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Factors Affecting University-Industry R&D Collaboration: The importance of screening and signalling

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Abstract
This paper presents an empirical analysis of the determinants of research cooperation between firms and Public Research Organisations (PROs) for a sample of innovating small and medium-sized enterprises. The econometric analysis is based on the results of the KNOW survey carried out in seven EU countries during 2000. In contrast to earlier works that provide information about the importance of PROs' research, we know how many collaborative projects a firm has had with PROs. This allows us to study the determinants of firms' collaboration with PROs in terms of both the *propensity* of a firm to cooperate with a university (do they cooperate or not) and the *extent* of this cooperation (the number of collaborations). Two questions are addressed. Which firms cooperated with PROs? And what are the firm characteristics that might explain the number of collaborations with PROs? The results of our analysis point to two major phenomena. First, the propensity to forge an agreement with an academic partner depends on the 'absolute size' of the industrial partner. Second the openness of firms to the external environment, as measured by their willingness to *search*, *screen* and *signal*, significantly affects the development of cooperations with PROs. Our findings suggest that acquiring knowledge through the *screening* of publications and involvement in public policies positively affects the probability of signing an agreement with a PRO, but not the level of collaboration developed. In fact, firms that outsource research and development (R&D), and patent to protect innovation and to *signal* competencies show higher levels of collaboration.

Keywords: Public Research Organisations, University-Industry R&D cooperation, Openness.

JEL: H4, L3, O3

1. Introduction

Since the 1980s, many countries have implemented policies to promote and sustain university–industry partnerships. In the light of this phenomenon, an increasing number of academic contributions have attempted to understand, explain, and justify these interactions in economic terms. In Europe, university–industry relationships have been analysed mainly from a qualitative point of view or by relying on case studies of single universities.[1] Very few contributions have been supported by systematic data analysis. Some country-specific data have been gathered and analysed: Meyer-Krahmer and Schmoch (1998) and Beise and Stahl (1999) provide interesting evidence of the contribution of public research to industrial innovation in Germany. At the European level, apart from the PACE[2] (Policies, Appropriability and Competitiveness for European Enterprises) questionnaire and the three CIS (Community Innovation Surveys)[3], there are few databases that facilitate analysis of the links between universities and firms taking into account firm, sector and country effects.

The aim of this paper is to develop an original quantitative analysis of the determinants of firms' participation in research cooperation with public research organisations (PROs are defined here as universities and other public research centres). Our analysis provides preliminary evidence of the characteristics that affect firms' involvement with PROs in R&D projects, controlling for country and sector fixed effects. We use the results of the 2000 KNOW survey covering seven EU countries, including the four largest. The survey was limited to five sectors: food and beverages, chemicals (excluding pharmaceuticals), communications equipment, telecommunications services and computer services, and focused on small and medium-sized enterprises (SMEs) employing a minimum of 10 and a maximum of 999.

The econometric estimations are based on direct measurement of the extent of the collaboration between firms and PROs. Unlike previous studies we have information on the number of R&D projects conducted jointly with PROs in the three years before the survey (1997-2000). This direct measure of university–industry interaction allows us to assess the factors that affect: (a) the probability of a firm developing a cooperation with a PRO; and (b) the number of collaborative projects developed by the firm in the previous three years. Specifically, we address two main questions. Which firms established cooperation with PROs during the three years before the

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[1] See, among others, Faulkner and Senker (1995) for a qualitative technology-specific study. See Geuna *et al.* (2004), among others, for a university specific case (University Louis Pasteur, Strasbourg).
[2] See Arundel *et al.* (1995) and Arundel and Geuna (2004) for an analysis based on the PACE data, which focused on the large EU R&D intensive firms.
[3] See, among others, Mohnen and Hoareau (2003) for an analysis based on CIS II.

questionnaire? What are the particular characteristics that might explain the number of their agreements with PROs?

Particular attention is devoted to the idea that the openness of the firm to the external environment has an important effect on the development of collaboration with PROs. Openness refers here to the broad set of activities that firms can conduct to acquire knowledge from, voluntarily disclose knowledge to and/or exchange knowledge with the external world. These activities include *searching, screening* and *signalling* and can be carried out in different ways. It is important to account for these activities in order to understand whether their impact on both the propensity and the extent of collaboration is similar. In addition to openness we analysed the influence of other variables on firms' collaborations with PROs. Among these control factors we tested for firm size, firms' R&D activity and firms' innovative activity.

The paper is organised as follows. Section 2 briefly reviews the literature on university–industry R&D cooperation. Section 3 discuses the information collected in the KNOW survey and in-depth interviews relevant to the understanding of university–industry cooperation. The propensity for and extent of PRO-firm collaborations are examined in Section 4 using an econometric model. Finally, Section 5 summarises the main results of the analysis.

