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Factors affecting university–industry R&D projects: The importance of searching, 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 (SMEs). 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 the number of firm/PRO collaborative research and development (R&D) projects. This allows us to study the determinants of firm collaboration with PROs in terms of both the *propensity* of a firm to undertake R&D projects with a university (do they cooperate or not) and the *extent* of this collaboration (number of R&D projects). Two questions are addressed. Which firms cooperated with PROs? And what are the firm characteristics that might explain the number of R&D projects 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 R&D projects 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 number of R&D projects developed. In fact, firms that outsource research and development, and patent to protect innovation and to *signal* competencies show higher levels of collaboration.
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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-

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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).

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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 (Policies, Appropriability and Competitiveness for European Enterprises)[2] questionnaire and the three Community Innovation Surveys (CIS),[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 and development (R&D) projects 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.[4] 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 cooperation between firms and PROs. Unlike previous studies we have information on the number of R&D projects conducted jointly with PROs in the 3 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 cooperation with a PRO and (b) the number of R&D projects developed by the firm in the previous 3 years. Specifically, we address two main questions. Which firms established partnerships with PROs during the 3 years before the questionnaire? What are the particular characteristics that might explain the number of their R&D projects 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, firms' innovative activity and firms' tendency to outsource R&D.

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

2. University–industry relationships

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. (2002a) and Fontana et al. (2003) 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. (2002a) 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

[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.

[4] In the paper, we look at R&D project between firms and PROs. However, the word 'collaboration' is frequently used throughput the text as a synonym. Indeed, R&D projects can broadly be interpreted as collaborations since the majority of R&D projects probably entail a collaborative element.

collaborative research and informal contacts. Finally, a set of econometric models highlights the characteristics of firms that draw upon the results of the research carried out in PROs to innovate. Very few analyses based on large surveys focus on R&D projects. The aim of this paper is to shed new light on the characteristics of firms involved in formal R&D projects with universities and other public research centres.[5]

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., 2002a; 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 and/or R&D intensity. Firms that invest heavily in R&D are likely to possess a high technological capability that also allows them to absorb the knowledge developed outside the firm. If 'absorptive capacity' (Cohen and Levinthal, 1990) has a major role we would expect that the higher the firm's 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.

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 mediate collaboration.

Typically firms can engage in product and/or process innovations (Klevorick et al., 1995). It is very likely that a complex link exists 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, which may be due to the fact that firms tend to perform both types of innovative activities in parallel and may use the same source of knowledge for both product and process innovation. 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 firms that are more innovative, 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.

A recent study (Laursen and Salter, 2004) introduces the concept of 'open' search strategies. In this study, firms' openness is a search strategy and the degree of openness depends on the number of external channels of information used to innovate.[6] Firms that are 'more open' have a higher probability of considering the knowledge produced by universities as important for their innovation activities. While search plays a crucial role in the management/organisation literature (Chesborough, 2003), for the asymmetric information literature (Spence, 1974) search is only one component in a range of activities a firm has to perform to identify potential partners (hire potential employees for instance). This paper argues that the concept of openness of a firm should be looked at from a broader perspective and may be considered as the set of activities carried out by firms to both gather information from and voluntarily reveal knowledge to the external world. In particular, taking on board the broader concept assigned by the management and organisation literature of searching, we break down the process of information gathering, management and handling involved in the identification of a collaborative partner into three components: *searching*, *screening* and *signalling*.

To gather information, firms implement a *search* strategy (Laursen and Salter, 2004) coupled with an in-depth *screening* activity. While *searching* implies a general attitude of looking at potential valuable sources of information, *screening* involves identifying and selecting the best within the set of possible information providers (Stiglitz, 2002). In the specific case of firms wanting to engage in R&D cooperation with other firms and/or PROs, *screening* means both a general open behaviour and a specific ability to identify the most suitable partners. To reveal knowledge, firms implement a *signalling*

[5] The word 'formal' is used here to differentiate between consultancy and/or other types of informal exchange of information. Throughout the paper we look at 'R&D projects' which we consider to be 'formalised agreements'.

