Title: Knowledge from businesses to universities: an investigation on the two-way knowledge transfer in university-business partnerships

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1. Introduction

A crucial tenet of the Triple Helix analytical framework is that interactions oriented to the co-production of knowledge between universities, businesses and government agencies are instrumental in leveraging the innovative potential of economic systems (Etzkowitz and Leydesdorff, 2000). As many scholars have pointed out, one of the potential benefits from research collaborations between universities and businesses is the contribution of the latter to bring complementary expertise and help expand the frontiers of knowledge by inspiring new avenues for academic research (Gibbons and Johnston, 1974; Branscomb et al., 1999; Valentin, 2000). Indeed, an increasing number of government initiatives are put in place to attenuate systemic failures based on the argument that favourable institutional arrangements are required to facilitate the co-production of knowledge between universities and businesses (Poyago-Theotoky et al., 2002).

However, while much of the public support of university-business research collaborations is based on the two-way flow of knowledge between these two types of partners, little is known about the factors that are more conducive to the active contribution of businesses to knowledge generation. In this research we aim at shedding some light on this issue by investigating two questions: (i) what are the conditions that favour businesses actively contributing to the co-production of knowledge, in the context of collaborations with universities; and (ii) to what extent manufacturing and services businesses exhibit systematic differences in their contribution to the co-production of knowledge.

We examine this by using a dataset based on a survey of businesses that have participated in research collaborations with universities. The selection of businesses to be surveyed is based on the records of grants awarded by the Engineering and Physical Sciences Research Council (EPSRC) over the period 1999 to 2006 to academic researchers, where businesses were listed as partners.

2. Literature background

Over the last decades, there has been a strong policy support to promote university – business partnerships in many countries (Branscomb et al., 1999; Hall et al., 2001; Mowery et al., 2004). One of the underlying rationales for these policies has been that university-business partnerships are conceived as effective instruments for addressing innovation-related market failures, since such collaborative projects might provide the appropriate incentive schemes for industry to invest in pre-competitive research (Martin and Scott, 2000).

In addition to the argument of overcoming social underinvestment in embryonic R&D activities, the support of university-business partnerships has also been anchored on the argument that these partnerships are instrumental to enable a two-way knowledge transfer. On the one hand, there has been a strong emphasis on stimulating knowledge transfer from university to industry, in order to favour the commercialisation of university-based technologies and realize the full potential of the scientific base in terms of technological performance and competitiveness. As a result, key legislation changes have been enacted in many countries to change the rules governing university management of intellectual property (e.g. the Bayh-Dole Act of 1980 in US).

On the other hand, and crucially for the argument of this paper, these policies have also been anchored on the understanding that much of the socio-economic impact of research conducted at universities can not be fully realised without the active contribution of the potential users of research, and particularly, of businesses. Or, in other words, that knowledge inputs are required from both parties - universities and businesses - in order to develop a product or technology from upstream research.

The knowledge contribution from the business side is crucial for at least two reasons: (i) to raise awareness of the context of application, and (ii) to facilitate the paths for exploitation. Regarding the first point, university scientists engaged in fundamental research often lack the knowledge and expertise to realise the potential applications of the results of their research. Business partners can provide insightful contributions with regards to both the identification of potential applications from fundamental research, as well as, furthering the understanding of academic scientists about the problems faced by users, and thus providing a richer contextualisation from which to frame questions to feed fundamental research.

Regarding the second point, there is some evidence pointing out that much of the inventions generated from university research are unlikely to reach the market unless university researchers and businesses are in frequent contact with each other. For instance, Jensen and Thursby (2001) show that successful development of university-based inventions required close cooperation between the academic inventor and the licensee.

However, regardless of the potential benefits of partnerships between universities and firms to bridge the knowledge gap between these two types of agents, these partnerships are often neglected or obstructed because firms lack adequate information about what university research is able to offer, or because university researchers fail to recognise the economic opportunities arising from their own research or the research opportunities from the technological problems faced by businesses. It is in this context that policy initiatives designed to facilitate university-business partnerships may be instrumental to make this two-way knowledge transfer possible, which in the absence of favourable policy initiatives might fail to happen.