2. University–industry collaboration

The extensive literature on university–industry relationships is mainly empirical and based on case studies, patent and bibliometric analyses, or large surveys. One part of the literature highlights the positive impacts of scientific results on the economic sphere. Without academic research outcomes many innovations could not have been realised or would have come much later (Mansfield 1991; Beise and Stahl 1999). Scientific results brought about increased sales and higher research productivity and patenting activity for firms (Cohen *et al.* 1998). A second strand of the literature examines the relative importance of PROs, from the point of view of firms, as an external source of information both for new ideas and innovation completion. Cohen *et al.* (2002) and Fontana *et al.* (2004) show that although in both phases public research is less important than contributions from the vertical chain of production (suppliers, buyers, the firm itself), among the sources that are not in the production chain (competitors, consultants, joint ventures) the contribution of PROs is indeed significant. Other contributions study the importance of the channels used by both actors to exchange knowledge. Cohen *et al.* (2002) find that the channels of open science (publications, public meetings and conferences) are crucial. Other studies (Meyer-Krahmer and Schmoch 1998; Arundel and Geuna 2004) underline the importance of collaborative research and informal contacts. Finally, a set of econometric models that highlights the characteristics of firms draws upon the results of the research carried out in PROs to innovate. Very few analyses based on large surveys focus on formal R&D cooperation. The aim of this paper is to shed new light on the characteristics of firms involved in formal R&D cooperation with universities and other public research centres.

The role of firm size in influencing the propensity of firms to collaborate with PROs is one of the basic tenets of the literature on university–industry relationships as acknowledged in recent empirical investigations (Mohnen and Hoareau 2003; Cohen *et al.* 2002; Arundel and Geuna 2004; Laursen and Salter 2004). Usually larger firms and start-ups have a higher probability of benefiting from academic research.

Other studies (Schartinger *et al.* 2001; Arundel and Geuna 2004) incorporate level of R&D expenditure or R&D intensity. Firms that invest heavily in R&D are likely to possess a high capacity to absorb the knowledge developed outside the firm (Cohen and Levinthal 1990). If 'absorptive capacity' has a major role we would expect that the higher the firm R&D intensity (or investment) the higher the probability will be of a relationship with a PRO being established and the greater will be the number of collaborative R&D projects.

A recent study (Laursen and Salter 2004) introduces the concept of the 'open' search strategies of firms. In this study, the strategy regarding openness is a search strategy and the degree of firms' openness depends on the number of external channels of information used to innovate.[4] Firms that are 'more open' have a higher probability of considering the knowledge produced by universities as important for their innovation activities.

The degree of openness of a firm may be looked at from a broader perspective and may be considered as the set of activities carried out by firms to import information from and to voluntarily disclose knowledge to the external world. To get access to external knowledge firms may implement a *search* strategy (Laursen and Salter, 2004) together with an in-depth *screening* activity. *Screening* entails the selection of particular sources to get precise information concerning a specific problem. Openness may also represent the willingness of firms to share information. Panagopoulos (2003) shows that firms that are willing to share their innovation (i.e. choose to have minimal intellectual property protection) are more likely to form collaborations with universities.

[4] They use 15 different sources of information to construct the openness variable. The more firms use different external and internal sources, the more open they are.

Some firms may find it profitable to disclose knowledge and to inform the outside environment about their range of competencies by activating a *signalling* activity. Pénin (2004) provides empirical evidence that shows how firms often voluntarily reveal important pieces of knowledge through scientific publications, conferences, patents and the Internet. The main reasons for adopting such a strategy are to trigger reciprocity from other firms, gain feedbacks from suppliers and users, and to expand their network and reputation, but also to improve higher order knowledge (i.e. to ensure that others know what you know). In short, by *signalling* their competence firms attract potential partners and open up new opportunities for collaboration.

We also recognise that cooperation may be influenced by the 'legal status' of the firm. It is generally accepted that R&D activities tend to be concentrated at the firm's headquarters. However, empirical studies have generally failed to explicitly include this determinant among the independent variables – mainly because of lack of information on the location of the respondent with respect to the company headquarters. In a recent paper, Mohnen and Hoareau (2003) found that independent firms rely more on collaborations with PROs than firms that are part of large organisations. This result can probably be explained by the fact that within large organisations, the headquarters usually mediates collaboration.

Typically firms can engage in product and / or process innovations (Klevorick *et al.* 1995). Although it is very likely that there is a link between the type of innovative activities carried out by firms and the propensity for and the extent of firms' collaborations with PROs, recent investigations provide mixed results concerning the direction and the extent of the relationship. Mohnen and Hoareau (2003) found a positive relationship between the introduction of radical product innovations and the extent of reliance on PROs. Laursen and Salter (2004) found only partial support for the hypothesis that the more innovative firms in terms of product innovations are those that rely more on public sources. Swann (2002) maintains that companies involved in process innovation are more likely to cooperate with PROs than those engaged in product innovation. Though in this paper we focus mainly on the impact of openness on both the probability of a firm to develop research cooperation with a PRO and the number of research agreements developed, we also test for the influence of the other control variables.

3. Firm—PRO Collaboration: Evidence from the KNOW survey and in-depth interviews

The empirical analysis presented in this paper is based on the results of the KNOW survey and on 70 in-depth interviews carried out in 2000.

3.1 The Know Survey

In covering seven EU countries,[5] including the four largest, the KNOW survey focused on five sectors: food and beverages (NACE 15), chemicals excluding pharmaceuticals (NACE 24 minus NACE 24.4), communications equipment (NACE 32), telecommunications services (NACE 64.2), and computer services (NACE 72). These specific sectors were chosen to provide a range of low, medium and high technology manufacturing and to include two innovative service sectors. In each country, a random sample of firms from two size classes (10–249 employees and 250–999 employees) within each of the five sectors was drawn from a national business registry. The response rates by country varied from a minimum of 9% in the UK to a maximum of 76% in Denmark. The average response rate was 25% and 33% not including the UK. Of the 675 firms that responded, 458 – all innovators – were retained for the analysis (non-innovative firms were excluded).[6]

Consistent with the findings from other surveys of firms' innovative activity (Klevorick *et al.* 1995; Arundel *et al.* 2000; Cohen *et al.* 2002; Swann 2002), the firms included in our sample only infrequently rated PROs as the most important source of information (Fontana *et al.*, 2004). However, about half of them had had some R&D cooperation with PROs in the three years before the questionnaire. Of the 458 firms, 222 said they had been involved in one or more cooperative agreements with PROs in the previous three years.