[6] 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.

activity. We define *signalling* as the activity carried out by firms aimed at voluntarily disclosing knowledge to less informed economic agents, to convince them of their firms' specific attributes (Spence, 2002). In the case of R&D cooperation, *signalling* refers to firms who have an incentive to convince prospective partners (both firms and PROs) of the opportunities available from engaging in a good R&D project.

Recent contributions point to the importance of *signalling* for establishing cooperative R&D agreements. For instance, Panagopoulos (2003) provides empirical evidence that firms that are willing to share their innovation (i.e. choose to have minimal intellectual property protection) are more likely to collaborate with universities. Penin (2005) argues that some firms may find it profitable to disclose knowledge and to inform the outside environment about their range of technical and scientific capability. Firms often voluntarily reveal important pieces of knowledge through scientific publications, conferences, patents and the Internet. The main reasons for adopting this strategy are to gain feedbacks from suppliers and users and to expand their networks and reputation, but also to improve higher order knowledge (i.e. to ensure that others know what you know). In short, by *signalling* their technical and scientific capability firms attract potential partners and open up new opportunities for collaboration.

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 cooperation: 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.[7]

3.1. The KNOW survey

In covering seven EU countries,[8] 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 random samples of firms from two size classes (10–249 employees and 250–999 employees) within each of the five sectors were 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. The total number of respondents to the KNOW questionnaire was 764, however, 89 respondents belonged to non-target sectors or had a number of employees that fell outside the target range, giving a total of 675 valid respondents.[9] Given the low response rate from non-innovators, the analysis focuses on a sample of 558 innovator firms.

The firms included in our sample only infrequently rated PROs as the most important source of information for their most economically important innovation (Fontana et al., 2003). However, about half had had some R&D cooperation with PROs in the 3 years before the questionnaire: 222 of the firms that responded to the question said they had been involved in one or more R&D project with PROs in the previous 3 years.[10]

Participation in R&D projects varied depending on the industry firms belonged to. Food and beverages, and chemicals are the industries with the largest share of firms collaborating with PROs while telecommunication services are the least involved. A relatively large number of computer services firms never cooperate with PROs, although some had developed a significant number of R&D projects (more than six in the last 3 years) with PROs.[11] Table 1 shows the number of respondents by sector.

Overall, the firms surveyed average 1.6 R&D projects with PROs. They collaborate with PROs from a minimum of 0 to a maximum of 25 times and the distribution of their cooperation is very skewed (see Table 2 for the descriptive statistics). The population of firms carrying

[7] A copy of the final version of the KNOW questionnaire is available upon request from the corresponding author.

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

[9] See Caloghirou et al. (in press) for the description of the KNOW survey's methodology and main results.

[10] Of the 558 innovators, 100 did not respond to question B3: "In the last 3 years, in how many research and development projects has your firm being engaged with Universities and Public Research Institutes".

[11] 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 services or consultancy work. Indeed, we think that in the case of SMEs firms an average of about 30 R&D projects per year seems to be an unreliable figure.

Table 1
Number of respondents by sector

Number of projects	Food	Chemicals	Communication equipment	Telecommunication services	Computer service
0	51	49	45	31	60
1	21	6	13	5	10
2	17	24	9	1	10
3	11	11	4	3	10
4	6	11	4	0	4
5	3	5	7	0	4
6	0	2	2	0	0
7	0	0	0	0	1
8	2	0	1	0	0
9	0	0	0	0	2
10	3	1	0	0	3
13	0	0	1	0	1
19	0	0	0	0	1
20	0	1	0	0	1
25	0	0	0	1	0
Total	114	110	86	41	107

out 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 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 sectors—a total of 10 in-depth interviews in each country. The companies were selected from those 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 the interview results that are relevant to the understanding of university–industry relationships.