Building upon the above discussion, this study aims at gaining further understanding about the factors that are more conducive to the active contribution of businesses to knowledge generation. The next to sub-sections discuss this in further detail.

2.1. Conditions that favour firms' knowledge contributions in partnerships with universities

This section discusses the factors that influence the decision of businesses to actively contribute to co-production of knowledge in R&D partnerships with universities. Based on the review of the literature on university-business interactions, we examine four factors that are likely to influence this decision: a) the type of knowledge exchanged; b) the orientation of partnerships towards exploration and exploitation; and c) attitudinal convergence with the university partner. We discuss these issues below.

a) Type of knowledge exchanged:

The knowledge exchanged in university-business partnerships exhibits a varied degree of complexity in terms of the easiness of transmission. As Bierly et al. (2009) point out, knowledge transferred into an organization can be classified on a continuum between fully explicit and fully tacit. The former refers to knowledge that can be easily codified and thus communicated between individuals and organizations. While tacit knowledge refers to knowledge that is deeply rooted in experience, skills and know-how, and therefore it is more difficult to transfer - though at the same time it is more valuable for the partnering organisations as it helps building capabilities that are more difficult to imitate by organizations not involved in the partnership.

As pointed out by Poyago-Theotoky et al. (2002), a great deal of useful knowledge involved in the generation of inventive ideas from R&D collaborations are tacit and can only be appropriately transferred through close interaction, and intensive knowledge exchange, between the academic scientists and the potential users - as opposed to a set of instructions for combining inputs and outputs that can be easily codified and transmitted, without much interaction between partners.

Consequently, we would expect that the more tacit is the knowledge exchanged in the university-business collaborations, the more likely that the company has an active role as knowledge contributor.

b) Exploration and exploitation oriented partnerships

One of the major components of a firm's innovation strategy is to organise the balance between exploration of new ideas and the exploitation of existing competencies (March, 1991; Leonard-Barton, 1995; Bercovitz and Feldman, 2007). Exploration refers to search and experimentation activities oriented to broaden firms' capabilities, while exploitation refers to the refinement and extension of existing capabilities.

R&D partnerships with universities are generally formed to reinforce either the firm's exploration learning strategies, the exploitation learning strategies, or both. A firm's exploration strategy can be strengthened by cooperating with universities to set up new research projects and open up new experimentation paths. Alternatively, a firm's exploitation strategy can be reinforced by interacting with universities in order to facilitate the assimilation of external knowledge to refine existing

competencies, and to apply external knowledge for commercial ends (Bercovitz and Feldman, 2007; Bishop et al., 2010).

Both types of strategic partnerships are potentially conducive to two-way flow of knowledge. When interactions with universities are dominantly formed to contribute to the exploration learning capabilities of the firm, knowledge exchange is likely to be required from both parties in order to solve the problems derived from the intrinsic complexity and uncertainty associated to upstream and exploratory research. Similarly, when interactions with universities are formed to contribute to exploitation learning strategies of firms, knowledge exchange is also required from both parties in order to appropriately bridging scientific research and the context of application.

However, exploration and exploitation oriented partnerships are frequently channelled through different mechanisms. Interactions with universities that have an orientation to exploitation are often channelled through relatively short-term contracts where research targets are well-specified at the outset, and might require a comparatively lower level of knowledge exchange during the partnership (compared to exploration oriented partnerships). We therefore would expect that knowledge contributions from the business side are likely to occur with both exploratory and exploitative R&D partnerships, but these contributions are likely to be more frequent, and probably more relevant for the success of the project, when firms dominantly engage in R&D partnerships of a more exploratory character.

c) Attitudinal convergence with the university partner

The divergence between norms, language, purposes and incentive structures between the academic and the business worlds are generally found to represent important obstacles for successful university-business partnerships. Indeed, university-industry collaborations are likely to be plagued with conflicts due to a weak attitudinal alignment between partners: firms often conflict with university researchers over attitudes towards the topics of research or the timing and form of disclosure of research results (Bruneel et al., 2010; Gomes et al., 2005).

