established in their careers may be more likely to capitalise on their reputation and to engage in commercialisation activities, while younger scientists are more likely to concentrate on publishing, particularly if commercialisation activities are not properly recognised within their academic community as a basis for promotion. On the other hand, some studies find that the growing acceptance of the role of scientists as entrepreneurs in academic institutions, may have caused a vintage effect in which the closer in time a researcher completes her training (e.g. PhD), the more likely she is to have adopted an attitude towards interaction with industry that conceives such interaction as an inherent part of the research mission (Bercovitz and Feldman, 2003).

The second group of explanatory variables relates to the characteristics of researcher's university department. As discussed in Section 3, we aim at examining whether the amount of research income at the department level has an impact on the interactions that researchers undertake with industry. We use two variables to capture this: *research income from industry per member of staff* and *research income from public sources per member of staff*, based on data collected by the UK HESA for the period 1998/1999–2000/2001. While a positive relationship is expected between the former variable and variety of interactions with industry, the effect of the latter is difficult to predict a priori and will largely depend on whether public research funding complements that from industry, or whether these two streams of funding are substitutes.[14]

The *research quality of the department* was proxied by the 2001 UK RAE rating. We used dummy variables to identify departments with the highest score (5*) and departments ranked lower than 5, using point 5 as the reference category.[15] A further variable that we included in our analysis was *size of university department*, as measured by the number of academic staff (i.e. the average of full-time-equivalent staff for the period 1998/1999–2000/2001, according to HESA), in order to control for scale effects.

The third group of variables measures the characteristics of the researcher's university. We constructed two variables, both capturing different aspects of the university's focus on interaction with industry. The first is based on research income from industry: *proportion of research income from industry relative to total university research income* (computed over the period 1998/1999–2000/2001). The second is a dummy variable indicating whether the institution is a *former polytechnic* (these are higher education institutions upgraded to university status in 1992, which have traditionally been less research oriented and more engaged in regional development compared to 'older' universities). The hypothesis here is that both variables should have a positive impact on the variety of interactions with industry, as both explanatory variables are related to a university culture favourable to commercialisation activities.

6.3. Results

Tables 7 and 8 present the results of our regressions.[16] Table 7 is based on all university researchers in our dataset, and Table 8 presents separate estimates for researchers in engineering and those in basic science fields.[17] One major result from the regressions in Table 7 is that the characteristics of the individual researcher have a much stronger impact in explaining the variety of interactions with industry than those of the department or the university. Our strategy involved successively introducing in the regressions, variables related to each of the three sets of characteristics. Thus the first regression in Table 7 only includes variables related to the university, the second includes those related to the department and the university, and the third and the fourth regressions include the variables related to all three levels.

The main point to note is that while some of the variables related to the university and the department are significant in the first two regressions, their significance declines when the characteristics of individuals are intro-

[14] All finance data at department level, as well as data on number of staff, were obtained from HESA (www.hesa.ac.uk). The variables for industry and public research funding, and number of staff, were computed at department level as an average for the academic years 1998–1999 and 2000–2001. Finance data were measured in £ thousands. Public sources refer to research grants received by the department from UK Research Councils.

[15] The decision to use these three categories was based on the fact that our reference category accounts for a large proportion of departments: the choice of three categories resulted in a relatively even distribution of departments. Information on UK RAE 2001 was obtained from: www.hero.ac.uk.

[16] See Appendix Tables A1 and A2 for descriptive statistics and correlation matrix of all the variables used in our analysis.

[17] Basic science fields cover chemistry, mathematics and physics. Applied science fields cover all five of our engineering fields plus computer science and metallurgy & materials.

Table 7
Factors influencing the variety of interactions. Ordered logit regressions. Dependent variable: variety of interactions with industry by university researcher: variety 1 and variety 2