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 hence

Table 2
Descriptive statistics for selected variables (all variables)

Variable	Obs	Mean	Standard deviation	Min	Max
Number of collaborations	458	1.62	2.84	0	25
R&D (log)	408	1.82	1.13	0	5.52
R&DInt (log)	406	0.13	0.17	0	0.69
Employees (log)	453	4.31	1.46	0.69	7.09
Headq (dummy)	456			0:207	1:249
Process (dummy)	448			0:80	1:368
Product (dummy)	453			0:18	1:435
ExtColl	397	14.68	18.46	0	100
Publications (dummy)	453			0:88	1:365
Subsidies (dummy)	413			0:279	1:134
Patents (dummy)	455			0:295	1:160
ExtR&D	348	14.55	22.48	0	100

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

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 gathering activities and they regarded these activities as strategic. They used a variety of tools to search for and screen 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 still 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 lag behind industry, in the sense that most graduate students tend to ignore recent industry developments.

Among the portfolio of formal agreements signed with universities, interviewees frequently 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 testing activities related to bacteriology. In the computer services sector, however, the main role of universities is to help firms acquire and update 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, which produced information about the importance of PRO research, here we 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). We are able to do this because we have information about how many R&D projects were conducted within a firm–PRO partnership. Two questions are addressed in this section. Which firms initiated collaboration with PROs during the 3 years before the questionnaire? What are the characteristics that might explain the number of R&D projects with PROs? Section 4.1 presents 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

Number of R&D projects is the measure we use for the extent of collaboration between firms and PROs, and is our dependent variable. Because it is a discrete variable, it is appropriate 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 projects firm i has been engaged in (where $i = 1, 2, \ldots, N$). The variable y_i would be distributed as a Poisson with parameter λ_i:

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

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

$$\ln \lambda_i = \beta_i x_i \qquad (2)$$

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

$$E(y_i|x_i) = \lambda_i = e^{\beta_i x_i} \tag{3}$$

There are two issues that arise when using Poisson models. The first concerns the fact that a Poisson distribution constrains the variance to being 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 a large number of firms in our sample with zero R&D projects. Although many firms have engaged informally in collaborations with PROs only a few have collaborated in R&D projects. These two features make the Poisson model unsuitable for modelling the level of firms' collaboration 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 various analyses based on innovation and patent counts (Silverberg and Verspagen, 2003; Nesta and Saviotti, 2005). It involves the use of a modified Poisson such as:

$$P(Y_i = y_i|u_i) = \frac{e^{-\lambda u}(\lambda_i u_i)^{y_i}}{y_i!} \tag{4}$$

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):

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

where $r_i = \lambda_i/(\lambda_i + \alpha^{-1})$. Eq. (5) is the form of the Negative Binomial distribution with mean λ_i and variance $\lambda_i(1 + \alpha\lambda_i)$ for $\alpha > 0$. This equation constitutes the starting point for 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 R&D projects between firms and PROs. However, the actual number is observable only if a firm decides to cooperate 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 projects. 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 R&D projects established in the 3 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 also for this potential source of mis-specification (Stephan et al., 2004).

We can indicate with z_i the (random) variable that says whether a firm engages or not in R&D projects and assume that, given a vector of covariates W_i, this variable follows a Logit distribution:

$$P(z_i = 0|W_i) = F(\gamma' W_i) = \frac{e^{\gamma' W_i}}{1 + e^{\gamma' W_i}}, \tag{6}$$

thus we can write the unconditional probability of the number of R&D projects as:

$$\begin{aligned} P(Y_i = y_i|X_i, W_i) &= P(z_i = 0|W_i) \\ &\quad + P(z_i = 1|W_i)P(Y_i = y_i|X_i, z_i = 1) \text{ or :} \\ P(Y_i = y_i|X_i, W_i) &= F(\gamma' W_i) \\ &\quad - F(\gamma' W_i)P(Y_i = y_i|X_i) + P(Y_i = y_i|X_i) \end{aligned} \tag{7}$$

which gives the ZINB model that will be estimated.