However, university collaboration is an activity in which firms learn from experience and develop richer and more refined ways of engaging with the university sector. Overtime, the experience of collaboration should enable academics and their industrial collaborators to converge in attitudes, learning to share common norms and understanding about the nature of the collaboration and the research process (Bruneel et al., 2010). Frequent and recurrent partners are particularly likely to capitalize on their collaboration experience by transferring the information and knowledge gained through their involvement in multiple and diverse R&D partnerships with universities. Consequently, we would expect that the larger the experience of firms in establishing formalised contracts with universities, the more likely that businesses become active knowledge contributors.

2.2. Service firms and university-business partnerships: what is different about technical consultancies?

The literature on university-business partnerships has mainly addressed linkages between universities and manufacturing, and it has largely neglected the role of services. This is unfortunate since service firms are often involved in partnerships with universities. Indeed, Cosh et al. (2006) show that high-tech services exhibit a similar pattern compared to high-tech manufacturing in the use of universities as a source of knowledge for innovation activities.

One of the difficulties associated with bringing the service sector to the forefront in the analysis of university-business partnerships is related to the huge heterogeneity of business activities covered by service companies. In this study, we aim at examining one specific type of services: knowledge intensive business services (KIBS). In particular, we focus on whether 'technical consulting" service firms display a distinct behaviour with regards to knowledge contributions in R&D partnerships with universities.

KIBS refers to firms that offer specialist professional, consultancy and outsourcing services to other organizations (Wood et al., 2009). The most generic classification of KIBS refers to the distinction between technology-based KIBS (providing highly technical services) and professional KIBS (providing accounting or management services) (Kask., 2009). In this paper we concentrate on

technology-based KIBS, including within this category 'architectural and engineering' consulting and 'R&D service' firms.

We compared technology-based KIBS with manufacturing and other service sectors in order to identify whether this type of firms share a common profile in their pattern of collaboration with university, or exhibit systematic differences with respect to manufacturing firms in particular. It is important to disentangle whether these technology-based firms display a differentiated pattern in terms of their collaboration with universities. Indeed, since KIBS are characterised as being business-to-business knowledge providers, we would expect technology-based KIBS to be particularly prone to act as knowledge contributors in their partnerships with universities, as opposed to responding to a pattern characterised by being users of knowledge provided by universities.

3. Data and measures

3.1. Data

The data used in this paper is based on a survey of businesses that have participated in research collaborations with universities. The selection of businesses to be surveyed is based on the records of grants awarded by the Engineering and Physical Sciences Research Council (EPSRC) over the period 1999 to 2006 to academic researchers, where businesses are listed as partners. The EPSRC is the UK's largest funding council in terms of budget distributed to conduct research, and it has a broad remit including engineering disciplines, computer science, mathematics, chemistry and physics.

This sampling strategy resulted in a frame list of 3119 businesses, covering both manufacturing and services. The survey was addressed to the lead person named as an industrial collaborator on the EPSRC grants. In the case of companies that participated in multiple ESPRC projects, our approach was to focus on the contact person most frequently named by the firm, as this individual is likely to be the key point of contact between the firm and its university partners. However, to ensure that our individual level responses were representative of views of their wider organization, we included a top up sample of 312 individuals that were listed as the second most frequent contact name on the collaborations. This approach left us with a final sample of 3,431 individuals.

Data collection was done in several stages. First, in November 2007, we wrote to 3,431 individuals in our sample with an invitation to the individual to go to a website to complete an electronic version of the survey. The invitation included a letter from Professor David Delpy, Chief Executive of the EPSRC, endorsing the study. This first stage elicited 276 responses. To improve the response rate, we telephoned non-respondents to encourage them to respond. This yielded another 176 responses. In the second stage we conducted another postal survey in February 2008, this time including a paper copy of the questionnaire in order that respondents had the choice of an electronic or paper-based version. This second stage yielded another 188 responses. In the third stage, we used the email addresses collected from the telephone contacts with organizations to send email reminders to non-respondents for whom we had email addresses. This yielded another 13 responses giving us a total of 646 usable responses, representing 602 organizations (44 responses were from individuals in the same firm as another respondent).