Explanatory variables	Variety 1				Variety 2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Individual characteristics								
Ln no. joint publications			0.400*** (0.075)	0.425*** (0.078)			0.415*** (0.077)	0.452*** (0.080)
Ln EPSRC collab. grants			0.238*** (0.022)	0.196*** (0.022)			0.242*** (0.023)	0.204*** (0.023)
Ln EPSRC non-collab. grants			−0.013 (0.022)	0.012 (0.023)			−0.038 (0.024)	−0.087 (0.024)
Age of university researcher			−0.024*** (0.006)	−0.024*** (0.006)			−0.026*** (0.007)	−0.028*** (0.007)
Status of professor			0.872*** (0.125)	0.943*** (0.128)			0.928*** (0.133)	0.987*** (0.137)
Department characteristics								
Ln industry research income per staff		0.876*** (0.073)	0.750*** (0.077)	0.271** (0.100)		0.746*** (0.077)	0.609*** (0.082)	0.216* (0.108)
Ln public research income per staff		0.179* (0.085)	0.028 (0.090)	−0.099 (0.129)		0.202* (0.092)	0.052 (0.099)	0.009 (0.139)
Ln department staff		−0.093 (0.091)	−0.091 (0.094)	−0.062 (0.102)		−0.072 (0.102)	−0.049 (0.100)	0.008 (0.108)
RAE 2001 low		0.430** (0.128)	0.473*** (0.133)	0.301* (0.140)		0.218 (0.135)	0.299* (0.142)	0.186 (0.150)
RAE 2001 high		0.045 (0.126)	−0.018 (0.131)	−0.041 (0.140)		0.157 (0.132)	0.143 (0.139)	0.056 (0.149)
University characteristics								
Univ. income ind./total res. income	3.003*** (0.707)	−1.387 (0.888)	−0.873 (0.919)	0.327 (0.986)	3.799*** (0.724)	0.841 (0.924)	1.413 (0.970)	1.757^t (1.047)
Post-1992 (former polytechnics)	0.089 (0.196)	0.840** (0.251)	0.541* (0.259)	−0.149 (0.291)	−0.050 (0.206)	0.847** (0.267)	0.465^t (0.279)	−0.012 (0.311)
Intercept	0.453***	−0.395	0.243	1.703**	−0.442***	−1.483***	−0.899^t	0.098
Discipline dummies				Significant				Significant
Number of obs.	1511	1500	1443	1443	1510	1499	1442	1442
Log likelihood	−561.96	−1330.09	−2183.95	−2136.06	−473.97	−1088.26	−1798.09	−1627.40
Restricted log likelihood	−570.96	−1439.28	−2417.87	−2417.87	−486.40	−1172.75	−2002.79	−2002.79
Pseudo R^2 Nagelkerke	0.012	0.140	0.287	0.335	0.017	0.114	0.264	0.302

*$p<0.5$; **$p<0.01$; ***$p<0.001$; $t<0.1$. Columns (4) and (8) are the only ones that include discipline dummies. Reference category for discipline dummies: general engineering. Standard errors in parenthesis.

Table 8
Differences according to disciplines in the factors influencing the variety of interactions. Ordered logit regressions. Dependent variable: variety of interactions with industry by university researcher

Explanatory variables	Variety 1				Variety 2			
	Applied disciplines (1)		Basic disciplines (1)		Applied disciplines (2)		Basic disciplines (2)	
	Estimate	Standard error	Estimate	Standard error	Estimate	Standard error	Estimate	Standard error
Individual characteristics								
Ln no. joint publications	0.326**	(0.113)	0.578***	(0.106)	0.382**	(0.114)	0.609***	(0.110)
Ln EPSRC collab. grants	0.195***	(0.029)	0.223***	(0.035)	0.200***	(0.030)	0.217***	(0.038)
Ln EPSRC non-coll. grants	−0.021	(0.029)	0.044	(0.038)	−0.043	(0.030)	0.030	(0.043)
Age of university researcher	−0.026**	(0.008)	−0.019*	(0.009)	−0.030**	(0.009)	−0.019^t	(0.010)
Status of professor	1.003***	(0.167)	0.767***	(0.198)	1.091***	(0.173)	0.665**	(0.220)
Department characteristics								
Ln industry res. income per staff	0.295*	(0.115)	0.774***	(0.125)	0.299*	(0.120)	0.497**	(0.137)
Ln public res. income per staff	0.092	(0.142)	0.199	(0.141)	0.175	(0.148)	0.294^t	(0.161)
Ln department staff	0.005	(0.116)	−0.063	(0.202)	0.047	(0.121)	−0.181	(0.227)
RAE 2001 low	0.481**	(0.172)	0.232	(0.228)	0.244	(0.180)	0.211	(0.252)
RAE 2001 high	−0.045	(0.178)	−0.220	(0.223)	0.091	(0.184)	−0.088	(0.250)
University characteristics								
Univ. ind./total res. income	0.403	(1.150)	−0.147	(1.692)	2.736*	(1.188)	0.163	(1.902)
Post-1992 (former polytechnics)	−0.081	(0.326)	1.085*	(0.519)	0.147	(0.343)	0.996^t	(0.562)
Intercept	0.935	(0.632)	−1.150	(0.866)	−0.718	(0.655)	−1.474	(0.980)
Number of observations		803		640		802		640
Log likelihood		−1283.82		−854.91		−1137.76		−629.37
Restricted log likelihood		−1364.48		−971.04		−1231.02		−711.05
Pseudo R^2 Nagelkerke		0.19		0.32		0.22		0.25