Participation in cooperative projects varied depending on which industry the firms belonged to. Food and beverages and chemicals are the industries with the largest share of firms collaborating with PROs while telecommunication services is the industry least involved with PROs. A relatively large number of computer services firms never cooperate with PROs, although some have developed a significant number of cooperative R&D projects with PROs (more than six in the last three years).[7] Table 1 shows the subdivision of the number of collaborative agreements by sectors.

[Insert Table 1 about here]

Overall, the firms surveyed have an average of 1.6 R&D cooperative projects with PROs. They collaborate with PROs from a minimum of 0 to a maximum of 25 times and the distribution of

[5] The countries are: Denmark, France, Germany, Greece, Italy, the Netherlands and the UK.

[6] See Caloghirou, Constantelou and Vonortas (2004) for the description of the KNOW survey's methodology and main results.

[7] The highest reported number of R&D projects with PROs was 25. Two respondents answered 80 and two responded 100. They were excluded from the analysis because we considered their answer was either incorrect or that the numbers included informal contacts.

their cooperation is very skewed (see Table 2 in the Appendix for the descriptive statistics). The population of firms carrying out collaborative projects with PROs can be described as being composed of a large number of organisations cooperating in only a small way and a small group of firms involved in a large number of cooperative agreements.

3.2 In-depth interviews

In each of the seven EU countries the KNOW team members interviewed one small and one large firm in each of the five selected sector – a total of 10 in-depth interviews in each country. We selected companies that replied to the questionnaire and the objective of the interview was to gain further knowledge on the means used by firms to gather external information (i.e. their screening and search strategies) and their cooperative behaviour (in general and with PROs). In this section we highlight those results from the interviews that are relevant to the understanding of university-industry collaboration.

Within groups, the division interviewed often underlined that the parent company was involved in the innovation process. The parent company either developed the innovation or was involved in the first stages of the R&D process (alone or in collaboration with external partners). The firm's policy was determined by the strategy of the parent company. A centralised R&D policy implied higher involvement of the parent company in terms of cooperation, competitive intelligence and patenting activities. However, in some cases firms were independent and were free to conduct research with their own network of partners. This information indicates that the status of the firm influences its innovative and thus cooperative behaviour, but headquarters are more likely to conclude cooperative agreements and to apply for patents.

A significant number (around 50%) of the companies interviewed collaborated with universities or PROs. These firms generally developed intense competitive intelligence activities and they regarded these activities as being strategic. They used a variety of tools to search for information about the external environment: they subscribed to professional and scientific journals, attended trade fairs and conference, used the Internet and deepened contacts with suppliers and clients. Some used reverse engineering and patent databases, although these particular tools were used less often. Firms that never cooperated with PROs also undertook search activities. In this sense then, searching behaviour was not a discriminating factor. Some of the interviews clearly highlighted that those firms that were not open to the external world or that only activated search tools occasionally never collaborated with third parties to innovate.

Among the reasons for not collaborating with universities, firms cited discrepancies between the objectives of the two parties, the length of time involved in university research, the different focus and hence different research questions addressed by universities and firms, cultural differences, and uneasiness with 'open science' disclosure procedures. Moreover, in some sectors it was considered that universities are lagging behind industry, in the sense that most graduate students tend to ignore recent industry developments.

Among the portfolio of formal agreements signed with universities, the interviewees often mentioned cooperative projects within a government research programme (which was in part subsidising the R&D cooperation). Respondents considered government research programmes to be a useful way to facilitate knowledge flows between different organisations. Clearly, the financial aspects were an important motivation for firms to collaborate with PROs, even if the bureaucracy was judged to be excessive. Generally, firms become involved in government-subsidised R&D agreements as a means to solve a specific technical problem.

Firms usually selected academic partners based on reputation and domains of competence. University partners were considered important for the innovation process because they were able to solve very specific problems and transfer important scientific and technical knowledge. Some respondents underlined that collaborating with universities increased their reputation and some clients saw gains in terms of reliability and innovative ability.

Finally, our interviews revealed that the role of universities differed between sectors. In chemicals, collaboration with universities mainly helps to reduce costs and risks and allows firms to acquire and update scientific knowledge in order to finalise products. In the agro-industry universities help firms to meet government regulations, especially in testing activities in bacteriology. In the computer services sector, however, the main role of universities is to help firms update and acquire technical knowledge.

4. Modelling PRO-firm collaboration

Direct measurement of the extent of collaboration between firms and PROs is unique to the KNOW survey. In contrast to earlier work that produced information about the importance of PRO research, here we know how many R&D projects were conducted within a firm–PRO partnership. This allows us to study the determinants of firms' collaboration with PROs in terms of both the propensity for a firm to cooperate with a university (do they cooperate or not) and the extent of this cooperation (the number of R&D projects). Two questions are addressed in this section. Which firms initiated collaboration with PROs during the three years before the questionnaire?What are the characteristics that might explain the number of R&D projects with PROs? In Section 4.1 we present the econometric models and Section 4.2 describes the explanatory variables included in the estimations. In Section 4.3 we estimate the models.