Based on a total survey population of 3,431, the response rate was 19 per cent. The sample covers a wide range of firms, with representation from organizations of different sizes, across all sectors, including technical and professional business services. Response rates across sectors are not significantly different for the largest populated sectors in our sample frame, ranging from 19% (e.g. Machinery and Metals) to 25% (e.g. Motor Equipment and Aircraft manufacture; and Business Services). However, response rates are lower (around 10%) for sectors where the number of firms in the sample frame was low (e.g. wholesale and retail trade; financial intermediation; manufacture of food products, among others).

3.2. Measures

Dependent Variables

We have constructed two dependent variables in this study: '*Knowledge contribution*' and '*Financial contribution*'. *Knowledge contribution* measures the extent to which firms have contributed ideas to the

research projects conducted in collaboration with university partners; while *Financial contribution* captures the extent to which the firms have contributed with funding to the research projects with universities.

To capture whether firms acted as knowledge and financial contributors in R&D partnerships with universities, we drew on the responses to a question about the different types of resources provided by the firm to the university partners. More specifically, firms were asked to report how important was their contribution in terms of providing 'Ideas for research projects' and 'Funding for research', using a five-point Likert scale ranging from 1, not at all important, to 5, crucial. To calculate the variables '*Knowledge contribution*' and '*Financial contribution*', the responses to these items were recoded into four categories, where 'not at all important' and 'unimportant´' were collapsed into a single category (the other three categories being: 'important', 'very important' and 'crucial').

We considered these two dependent variables in order to build an adequate benchmark to assess results about knowledge contributions. The justification for this is that pecuniary contributions have been the most frequently examined resources provided by firms, in previous studies. Thus, financial contributions serve as a point of reference to assess the peculiarities that characterize knowledge contributions from firms.

Explanatory variables

In order to capture the type of knowledge exchanged, we created a variable measuring the extent to which the knowledge exchanged in the partnerships has been of a *tacit* character (*knowledge tacitness*). To construct this variable we drew on responses to a question where firms were asked to agree or disagree with the following three items: 'knowledge exchanged was already well documented, contained in reports, documents and self-explanatory software'; 'knowledge exchanged was easily explained to others in the organisation in writing'; and 'knowledge exchanged was mainly personal practical know-how, tricks of the trade'. Each item was measured on a five point likert scale from 'strongly disagree' to 'strongly agree'. Responses to the first two items were reversed coded, and a variable was calculated averaging the responses for the three items.

In order to measure the exploration and exploitation orientation of the partnerships in which firms have been involved, we drew on the responses to a question about the benefits that firms more frequently obtain from the partnerships with universities. The following items were included: 'creation of long term links with university researchers', 'improved understanding of foundations of particular phenomena', 'source of information suggestion new projects and identifying new trends', 'assistance in problem solving (e.g. support in the development process)', 'contribution to the successful market introduction of new products/processes', 'cost reduction in the product or process development (e.g. new prototypes)', and 'reducing the time required for the completion of the company's R&D'. Respondents were asked to score each item on a five-point likert scale ranging from 'not at all important' to 'crucial'.

The results of a principal component factor analysis allow us to identify two factors with an eigenvalue higher than 1, explaining 60% of the variance. We used the factor scores of the last four items, which load on the first factor, to create the variable '*exploitation-oriented*' partnerships, and the factor scores of the first three items, which load on the second factor, to create the variable '*exploration-oriented*' partnerships.[1]

We capture a firm's *experience* in partnerships with universities by considering the extent to which firms have been frequently involved in formal partnerships with universities over the period 2005 and 2006. In particular, we drew on a question that asks companies how frequently were they involved in 'joint research projects', 'contract research' and 'consultancy agreements'. To construct our 'experience' variable, we used a binary code for each type of partnership, which takes the value of 1 if the firm reports having been engaged in a given type of partnership 3 times or more, and zero otherwise. We then simply added up the scores for joint research, contract research and consultancy, in order to have a measure of how frequently the firms have been engaged in these types of partnerships.