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 R&D 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 relationships 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; and (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. The Appendix A reports the full questions from the questionnaire for a selection of key variables.

4.2.1. 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 relationships with PROs: the smaller the firm, the smaller the resources available to develop multiple relationships.[12] 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 take the logarithms of both variables and would expect the absolute size to affect propensity to collaborate more than extent of collaboration.

4.2.2. 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 test for this effect, we included (the logarithm of) 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 a firm's 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.

[12] Whether a higher propensity for big firms to collaborate with PROs corresponds to greater 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 allows large firms to reap a higher profit from innovation in general.

4.2.3. Firm innovative activity

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 variables test for the effects of different innovative processes on the development of collaboration with PROs although, given that firms may do both product and process innovation, these dummies may not be able to fully disentangle the effect (see also footnote 19 below).

4.2.4. Openness of the firm

In defining openness in Section 2, we distinguished between three types of activities: *searching screening* and *signalling*. In our preliminary consideration of these aspects we devise some proxies for each type of activity.[13] As pointed out previously, Laursen and Salter (2004) characterised the openness of firms by the means used to gather external information (i.e. the search strategy of a firm), proxied by the number of channels of information drawn upon to import knowledge. 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. Here we assume that to collect external information, firms must implement both *search behaviour* and *screening activities*. Following Larsen and Salter, we constructed a proxy for the *search* activity (SEARCH) that accounts for the number of channels used by the firm to relate to the outside world. As an alternative for this discrete variable, we proxied *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. These variables capture the general willingness of firms to look for external information to incorporate in its innovations. We would expect the alternative *searching* variables to positively affect participation in R&D projects with PROs. *Screening* entails both general search behaviour and an ability to select the appropriate

[13] Some of the variables used as a proxy for openness in the estimation may also be considered to capture other influences on firm-PRO R&D projects. This may introduce an identification problem and represents a limitation of the present study. However, given the fact that we are considering a sample of SMEs, and that we are controlling for other possible influences, we are confident that our interpretation is the most likely.

source of information to solve a specific technical problem. *Screening* can be proxied by different 'enablers' in the following way. First, looking at publications as a source of ideas seems to be a particularly important element, since this indicates the relevance of academic research for the innovative process. In addition to getting new ideas, SMEs looking for partners read publications to identify competences in universities and enable them to select the right researchers. 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 a good way to meet new partners, and to learn about them, their competencies, and their networks, and to select them (the second component of *screening*). 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 3 years preceding the questionnaire.[14] We expect *screening* activities to affect the probability of being involved in at least one R&D project (if a SME does not engage in *screening*, it is not willing to cooperate).

Openness also refers to *signalling* (i.e. the way firms disclose knowledge to better inform external economic agents about their competences). *Signalling* is proxied by one variable: patents. As the outcome of a research process, patents are usually used to protect product innovations from imitation (Levin et al., 1987). However, more recent contributions have stressed that the motives for patenting have broadened. For instance, Blind et al. (2004) analyse the patent upsurge in Germany. They highlight that besides the traditional motive of protection (ranked first), firms also patent to secure European and national markets, to implement defensive and offensive blockading strategies, and to improve reputation and technological image (which is ranked sixth out of 15 motives). More significantly, how the importance of these motives had changed in the last 5 years was assessed; it was found that "patenting played a stronger role in improving the technological image of the enterprise in the last years" (Blind et al., 2004, p. 31). The reputation (and thus *signalling*) motive was also underlined by Cohen et al. (2002b) and by the Ifo survey (1999).[15] Other authors stress that firms are increasingly using patents both to increase their negotiating power (Hall and Ziedonis, 2001) and more generally to facilitate coordination among the participants to the innovation process (Kortum and Lerner, 1999). In particular, Penin (2005) argued that there are different ways in which patents as 'coordinating devices' can ease collaboration among firms. Patents stimulate cooperation because they reduce the risks involved in R&D collaboration between firms. Moreover, patents *signal* firms' competences and in this way help to identify potential partners and establish the terms of collaboration as negotiations progress. This role of patents is particularly important in the case of cooperation between SMEs and universities/PROs. SMEs may be willing to collaborate with universities/PROs, but a prestigious university may not be as willing to work with SMEs that do not have appropriate technological competences. Therefore, in their terms of agreement a university may require a minimum level of competence from the SME before deciding on the extent of engagement. It can be assumed that this would apply more in the case of R&D projects, which we are considering here, than in 'service oriented' activities. We expect *signalling* to affect the extent of R&D projects with PROs. More specifically, using patents to *signal* technical and scientific competence should have positive effects on participation in collaborative projects with PROs. A dummy variable (PATENT) is employed to capture this effect. *Signalling* should influence the extent of participation in R&D projects with PROs.