*$p<0.05$; **$p<0.01$; ***$p<0.001$; $t<0.1$.

duced. Hence, in the final regressions (numbers 4 and 8 in Table 7), when we control for discipline dummies, only two out of the seven variables related to the university or the department are significant. However, four out of the five variables related to individual characteristics are significant in explaining the variety of university–industry interactions.

The results in Table 7 show that previous experience of collaborative research, as measured by joint publications and collaborative grants, is extremely important in explaining both the probability of a university researcher engaging in a greater variety of interactions, and the probability of a university researcher engaging more frequently across a larger range of interactions. In other words, all other things being equal, some researchers show a disposition to interact repeatedly with industry over time. The results in Table 8 show that these two measures of previous collaboration have differential impacts when we consider basic science and applied fields separately. While the impact of collaborative grants is similar in all regressions, this is not the case for joint publications, where the impact in applied disciplines is smaller than in the basic science fields.

The effect of other individual characteristics is mixed. Being a fund-raiser has no significant impact on the variety of interactions that an individual engages in. The sign on the age variable is negative and the impact is significant for the overall sample and for applied disciplines, suggesting that the younger the researcher the higher the probability of engaging in a greater variety of interactions and also of engaging more frequently across a wider range of interactions. Finally, the academic status variable always has a positive and significant impact.

Amongst departmental characteristics, all other things being equal, the amount of departmental research income (per member of staff) received from industry has a positive and significant effect on the variety of interactions of an individual researcher, as measured in terms of the range of categories in which the researcher is engaged (Variety 1) and in terms of the frequency (Variety 2).

Most other departmental variables lose their significance once individual characteristics are introduced. The only exception is the variable for the research quality of the department, in the case of 'Variety 1'. The results for this variable indicate that being a member of a highly rated university department has no impact on the probability of engaging in a variety of interactions. Although researchers from departments that are poorly rated in the UK RAE exercise seem to engage in a wider range of university–industry interactions, Table 8 shows that this is only valid in the case of applied disciplines. One explanation for this result is that researchers in engineering disciplines could be working on problems that are more 'relevant' to industry, and that the RAE exercise does not give adequate weight to this type of research.

Finally, the results in relation to university characteristics indicate that researchers in universities with a higher proportion of research income from industry, engage more frequently across a wider range of interactions (i.e. variety 2), though this is only valid for researches in applied fields. While researchers in former polytechnics engage in a wider range of interactions (variety 1), though this is only valid in basic disciplines.

7. Conclusions

Despite the increased focus on the role of universities in knowledge transfer activities and their contribution to economic development, there is still little consensus in the literature about patterns of interaction with industry amongst university researchers. This paper analyses the extent to which knowledge transfer activities are spread across the academic community, by focusing on the variety of channels of interaction. Based on a large-scale survey of university researchers, it presents empirical findings that aim to contribute towards establishing some stylised facts on knowledge transfer activities and towards informing empirically grounded theoretical and policy approaches.

The results show that university researchers interact with industry using a variety of channels. We highlight five broad categories of interaction: *creation of new physical facilities*, *consultancy and contract research*, *joint research*, *training*, and *meetings and conferences*, each reflecting largely non-overlapping modes of interaction. Interaction with industry is fairly common among university researchers in the UK: in four (out of the five) interaction categories, over 40% of the respondents to our survey reported involvement at least once over the period 2002–2003.We found that the proportion of researchers involved in interactions with industry varies across scientific disciplines: for instance, there is a higher level of interaction within the engineering disciplines as compared to mathematics and physics. Finally, university researchers' interactions with industry partners (wherever they might be located) are evenly spread across UK regions.