[1] We have used an oblique factor rotation procedure so that the extracted factors are allowed to be correlated, rather than constraining the factor rotation to an orthogonal solution.

Finally, we have constructed a dichotomous variable to capture the effect of a firm being a 'technology-based' KIBS. This variable takes the value of 1 if the firm is a consulting firm in the field of 'architectural and engineering activities' (i.e. ISIC 7420), a firm providing technical testing and analysis (ISIC 7430) or a R&D service provider (ISICs 7310 and 7320).

Control variables

We included several control variables that may have an influence on the firm's contribution to the coproduction of knowledge in partnerships with universities. First, we control for the proportion of firm's staff with a higher education degree, in order to capture the organization's level of human capital (*Human capital*). The measure is constructed from a categorical question on the survey that ranges from 1 to 5: 1 = percentage of higher education staff equal to or less than 10%; 2 = percentage of higher education staff between 11% and 20%; 3 = percentage of higher education staff between 21% and 40%; 4 = percentage of higher education staff between 41% and 60%; and 5 = percentage of higher education staff between 61% and 100%. Second, we included a measure of firm size, as the logarithm of the number of employees (*Size*).

Third, we controlled for the type of university partner with whom the companies most frequently interact (*Quality rank*). More precisely, we used the scores awarded to the university departments by the UK Research Assessment Exercises (i.e. UK RAE 1996 and 2001), in order to compute the average score of the academic units with whom each company engaged, via EPSRC projects, over the period 1991-2005. These scores range along seven categories, from 1 (indicating 'quality that equates to attainable levels of national excellence in none, or virtually none, of the research activity submitted to the assessment') to 7 (indicating that in more than a half of the department's submitted activities, research quality has achieved international excellence). The rationale to include this variable is that organisational conflicts are likely to be particularly strong when the academic partner is most oriented towards upstream, blue-sky research as compared to research closer to the context of application (Dasgupta and David, 1994). We would therefore expect that interacting with top quality research partners will accentuate the problems of attitudinal convergence between university and business, making it less likely that businesses become actively engaged in a two-way flow of knowledge. Finally, we included 11 dummy variables to account for inter-industry differences. Table 1 reports the descriptive statistics for all the variables discussed above.

Table 1. Descriptive statistics

Variables	Mean	Std. Dev.	Min.	Max.
Knowledge contribution	2.40	0.87	1.00	4.00
Financial contribution	1.97	0.88	1.00	4.00
Knowledge tacitness	2.12	0.60	0.67	4.33
Exploration oriented	0.00	1.00	-3.14	2.59
Exploitation oriented	0.00	1.00	-2.21	3.37
Experience	0.43	0.76	0.00	3.00
Human capital	3.29	1.58	1.00	5.00
Size (Ln employees)	4.50	2.32	0.00	11.51
Quality rank	5.80	0.76	2.00	7.00

Note: the number of observation varies among variables, as a consequence of missing values. It ranges from 554 observations for Size to 597 observations for the dependent variables.

4. Results

Table 2 presents the variation between sectors on the extent to which firms report having contributed with knowledge and funding. Table 2 shows that about half the companies involved in partnerships are from the service sector, with technology-based consultancy firms being the largest single sector in number of firms, representing about 20% of the companies in our sample. With the only exception of firms in the Machinery & Metals sector (and to a lower extent in Manufacture n.e.c.), firms assess that 'very important' or 'crucial' knowledge contributions are more frequent than similarly important financial contributions (for many sectors, knowledge contributions are twice as frequent as financial contributions). The three sectors where knowledge contributions seem to be more widespread are: (i) Aerospace/Motor Vehicles; (ii) Gas/Electricity/Water Services; and (iii) Technology-based consultancy firms. With Computer Service companies (i.e. software and hardware providers) being at the opposite extreme, with the lowest proportion of companies reporting substantial knowledge contributions in their partnerships with universities.