We also included some additional control variables in the regression. The first is ExtR&D measured by the (percentage of) external expenditure of independent organisations in total firm R&D expenditure. Firms with a higher propensity to establish R&D collaborations with independent organisations may be involved in a higher number of collaborations with PROs. One reason for this is that once firms have developed the skills needed to manage cross-boundary relationships, they will likely be more willing to cooperate with external partners in the development of an innovative activity. 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 also included in the regression a dummy variable (COUNTRY) to account for

[14] As a proxy for *screening*, this variable has a limitation. The KNOW survey asked: "During the most recent three years has your firm received any public subsidies from regional, national, or EU authorities for R&D activities?". We cannot rule out the possibility that subsidy was some sort of tax credit although the inclusion of the EU among the possible sources of subsidies seems to point to the fact that subsidies indeed funded participation to R&D projects.

[15] In 1997, the Ifo Institute carried out a survey in Germany on the diffusion of knowledge.

Table 3
Regression summary—negative binomial regressions (Dependent Variable: Number of R&D projects)

		(1)	(2)	(3)	(4)	(5)
	Intercept	−2.091 [0.51]**	−2.065 [0.56]**	−2.601 [0.62]**	−2.589 [0.61]**	−3.823 [0.91]**
Relative size	ln(R&D)	0.375 [0.07]**	0.354 [0.08]**	0.231 [0.08]**	0.187 [0.08]**	0.195 [0.09]**
Abs capacity	ln(R&DINT)	0.970 [0.49]**	1.169 [0.54]**	1.440 [0.53]**	1.515 [0.52]**	1.280 [0.56]**
Status	Headq (dummy)	0.440 [0.16]**	0.434 [0.17]**	0.504 [0.18]**	0.539 [0.18]**	0.371 [0.21]*
Type of innovative activity	Process (dummy)	0.792 [0.22]**	0.846 [0.25]**	0.710 [0.26]**	0.587 [0.26]**	0.614 [0.28]**
	Product(dummy)	0.703 [0.46]	0.571 [0.50]	0.525 [0.50]	0.404 [0.50]	0.326 [0.51]
Searching	ExtColl		0.005 [0.00]	0.004 [0.00]	0.005 [0.00]	0.005 [0.00]
Screening	Publications (dummy)			0.786 [0.24]**	0.777 [0.24]**	0.928 [0.29]**
	Subsidies (dummy)			0.591 [0.18]**	0.569 [0.18]**	0.581 [0.20]**
Signalling	Patent (dummy)				0.429 [0.17]**	0.495 [0.19]**
Controls	Ext R&D					0.007 [0.00]
	Sector (dummy)					Yes
	Country (dummy)					Yes
log-likelihood		−643.11	−550.91	−506.74	−502.64	−418.41
LR chi square		67.95**	58.81**	70.20**	76.93**	99.73**
Pseudo Rsq		0.050	0.050	0.065	0.071	0.106
No obs.		395	336	304	303	255
LR chi square $\alpha = 0$		370.20**	324.04**	268.09**	257.60**	163.34**

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

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 projects 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, the sector and the 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 in model (4). Table 3 presents the results.