4.1 The econometric model

The number of collaborative projects is the measure we use for the extent of collaboration between firms and PROs, and our dependent variable. Being a discrete variable, it appropriate for the estimation to employ a model for count data based on a Poisson distribution. In this case, we would define y_i as the number of R&D collaborations firm *i* has been engaged in (where *i* = 1, 2, …, N). The variable y_i would be distributed as a Poisson with parameter l_i:

$$P(Y_i = y_i) = \frac{e^{-l} l_i^{y_i}}{y_i!} \qquad (1)$$

where l_i can be specified by a vector of covariates Xi that includes the variables that will be introduced in Section 4.2. The most common formulation for l_i is the log linear model:

$$\ln l_i = b_i x_i \qquad (2)$$

which guarantees that the expected number of collaborations is non negative and is given by:

$$E(y_i | x_i) = l_i = e^{b_i x_i} \qquad (3).$$

There are two issues that arise when using Poisson models. The first concerns the fact that a Poisson distribution constrains the variance to be equal to the sample mean. This is a problem in our case given that the sample is very skewed. The second issue concerns the presence of the large number of firms in our sample with zero collaborations. Although many firms have engaged in R&D collaboration with PROs only a few have collaborated in projects. Both these features make the Poisson model unsuitable for modelling the level of participation of firms in collaborations with PROs.

One way to deal with the overdispersion issue is to add a random unobserved effect to the mean of the Poisson distribution. This solution was first proposed by Hausman *et al.* (1984) and taken up by others in several analyses based on innovation and patent counts (Silverberg and Verspagen, 2003; Nesta and Saviotti, 2004). It involves the use of a modified Poisson such as:

$$P(Y_i = y_i | u_i) = \frac{e^{-l u} (l_i u_i)^{y_i}}{y_i !} \qquad (4).$$

In our case u_i accounts for unobserved cross-sectional heterogeneity among firms not adequately accounted for by the chosen covariates. If u_i is distributed as a Gamma, then the unconditional distribution for y_i that can be obtained is a mixture of Poisson and Gamma distribution (Cameron and Trivedi, 1998):

$$P(Y_i = y_i | X_i) = \frac{\Gamma(a^{-1} + y_i)}{\Gamma(y_i + 1)\Gamma(a^{-1})} r_i^{y_i} (1 - r_i)^{a^{-1}} \qquad (5)$$

where $r_i = \frac{l_i}{l_i + a^{-1}}$. Equation (5) is the form of the Negative Binomial distribution with mean l_i and variance $l_i (1+ a\, l_i)$ for $a > 0$. This equation constitutes the starting point of our estimations.

The issue of 'excess zero' will be dealt with by employing a Zero Inflated Negative Binomial (ZINB) model. Our dependent variable describes the number of collaborations between firms and PROs. However, the actual number is observable only if a firm decides to collaborate with PROs. There is a substantial 'qualitative' difference between a decision to increase the number of projects from 0 to 1 and from 1 to 2 or 3 etc. The former decision reflects the *propensity* of the firm to collaborate. The latter captures the *extent* to which the firm is engaged in R&D collaborations. ZINB models capture both these aspects by estimating a combined qualitative regression that explains the decision not to collaborate, and therefore acts as 'selection model', and a quantitative regression that explains the extent of collaboration for those firms that collaborate. Moreover, it must be noted that our dependent variable refers to the number of collaborations established in the three years preceding the survey. A bigger window would probably have produced a less skewed distribution since firms that record 0 projects may have recorded engagement in R&D projects with PROs for a longer time span. The ZINB model enables us to control for this potential source of mis-specification (Stephan *et al*. 2004).

4.2 The explanatory variables

The aim of the regression analysis is twofold. The main purpose is to measure the *extent* of the relationship as proxied by the number of projects that firms engage in with PROs. In addition, we aim to test for the existence of a relationship by analysing the propensity for firms to engage in collaborations with PROs and identifying some firm-specific characteristics, controlling for industry and country fixed effects. To achieve these aims we chose a list of covariates that facilitates evaluation of the effect of firm-specific factors upon the number of projects between firms and PROs.

Following the discussion presented in Section 2 on the determinants of university–industry R&D cooperation and the evidence obtained from the detailed interviews we focus on four broad classes of firm characteristics. In particular we identified: (1) firm size; (2) firm R&D activity and status; (3) firm innovative activity; (4) openness of the firm. Specific questions designed to glean information regarding each of these classes were selected from the questionnaire in order to construct independent variables. In this section we discuss the choice of these variables. Descriptive statistics are reported in Table 2 in the Appendix.

Firm size

The rationale underlying the role of firm size in affecting the progress of R&D collaboration is that big firms have more resources to help them to establish their relationships with PROs: the smaller the firm, the less are the resources available to develop multiple relationships.[8] We use two measures of firm size. First, we consider the impact of R&D employment *(R&D)*. This is an indicator of the 'relative' (i.e. the research) size of the firm rather than of its overall size. As a measure of the absolute size of the firm we used the number of employees *(EMPLOYEES)*. We would expect the absolute size to affect the propensity to collaborate more than the extent of collaboration.