Table 2. Contributions to research projects, ranked as 'very important' or 'crucial'

	Knowledge Contribution (%)	Financial Contribution (%)	N° observations
Chemicals & Chemical-related	46.5	23.9	71
Electrical & Electronics	33.3	17.4	69
Instruments	42.4	12.1	33
Machinery & Metals	31.3	29.7	64
Aerospace/Motor Vehicles	67.9	42.9	28
Manufacture n.e.c.	35.6	31.1	45
Computer Services	25.5	12.7	55
Professional-based consultancy	46.2	25.6	39
Technology-based consultancy	51.3	30.8	117
Services n.e.c.	45.2	35.5	31
Electricity/Gas/Water Supply	55.6	26.7	45
Total	*42.9*	*25.8*	*597*

Table 3 reports the results of the analysis. Ordered logistic regressions were conducted to examine the extent to which businesses' knowledge contributions, in partnerships with universities, are significantly correlated with the explanatory factors discussed in the previous Sections. Ordered logistic regressions were conducted because of the categorical and ordered nature of our dependent variables. Table 3 reports the results for both knowledge and financial contributions.

The results reported in Table 3 show that, in partnerships where knowledge is more difficult to transfer in a written format, and face-to-face interactions are more strongly required for effective knowledge transfer, firms are more likely to become active knowledge contributors to university partners (see column 1b). Conversely, the results in column (2b) show that the nature of the knowledge transferred has no influence on the firms' financial contributions to partnerships.

Table 3 also shows that firms involved in exploratory-oriented partnerships are more likely to contribute substantially to co-production of knowledge, while being involved in exploitative-oriented partnerships is not particularly conducive to higher levels of knowledge contributions from firms. Table 3 also shows that exploratory-oriented partnerships are more strongly associated with firms' knowledge contributions than with firms' financial contributions. This is in contrast with the results for exploitative-oriented partnerships, which seem to be much more conducive to elicit financial contributions from firms than knowledge contributions.

Regarding firms' experience, Table 3 shows that the higher the experience in formalised contractual arrangements with universities, the more likely it is that firms engage in both financial and knowledge contributions in research partnerships with universities.

Finally, the results reported in Table 3 also point out that certain types of service firms are particularly prone to engage in the co-production of knowledge with universities, as compared to firms in manufacturing. In particular, this is the case of technology-based consultancy firms and firms involved in energy and water supply. These findings indicate that some service firms are particularly likely to actively engage in a two-way flow of knowledge with their university partners, compared to manufacturing firms. However, we do not observe substantial differences compared to manufacturing, with regards to the probability of engaging in financial contributions. It is also important to point out that, when splitting the overall sample between manufacturing and service firms, we did not find statistically significant differences between the two sub-groups with regards to the impact of our explanatory variables on the probability of contributing to knowledge.[2]

[2] The results of the Chow tests are not reported in this document, but are available from the authors upon request.

Table 3. Ordered Logistic regression estimates of *knowledge* and *financial* contributions to partnerships with universities

	Knowledge contributions		Financial contributions	
	(1a)	(1b)	(2a)	(2b)
Explanatory Variables				
Knowledge tacitness		0.387 ***		0.129
		(0.145)		(0.151)
Exploration-oriented		0.821 ***		0.448 ***
		(0.110)		(0.110)
Exploitation-oriented		0.176		0.225 **
		(0.114)		(0.097)
Experience		0.408 ***		0.420 ***
		(0.118)		(0.123)
Control variables				
Human Capital	0.091	0.020	0.156 ***	0.102 *
	(0.056)	(0.059)	(0.057)	(0.060)
Size	0.081 **	-0.021	0.204 ***	0.130 ***
	(0.040)	(0.043)	(0.039)	(0.043)
Quality rank	0.051	0.052	0.145	0.183 *
	(0.104)	(0.114)	(0.104)	(0.110)
Industry dummies [i]				
Technology-based consultancy	0.366 *	0.450 **	0.074	0.099
	(0.207)	(0.223)	(0.227)	(0.236)
Professional-based consultancy	-0.041	-0.054	-0.782 *	-0.865 *
	(0.402)	(0.378)	(0.420)	(0.453)
Computer Services	-0.261	-0.006	-0.556 *	-0.502
	(0.282)	(0.313)	(0.323)	(0.341)
Electricity/Gas/Water Supply	0.786 **	1.055 ***	-0.002	0.017
	(0.322)	(0.352)	(0.269)	(0.298)
Services n.e.c.	0.575	0.528	0.229	0.131
	(0.433)	(0.408)	(0.451)	(0.409)
Log Likelihood	-674.25	-582.93	-651.88	-597.12
N. observations	554	534	554	534
Pseudo-R^2 Mckelvey & Zavoina	0.04	0.25	0.09	0.20