Our results show that in explaining the variety and frequency of interactions with industry among academic researchers, individual characteristics have a stronger impact than the characteristics of their departments or universities. Our findings show that previous experience of collaborative research plays a very significant role: those researchers with a record of past interaction are more likely to be involved in a greater variety of interactions with industry, and also to engage more frequently across a wider set of interaction channels. Academic status (i.e. being a professor) has a significant and positive impact on the variety of interactions with industry among university researchers, which is consistent with the career life cycle argument that individuals who are well established in their academic careers will be more likely to capitalise on their reputation to increase their engagement in commercialisation activities. However, we find that, other things equal, the older the researcher the narrower the variety of interactions. This is particularly so in applied disciplines, in which younger researches engage more intensively in a broader range of interactions. One explanation for this relationship between age and variety of interactions could be that interaction with industry is increasingly perceived as positively contributing to the scientist's reputation, encouraging researchers to actively engage with industry in the earlier stages of their careers.

Nevertheless, our findings do not imply that the institutional environment has a marginal role in shaping the variety and frequency of interactions among academic researchers. The influence of individual factors is likely to be mediated by the characteristics of university and departments to which researchers are affiliated. While such interdependencies are beyond the scope of this study, they point to fruitful areas of further research.

An intriguing result from our analysis is that, in general, the research quality of the department has no impact on the probability of a university researcher engaging in a wide variety of interactions. For instance, our results do not support the concentration of research resources in high-quality research departments as a means of encouraging university–industry interactions, as the difference between high and low quality departments seems to be very small in terms of their impact on a researchers' engagement in a wider variety of interactions. In fact, the only case where the department's research quality has an impact is in applied disciplines, where a *lower quality* rating seems to have a positive influence on the probability of a researcher's involvement in a greater variety of interactions. It might be that less prestigious departments have a comparative advantage in satisfying firms' demands for university personnel who are willing to focus on their immediate problems by helping them to apply new knowledge to these problems (see Mansfield and Lee (1996) for an elaboration of this argument).

Finally our results challenge two aspects of government polices directed at university–industry interactions. First, much of the public scrutiny on government policies aimed at encouraging knowledge transfer, either in the UK and elsewhere in many OECD countries, has been devoted to measuring rates of patenting and spin-off activities. This may have the negative effect of obscuring the presence of other types of university–industry interactions that have a much less visible economic pay-off, but can be equally (or even more) important, both in terms of frequency and economic impact.

Moreover, if policies oriented to encouraging knowledge transfer activities are to succeed, support for a variety of interaction channels would seem to be more profitable as a route to building a solid integration between science and technology, than focusing on a narrowly defined set of commercialisation activities. A wide range of interaction channels should make a more powerful contribution to the accumulation by university researchers of the individual skills required to make the integration between science and technology more effective and enduring.

Second, our results also suggest that policies that are mainly targeted towards universities are likely to have a limited impact on encouraging university–industry interactions, unless they take a better account of the characteristics of the individual researchers engaged in such interactions. This would imply that future research should be aimed at identifying the common features among researchers who actively engage with industry, and investigating the ways in which they have managed, for instance, to establish a stable network with the wider community of potential users of their research. It should also investigate the main incentive mechanisms and motivations among university researchers for engaging in interactions with industry, together with the factors that shape the development of integration skills that contribute to resolving the conflicting interests that potentially arise between academic research and commercialisation activities.

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Appendix A

Question on the number of interaction channels and frequency of interaction.

Joint Research projects refer to collaboration agreements between university and industry that involve research work undertaken by both parties/*Contract Research* refers to research commissioned by industry and undertaken only by university researchers/*Consultancy work* refers to work commissioned by industry, which does not involve original research (e.g. conducting routine tests or providing advice to industry).