Firm R&D activity and status

R&D intensive firms might be more likely to set up collaborations with PROs as they are active at the technological frontier and thus are more reliant than other firms on scientific developments. To

[8] Whether a higher propensity for big firms to collaborate with PROs corresponds to a better capability to exploit the benefits deriving from the collaboration is controversial. Link and Rees (1990) and Acs *et al.* (1994) argue that big firms have lower R&D productivity than small firms and are therefore less efficient at exploiting the benefits deriving from interactions with PROs. Cohen and Klepper (1996), however, argue that the lower productivity of big firms is not related to R&D efficiency linked to firm size, but is instead the consequence of the presence of high fixed costs. However, we have to remember that the scale effect makes large firms to reap a higher profit form innovation in general.

test for this effect, we included a variable for R&D intensity of the firm *(R&DINT)*, based on the ratio between R&D employment and total employment.

The level of detail provided by the KNOW survey enables us to test if collaboration depends on the status of the firm. In particular, if R&D activity is concentrated in the firm headquarters this may affect the extent of collaboration between firms and PROs. A dummy variable *(HEADQ)* was used to account for whether the respondent was located within the central headquarters of the company. We expect this dummy to positively affect the development of collaborations.

Firm innovative activity

In an attempt to shed additional light on both the direction and the extent of the relationship between the type of innovative activity of the firm and the propensity for firms to collaborate with universities we decided to include in the regression two dummy variables – one to capture whether the firm has introduced process innovation *(PROCESS)* and one focused on product innovation *(PRODUCT)*. These test for the effects of different innovative processes on the development of collaboration with PROs.

Openness of the firm

In defining openness, we distinguish between three types of activities: *searching*, *screening* and *signalling*. Laursen and Salter (2004), assume that the number of channels of information firms draw upon to import knowledge correspond to a search strategy. Among the 15 internal and external channels of information they considered are participation in fairs, conferences and meetings, searching databases, looking at competitors' products, etc. Instead of using a discrete variable we proxy *search* activity with a variable in levels *ExtCOLL*, which is the mean of the percentage of new products and processes introduced in collaboration with external partners. We would expect this variable to positively affect participation in projects with PROs.

Openness also refers to *screening* and *signalling* strategies. A *screening* strategy can be proxied by different 'enablers' in the following way. First, publications as a source of ideas seem to be a particularly important determinant of collaboration with PROs since reliance on them indicates the relevance of academic research for the innovative process. We therefore constructed a dummy variable *(PUBLICATIONS)*, which takes the value 1 when the firm *screens* information from scientific and business journals, and 0 when it does not. Second, participation in government-funded R&D projects is an appropriate way to directly meet *(screen)* new partners, learn about them, their competencies and their networks. To account for this effect, we created a dummy variable *(SUBSIDIES)*, which takes the value 1 if a firm has received public subsidies from regional, national or EU authorities for R&D activities in the three years preceding the questionnaire.

Signalling is also proxied by two variables. The first is patents. As the outcome of a research process, patents are usually used to protect product innovations from imitation (Levin *et al.* 1987) increase the bargaining power of firms in negotiations (Hall and Ziedonis, 2001) and in R&D cooperation and knowledge exchange (Pénin, 2004). We would expect appropriation and *signalling* to affect the extent of R&D projects with PROs. More specifically, using patents to protect innovation and *signal* competencies should have positive effects on participation in collaborative projects with PROs. A dummy variable *(PATENT)* is employed to capture this effect.

In addition to patenting, outsourcing R&D expenditure is another way in which firms *signal* their propensity to establish collaborative relationships. Firms with a higher propensity to establish R&D collaborations with independent firms may be involved in a high number of collaborations with PROs. One of the reasons for this is that once they have developed the skills needed to manage cross-boundary relationships, firms are more willing to cooperate with external partners in the development of an innovative activity for the firm. To capture this influence, we used information on the (percentage) external expenditure in independent organisations to total firm R&D expenditures *(ExtR&D)*. This variable is clearly another proxy for the openness of a firm to the external R&D environment. Firms with high external R&D expenditures are more open to interaction with external organisations. We would expect *screening* activities to affect the probability of being involved in at least one R&D collaboration (if you do not screen you do not want to cooperate) while *signalling* should influence the extent of participation in collaborative projects with PROs.

We also included in the regressions two additional dummy variables.A dummy variable *(COUNTRY)* to account for country fixed effects and a control dummy *(SECTOR)* to account for sector-specific effects.

4.3 Estimation results

In this section we present the results from the estimation of several negative binomial models. Five models were estimated taking the number of R&D cooperations as the dependent variable. Model (1) considers the logs of relative size (R&D) absorptive capacity (R&DINT) and the dummies related to firm status (HEADQ) and the type of innovative activity carried out by the firm

(PROCESS and PRODUCT). Models (2) to (5) take account of the impact of the openness and the sector as well as country dummies. In these models the variables that are proxies for openness are added in sequence. Thus we are able to capture the impact of the searching strategy as proxied by ExtCOLL in model (2), to estimate the contribution of screening as proxied by PUBLICATIONS and SUBSIDIES in model (3) and to capture the influence of signalling as proxied by PATENT and EXT R&D in model (4). Table 3 below presents the results.