Notes:

[i] Manufacturing companies are taken as reference category.

Unstandardised coefficients are reported, with robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Discussion and conclusions

Most policy initiatives oriented to support university-business partnerships have been geared around the logic of stimulating private investment in research and development activities and favouring the conditions for a two-way flow of knowledge. Regarding the latter, the empirical research has been oriented to investigate the extent to which the innovative activities of firms benefit from knowledge transferred by universities, and under what conditions such benefits are larger. However, very little research has investigated whether firms actually transfer knowledge to their university partners, and the conditions that favour a jointly knowledge creation process. This study has tried to shed light on this issue by focusing on the factors that are likely to elicit a knowledge contribution from firms, in the context of university-business partnerships. More specifically, the results from this study show the following.

First, while the literature on university-business interactions has paid particular attention to the income stream coming from industry to support university research, this study shows that there is more than funding when it comes to contributions from businesses. Indeed, our results show that firms report having substantially contributed with knowledge much more frequently than they report having contributed with funding. This results hold for almost every sector (with the exception of Machinery & Metals), regardless of whether the sector is a high or a low tech, or whether it is a manufacturing or a

service one. For half the sectors in our sample, the proportion of firms reporting contributing with knowledge doubles that of firms reporting contributing through funding.

Second, our results show that firms engaged in partnerships involving tacit knowledge and oriented towards exploratory research, are particularly likely to become knowledge contributors. In contrast, engagement in exploitative-oriented partnerships does not have a significant impact on eliciting firms' knowledge contributions. These results support the argument that a high degree of ambiguity with regards to methods, time horizons and expected results, which are inherent features of exploratory research, are particularly conducive to a two-way flow of knowledge between university and businesses.

This is not to argue that exploitation-oriented partnerships do not involve jointly production of knowledge. On the contrary, much applied research requires a frequent and intense level of interactions between university and business partners to facilitate a transfer of knowledge that is highly embedded in people (and generally difficult to codify). However, a substantial proportion of these partnerships are likely to be well-defined problem solving projects, which may require comparatively little substantial knowledge contributions from businesses.

It is important to note that these results are in line with much of the rationale underlying public policies oriented to support university-business collaborations, which tend to prioritise upstream and fundamental research for eligibility of public funding support, rather than downstream and applied research.

Finally, while much of the literature on university-business interactions has drawn on evidence from manufacturing firms, the results of this study indicates that further attention to the service sector is called for. First, because services account for almost halve of the firms involved in university-business partnerships. And second, because firms in some service sectors seem to be particularly engaged in the coproduction of knowledge, compared to manufacturing firms. This is not entirely surprising, since some of the very active knowledge contributors belong to sectors such as 'technology-based consultancy', which by definition of their main economic activity should be mainly characterised as knowledge providers. However, it does have an important implication for the analysis of university-business partnerships, since it suggests that the model of interaction between university and businesses might be substantially different for manufacturing and service firms.

We believe that this paper contributes to uncover the conditions that favour a two-flow knowledge exchange between universities and businesses. Moreover, it sheds new light on the distinct role of manufacturing and services in their patterns of interactions with universities. While this paper provides some preliminary findings, further investigation is required along these lines.

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