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, 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 R&D projects with PROs than do small firms.[16] Moreover, we find evidence of a positive correlation between the status of the firm and the extent of collaboration indicating that firms that belong to large units tend to collaborate more than independent firms. Finally, engaging in process innovation seems to increase the extent of involvement in R&D projects while, as mentioned above, there is no evidence of a significant correlation between product innovation and engagement in collaborations with PROs.

[16] Several attempts to include other variables in the list of independent variables were made. In particular we checked for the influence that 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.

Models (2)–(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 processes 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. This result contradicts that obtained by Laursen and Salter (2004) who found *searching* to be an important determinant of university–industry collaborations. To check its robustness we ran the models using the SEARCH rather than the ExtCOLL variable (results available from the authors); in this case, too, there was no significant relationship between the extent that firms engage in R&D projects and *searching* as a proxy for openness.

Models (3) and (4) relate respectively to the two other activities that constitute openness: *screening* and *signalling*. *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. Patenting, our proxy for *signalling*, has the expected coefficient (positive and 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 seem 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 the propensity to outsource R&D (ExtR&D) as well as 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)–(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 α-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 use instead 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.[17] A value of $\upsilon = 3.62$ seems to suggest that a ZINB model provides a better fit than a Negative Binomial. Table 4 below reports the results.

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 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.[18]

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 R&D projects 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

[17] If we 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 statistic for testing the hypothesis of the ZINB against the Negative Binomial is $\upsilon = \sqrt{n}\left[1/n\sum_{i=1}^{n} m_i\right] / \sqrt{1/n\sum_{i=1}^{n}(m_i - \bar{m})}$. If $\upsilon > 2$ the ZINB model presents a better fit than the Negative Binomial. However, if $\upsilon < -2$, the Negative Binomial presents a better fit. For $-2 < \upsilon < 2$, neither is the preferred model (Greene, 2000, p. 891).

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

Table 4
Regression summary—ZINB and logit selection equation

		ZINB	
		(6)	(7) Logit selection
	Intercept	−1.17 [0.83]	3.35 [4.50]
Relative size	ln(R&D)	0.15 [0.07]**	
Abs capacity	ln(R&DINT)	0.83 [0.48]*	−3.22 [1.89]*
Absolute size	ln(Employees)		−0.42 [0.22]*
Status	Headq (dummy)	0.08 [0.19]	−1.16 [0.63]*
Type of innovative activity	Process (dummy)	0.50 [0.31]	−0.32 [0.70]
	Product (dummy)	0.74 [0.44]*	2.78 [3.69]
Searching	ExtColl	0.00 [0.00]	−0.00 [0.01]
Screening	Publications (dummy)		−2.05 [0.60]**
	Subsidies (dummy)		−1.58 [0.62]**
Signalling	Patent (dummy)	0.44 [0.16]**	
Controls	Ext R&D	0.01 [0.00]**	
	Sector (dummy)	Yes	
	Country (dummy)	Yes	
log-likelihood		−369.92	
LR chi squre		60.90**	
No obs.		255	

A positive (negative) coefficient in the Logit Selection regression indicates that a firm is less (more) likely to collaborate with PROs. Standard errors between brackets.
* Significance at 10% confidence interval.
** Significance at least at 5% confidence interval.