[Insert Table 3 about here]

In model (1), all the independent variables chosen have a positive effect on the extent to which firms engage in collaborations with PROs, and all the coefficients excluding PRODUCT are significantly different from zero. We find evidence of an 'R&D size and activity effect' on the extent to which firms engage in projects with PROs as represented by the positive coefficients for R&D, our proxy for relative size and absorptive capacity. This result suggests that larger firms that are heavily engaged in R&D activities (high R&D intensity) become involved in a higher number of collaborations with PROs than do small firms.[9] Moreover, we find evidence of a positive correlation between the status of the firm and the extent of collaboration indicating that firms that are part of large units tend to collaborate more than independent firms. Finally, engaging in process innovation seems to increase the extent of involvement in R&D cooperations while, as mentioned above, there is no evidence of a significant correlation between product innovation and engagement in collaborations with PROs.

Models (2) to (4) estimate the contribution of the various activities that constitute openness. Model (2) considers the contribution of *searching* as proxied by the mean of the percentage of new products and process introduced in collaboration with external partners (ExtCOLL). The coefficient of this variable is positive, but not significant, suggesting that searching does not affect the number of collaborations between firms and PROs. It is interesting to note that this result

[9] Several attempts to include other variables in the list of independent variables were made. In particular we checked for the influence of firm strategy, other than looking at external collaboration in R&D expenditures, might have on the propensity for firms to engage in projects with PROs. For instance, to analyse the possibility that firms involved in strategic business alliances are more likely to participate in R&D cooperative projects with PROs, we introduced in the regression a dummy variable (RJV) that takes the value of 1 when the firm is involved in a business joint venture, and 0 when it is not. While the effect of this variable on the number of R&D projects was generally positive, the coefficient of the variable was not significant.

contradicts that obtained by Laursen and Salter (2004) who found *searching* to be an important determinant of university–industry collaborations.[10]

Models (3) and (4) relate to the two other activities that constitute openness: *screening* and *signalling* respectively. *Screening* as proxied by looking at publications, and participation in projects subsidised by regional, national or EU authorities, positively affects the number of collaborations with PROs. Both our proxies for *signalling* have the expected (and positive) sign although only one of them (patenting) is significant. More generally, the addition of these variables does not change the sign of the others although the level of significance is slightly affected. These results confirm that *searching* does not seems to affect collaboration with PROs while the other measures of openness do. Thus, the usefulness of distinguishing between *searching*, *screening* and *signalling* activities as constituents of openness is stressed.

Finally, in model (5) we control for country and sector fixed effects. Results from this model generally confirm the results of models (1)-(4) although the coefficients of some variables (R&DINT, HEADQ) become less significant.

A final comment is needed about the appropriateness of the choice of the Negative Binomial for the estimation of Models (1) to (5). We have stressed that overdispersion in our data seems to point to the inadequacy of employing the Poisson distribution for estimation. This impression was confirmed by the outcome the *a*-Likelihood Ratio tests carried out for each of the specifications, the values of which are displayed at the bottom of Table 3. In each case the test value of the Chi square suggests that the probability of the data having been generated by a Poisson process is very low. This led us to reject the null hypothesis and prefer a Negative Binomial.

The sensitivity of these results was checked by estimating a ZINB model. Before running these regressions we performed a Vuong test to select between the Negative Binomial and the ZINB.[11] A

[10] To further check this result we constructed another proxy for search following Laursen and Salter (i.e. considering the number of channels used by the firm to relate to the outside world). In this case, too, there was no significant relationship between the extent that firms engage in R&D collaborations and *searching* as a proxy for openness.

[11] Define $f_1(y_i|X_i)$ the density function of the ZINB model and $f_2(y_i|X_i)$ the density function of the Negative Binomial model and let $m_i = Ln\, f_1(y_i|X_i) / f_2(y_i|X_i)$, the Vuong statistics for testing the hypothesis of the ZINB against the Negative Binomial is $v = \sqrt{n}\left[\frac{1}{n}\sum_{i=1}^{n} m_i\right] \Big/ \sqrt{\frac{1}{n}\sum_{i=1}^{n}(m_i - \overline{m})}$. If v >2 the ZINB model presents a better fit than the Negative Binomial. However, if $v < -2$, the Negative Binomial presents a better fit. For $-2 < v < 2$. Neither model then can be said to be preferred (Greene, 2000, p. 891).

value of $v = 3.62$ seems to suggest that a ZINB model provides a better fit than a Negative Binomial. Table 4 below reports the results.

[Insert Table 4 about here]

The last two columns in the table separate the coefficients of the ZINB regressions (Model 6) from those from the Logit Selection regression (Model 7). These results were produced using the same covariates in both models with the exception of absolute size (EMPLOYEES) which was used in place of relative size (R&D), the inclusion of screening variables in the Logit Selection model only, and the inclusion of the signalling variables in the ZINB regression only.

The results of the ZINB model are similar to the Negative Binomial. Compared to the Negative Binomial, in the ZINB regression HEADQ and PROCESS no longer exhibit a significant coefficient. In terms of the effect of the other independent variables, both signalling variables have a positive influence on the number of cooperative R&D activities between firms and PROs.