A.2 How frequently have you been engaged in the following types of activity in the calendar years 2002 and 2003? (Please tick √ the appropriate response)

	0 times	1-2 times	3-5 times	6-9 times	≥10 times
1. **Creation of new physical facilities** with industry funding (e.g. new laboratory, other buildings on campus)	☐	☐	☐	☐	☐
2. ***Setting up equity interests in companies*** *(e.g. spin-off companies)*	☐	☐	☐	☐	☐
3. A new **joint research** agreement (original research work undertaken by both partners)	☐	☐	☐	☐	☐
4. A new **contract research** agreement (original research work done by University alone)	☐	☐	☐	☐	☐
5. A new **consultancy** agreement (no original research undertaken)	☐	☐	☐	☐	☐
6. **Training of company employees** (through course enrolment or through temporary personnel exchanges)	☐	☐	☐	☐	☐
7. **Postgraduate training in the company** (e.g. joint supervision of PhDs)	☐	☐	☐	☐	☐
8. **Secondments to industry** (short or long term)	☐	☐	☐	☐	☐
9. Attendance at **conferences** with industry and university participation	☐	☐	☐	☐	☐
10. Attendance at **industry sponsored meetings**	☐	☐	☐	☐	☐
11. Creation of **electronic networks**	☐	☐	☐	☐	☐
12. **Other** (please specify):	☐	☐	☐	☐	☐

Tables A1–A2.

Table A1
Descriptive statistics

Variables	Mean	S.D.	Median	Min.	Max.	Obs.
1a. Variety of interaction 1	2.28	1.78	3.00	0	5	1513
1b. Variety of interaction 2	1.04	1.29	1.00	0	5	1512
2. Ln no. joint publications	0.43	0.68	0.00	0	3.81	1508
3. Ln EPSRC collab. grants	2.27	2.48	0.00	0	7.60	1508
4. Ln EPSRC non-collab. grants	2.78	2.32	3.94	0	9.39	1506
5. Age of researcher	45.28	10.0	43.00	23	75	1488
6. Status of professor	0.47	0.50	0.00	0	1	1522
7. Ln industry res. income per staff	1.44	0.83	1.51	0	3.53	1525
8. Ln public res. income per staff	2.56	0.75	2.71	0	4.33	1525
9. Ln department staff	4.20	0.68	4.17	2.07	5.6	1525
10. RAE 2001 low	0.28	0.45	0.00	0	1	1518
11. RAE 2001 high	0.29	0.45	0.00	0	1	1518
12. Ratio ind./tot. univ. income	0.13	0.06	0.12	0.02	0.47	1526
13. Post-1992 universities	0.06	0.23	0.00	0	1	1528

Table A2
Correlation matrix of the variables included

Variables	1a	1b	2	3	4	5	6	7	8	9	10	11	12
1a. Variety of interaction 1													
1b. Variety of interaction 2	**0.74**												
2. Ln no. joint publications	**0.25**	**0.22**											
3. Ln EPSRC collab. grants	**0.40**	**0.35**	**0.15**										
4. Ln EPSRC non-collab. grants	0.01	−0.01	**0.14**	−0.04									
5. Age of researcher	**0.11**	**0.11**	**0.17**	**0.26**	**0.15**								
6. Status of professor	**0.25**	**0.25**	**0.22**	**0.27**	**0.23**	**0.58**							
7. Ln industry inc. per staff	**0.34**	**0.31**	**0.16**	**0.21**	0.05	0.03	0.03						
8. Ln public inc. per staff	**0.11**	**0.10**	**0.14**	**0.15**	**0.23**	−0.01	0.05	**0.36**					
9. Ln department staff	**0.08**	**0.11**	**0.07**	**0.09**	**0.13**	0.01	0.01	**0.39**	**0.41**				
10. RAE 2001 low	**0.09**	0.05	0.01	−0.02	**−0.14**	−0.01	**−0.05**	−0.05	**−0.30**	**−0.39**			
11. RAE 2001 high	**0.05**	**0.07**	0.05	**0.08**	**0.12**	**0.05**	**0.07**	**0.20**	**0.33**	**0.47**	**−0.39**		
12. Ratio ind./tot. univ. inc.	**0.11**	**0.15**	0.00	0.04	**−0.08**	0.03	−0.02	**0.36**	**−0.11**	**0.11**	**0.29**	**−0.22**	
13. Post-1992 universities	0.01	−0.01	−0.04	−0.01	**−0.14**	0.04	0.01	**−0.26**	**−0.55**	**−0.21**	**0.33**	**−0.14**	0.00

Correlation coefficients significant at the 0.05 level in bold.

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