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, but this characteristic does not affect the level of cooperation. Finally, 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.[19]

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 project, and *signalling* positively influences the number of times a firms signs agreements with PROs. 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, taking out patents, our proxy for *signalling* positively affects the extent to which firms engage in R&D projects with PROs. Finally, among our control variables, outsourcing R&D activities positively affects the extent of collaboration while country fixed effects are generally significant in the ZINB regression only (Model 6) and sector fixed effects are generally not significant in either model.[20]

Our findings can be summarised as follows. The propensity of firms to engage in R&D projects 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

[19] In our sample, 80 firms (18% of respondents) do product innovation only. Only 18 firms (about 4% of respondents) do process innovation only. Three hundred and forty-five firms (about 78% of respondents) do both process and product innovation. Regression results hold when the PROCESS and PRODUCT dummies are interacted. This seems to suggest that the finding is due to joint product and process innovation rather than to low numbers.

[20] Only food and chemicals reveal negative and significant coefficients in the Logit selection equation (Model 7). Separate regressions carried out for these two sectors have generally confirmed our results concerning both the sign and the significance of our proxies for openness.

propensity for 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, and 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. 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*. 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 greater R&D involvement, that are more involved with external R&D suppliers and which signal their competences, tend to develop a larger number of R&D projects with PROs

5. Conclusions

The KNOW questionnaire provides a unique data set for the researcher to analyse the innovation processes of SMEs with less than 999 employees. This paper looked at the characteristics of the firms that developed R&D 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 3 years previous to the KNOW survey. The results of this analysis point to two main findings.

The first focuses on the role of the size and the R&D activity on the collaborative behaviour (propensity and intensity) of the firms. The findings mainly confirm the empirical findings for large firms (over 1000 employees). The propensity to conclude an R&D project with an academic partner depends on the 'absolute size' of the industrial partner (Arundel et al., 2000; Cohen et al., 2002a; 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 SMEs, that is, their willingness to *search* for external knowledge, to *screen* the outside world using publications databases, and also to *signal* their competencies by patenting. Our findings suggest that acquiring knowledge through the *screening* of publications affects the probability of signing an agreement with a PRO, but not the level of collaboration developed. In fact, SMEs that patent to protect innovation and to *signal* competencies show higher levels of collaboration. These results imply that the existence of a *screening* strategy somehow determines the start of a relationship between SMEs and PROs; whereas the activation of a *signalling* strategy explains the intensity of the interaction, other things being equal. In other words, the SMEs 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 their willingness to *signal* their competences as well as on the relative weight of network interactions in their production of knowledge (as measured by their outsourcing decisions).

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 in the absence 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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Appendix A

A selection of some key questions from the KNOW questionnaire.

B3: in the last 3 years, in how many research and development projects has your [firm] been engaged with Universities and public research institutes?________[Write in - Dk]

This question has been used to construct our *dependent variable*: *No of R&D PROJECTS*

B1: does your [firm] regularly seek to obtain ideas for innovation by? [Yes/No/Dk in each case]

b1.1	Searching patent databases
b1.2	Reading scientific or business journals
b1.3	Attending trade fairs and conferences
b1.4	Technical analysis of competitors' products [reverse engineering]

b1.2 has been used to construct our first proxy for *screening*: PUBLICATIONS

E5: during the most recent 3 years has your [firm] received any public subsidies from regional, national or EU authorities for research and development activities? (Yes/No/Dk)

This question has been used to construct our second proxy for *screening*: SUBSIDIES

B4: Does your [firm] use any of the following methods to protect innovations? [Yes/No/Dk in each case].

b4.1	Patents
b4.2	Secrecy
b4.3	Lead time advantages

b4.1 has been used to construct our proxy for *signalling*: PATENT

What percentage of your [firm's] new or improved production processes were introduced using any of the following methods? The percentages should add up to 100%

a5.1	1. Buying in________%Dk
a5.2	2. In-house development________%Dk
a5.3	3. Collaboration with external partners________%Dk

What percentage of your [firm's] new or improved products were introduced using any of the following methods? The percentages should add up to 100%

a6.1	1. Buying in________%Dk
a6.2	2. In-house development________%Dk
a6.3	3. Collaboration with external partners________%Dk

The simple mean of a5.3 and a6.3 has been used to construct our proxy for *searching*: EXTCOLL

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