More interesting in the context of this paper is the comparison between the coefficients in the ZINB regression (Model 6) and those in the Logit Selection regression (Model 7). While the former accounts for the influence of the independent variables on the extent to which firms engage in collaborations with PROs, the latter captures the influence of the variables on the propensity of firms to participate in a collaborative agreement.[12]

In the Logit regression, EMPLOYEES, the proxy for the 'absolute size' of the firm, positively affects the propensity to participate. Other things being equal we can argue that there is indeed an 'absolute size' effect determining the propensity for a firm to engage in collaborations with PROs, while there is no significant 'relative size' effect as captured by R&D employment, on the extent of participation in projects. R&D intensity, the proxy for the position of the firm with respect to the technological frontier rather than firm size, is a significant explanatory variable for both extent of and propensity for collaboration, though with a higher probability in the Logit regression. The HEADQ variable changes in significance between the Logit and the ZINB regression. Respondents located in the headquarters of a firm have a higher propensity to collaborate with PROs compared to other respondents, but this characteristic does not affect the level of cooperation. Finally,

[12] A positive coefficient in the Logit Selection regression indicates that a firm is less likely to collaborate with PROs.

making product innovations significantly affects the extent of collaboration while engaging in process and / or product innovation does not significantly affect the propensity to collaborate.

Among the different types of activities explaining openness, *searching* is never significant while *screening* positively affect the probability of being involved in at least one R&D collaboration and signalling positively influences the number of times a firms signs agreements with a PRO. Other effects being equal, *screening* by consulting scientific or business journals for ideas, and possibly for signals of the competences of potential partners, has a positive impact on the propensity to collaborate with PROs. Similarly, SUBSIDIES has a positive and significant effect in the Logit estimation. On the other hand, outsourcing R&D activities and taking out patents, our proxy for *signalling*, positively affects the extent to which firms engage in collaborations with PROs.

Our findings can be summarised as follows. The propensity of firms to collaborate with PROs is positively affected by their absolute size, their R&D activity and their degree of openness, but not by the type of innovation they generate (process or product innovation). Larger firms with a high absorptive capacity generally tend to cooperate with the academic world. Openness of the firm to the external environment affects the propensity and level of collaboration with PROs. The general *searching* activity does not influence the propensity for cooperation. *Screening* activities, however, constitute important explanatory variables of R&D cooperation. Seeking information in scientific and business journals (i.e. the major channel used by open science to share information and signal competences) and also participating in government-funded projects positively affect the propensity for firms to collaborate with PROs. In short, larger firms with higher learning abilities which engage in in-depth screening activities are the most likely partners for universities. Openness also positively affects the number of agreements concluded by firms through patenting, and the extent of R&D outsourcing. Patents may constitute a way to signal the firms' competencies, especially in the case of SMEs for whom secrecy is the usual way to approach appropriability and thus patents could be interpreted as a proxy for *signalling*. R&D outsourcing is itself a signal that firms are willing to engage in collaborations with external partners. Finally, the extent of involvement in cooperation with PROs is affected only by the intensity of R&D activities carried out by firms. In short, firms with more R&D involvement, that are more involved with external R&D suppliers and which signal their competences, tend to develop a larger number of collaborative agreements with PROs

5. Conclusions

The KNOW questionnaire provides a unique data set for the researcher to analyse the innovation processes of SMEs with a minimum of 10 and a maximum of 999 employees. This paper looked at the characteristics of the firms that developed R&D collaborative projects with PROs taking into account sector and country fixed effects. One of the main contributions of this analysis is to characterise firms through the activities used to manage internal and external knowledge. Firms that actively screen their environment and voluntarily disclose internal competencies have a higher propensity to collaborate with academic partners and cooperate in a more extensive way.

About half of the firms surveyed had developed R&D projects with PROs. The econometric models developed estimate the impact of firm-specific factors, controlling for sector and country fixed effects, upon both the probability of developing a collaboration and the number of collaborations with a PRO entered into by the firm in the three years previous to the KNOW survey. The results of this analysis point to two main findings.

The first findings focus on the role of the size and the R&D activity on the collaborative behaviour (propensity and intensity) of the firms. They mainly confirm the empirical findings for large firms ((over 1000 employees). The propensity to conclude an agreement with an academic partner depends on the 'absolute size' of the industrial partner (Arundel *et al.* 2000; Cohen *et al.* 2002; Mohnen and Hoareau 2003; Laursen and Salter 2004). Larger firms are much more likely to collaborate. We also found that the chances of firms with intense R&D activities to cooperate are much higher as is the likelihood of concluding agreements with PROs: firms with small absorptive capacities had lower probabilities on both counts (Arundel and Geuna, 2004).

The second set of results concerns the openness of firms, that is, their willingness to *search* for external knowledge, to *screen* the outside world using publications databases and participating in publicly-funded programmes and also to *signal* their competencies by patenting, and by outsourcing R&D expenditures. Our findings suggest that acquiring knowledge through the *screening* of publications and involvement in public policies affect the probability of signing an agreement with a PRO, but not the level of collaboration developed. Instead, firms that outsource R&D expenditure and patent to protect innovation and to *signal* competencies show higher levels of collaboration. These results somehow imply that the existence of a *screening* strategy would determine the start of a relationship between firms and PROs; whereas the activation of a *signalling* strategy would explain the intensity of the interaction, other things being equal. In other words, the firms that actively observe and monitor outside knowledge (especially through *screening* publications, i.e. the channels of open science) tend to develop R&D cooperation with PROs; however, the level of interaction (as measured by the number of R&D projects) depends on the willingness to *signal* their competences and the relative weight of network interactions in their production of knowledge.

The results of our analysis support the view that relationships between firms and PROs are characterised by a high degree of heterogeneity. To generalise about university–industry relationships, and develop policies on the basis of such generalisations will lead to unintended inter-sectoral differences. The various actors will react to these policies in different ways depending on their specific characteristics. Furthermore, it is extremely important to take into account that policies in support of collaboration between PROs and firms should create incentives for both sets of actors to cooperate. Current policies are mainly directed to creating incentives for PROs to interact with firms, with no acknowledgement that without an appropriate ‘demand’ little will be achieved. This paper provides strong evidence that, after controlling for firm size and other factors, the openness of firms to the external environment (and therefore their willingness to interact with it in different ways) is very important in explaining their patterns of collaboration with PROs.

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Table 1: Share of respondents for PROs contract classes

Contract Classes	Food	Chemicals	Comm Eq	Telecomm Serv	Comp Serv
0	44.7%	44.5%	52.3%	75.6%	56.1%
1	43.0%	37.3%	30.2%	22.0%	28.0%
2	7.9%	16.4%	15.2%	0%	7.5%
3	4.4%	1.8%	2.4%	2.4%	8.4%

0 = zero contracts; 1 = 1 contract; 2 = 2 contracts; 3 = more than 2 contracts

Table 3: Regression Summary – Negative Binomial regressions

(Dependent Variable: Number of R&D collaborations)

		(1)	(2)	(3)	(4)	(5)
	Intercept	-2.091**	-2.065**	-2.601**	-2.433**	-3.823**
		(.51)	(.56)	(.62)	(.66)	(.91)
RELATIVE SIZE	LN(R&D)	.375**	.354**	.231**	.180*	.195**
		(.07)	(.08)	(.08)	(.09)	(.09)
ABS CAPACITY	LN(R&DINT)	.970**	1.169**	1.440**	1.813**	1.280**
		(.49)	(.54)	(.53)	(.55)	(.56)
STATUS	HEADQ	.440**	.434**	.504**	.486**	.371*
	(dummy)	(.16)	(.17)	(.18)	(.19)	(.21)
TYPE OF INNOVATIVE ACTIVITY	PROCESS	.792**	.846**	.710**	.731**	.614**
	(dummy)	(.22)	(.25)	(.26)	(.28)	(.28)
	PRODUCT	.703	.571	.525	.138	.326
	(dummy)	(.46)	(.50)	(.50)	(.53)	(.51)
SEARCHING	ExtCOLL		.005	.004	.005	.005
			(.00)	(.00)	(.00)	(00)
SCREENING	PUBLICATIONS			.786**	.764**	.928**
	(dummy)			(.24)	(.27)	(.29)
	SUBSIDIES			.591**	.537**	.581**
	(dummy)			(.18)	(.19)	(.20)
SIGNALLING	PATENT				.415**	.495**
	(dummy)				(.18)	(.19)
	EXT R&D				.007	.007
					(.00)	(.00)
	SECTOR (dummy)					YES
	COUNTRY (dummy)					YES
Log-likelihood		-643.11	-550.91	-506.74	-434.52	-418.41
LR Chisq		67.95**	58.81**	70.20**	67.51**	99.73**
Pseudo Rsq		.050	.050	.065	.072	.106
No Obs		395	336	304	255	255
LR Chisq $\alpha = 0$		370.20**	324.04**	268.09**	216.70**	163.34**

*indicates significant at 10% confidence interval.

** indicates significant at least at 5% confidence interval.

Standard errors between brackets

Table 4: Regression Summary – ZINB and Logit Selection Equation

		ZINB (6)	(7) LOGIT SELECTION
	Intercept	-1.17 (.83)	3.35 (4.50)
RELATIVE SIZE	LN(R&D)	.15** (.07)	
ABS CAPACITY	LN(R&DINT)	.83* (.48)	-3.22* (1.89)
ABSOLUTE SIZE	LN(EMPLOYEES)		-.42* (.22)
STATUS	HEADQ (dummy)	.08 (.19)	-1.16* (.63)
TYPE OF INNOVATIVE ACTIVITY	PROCESS (dummy)	.50 (.31)	-.32 (.70)
	PRODUCT (dummy)	.74* (.44)	2.78 (3.69)
SEARCHING	ExtCOLL	.00 (.00)	-.00 (.01)
SCREENING	PUBLICATIONS (dummy)		-2.05** (.60)
	SUBSIDIES (dummy)		-1.58** (.62)
SIGNALLING	PATENT (dummy)	.44** (.16)	
	EXT R&D	.01** (.00)	
	SECTOR (dummy)	YES	
	COUNTRY (dummy)	YES	
Log-likelihood		-369.92	
LR Chisq		60.90**	
No Obs		255	

*indicates significant at 10% confidence interval.
** indicates significant at least at 5% confidence interval.
Standard errors between brackets

Appendix

Table 2: Descriptive Statistics for selected variables (all variables)

Variable	Obs	Mean	Std. Dev	Min	Max
No of Collaborations	458	1.62	2.84	0	25
R&D	491	13.53	32.52	0	300
R&DINT	485	0.15	0.23	0	1
EMPLOYEES	546	194.82	261.52	2	1200
HEADQ (dummy)	554			0:241	1:313
PROCESS (dummy)	543			0:95	1:448
PRODUCT (dummy)	553			0:22	1:531
ExtCOLL	483	14.93	18.93	0	100
PUBLICATIONS (dummy)	552			0:99	1:453
SUBSIDIES (dummy)	492			0:341	1:151
PATENTS (dummy)	551			0:354	1:197
ExtR&D	417	14.32	22.44	0	100

For dummy variables, the last two columns report the number of cases in which the variables take the value 0 or 1.

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