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1. Introduction

The discussion of university-industry relationships, which entered the policy arena in the early 1980s, has become the property of both academics and the general public. An enormous number of contributions to academic writings and articles in the business and public press have come from policy makers in the last few years in a bid to explain, justify and regulate the interactions between universities and firms. At the European level, very few of these works have been supported by systematic data analysis. If we exclude the results of the Policies, Appropriability and Competitiveness for European Enterprises (PACE) questionnaire (which focused on large EU R&D intensive firms) and the scant information on the role of universities and public research centres available from Community Innovation Surveys (CIS) I, II and III, there is little evidence left.[1] In a few European countries in recent years, country-specific data have been gathered and analysed. For example, the studies of Meyer-Krahmer and Schmoch (1998) and Beise and Stahl (1999) provide interesting evidence of the contribution of public research to industrial innovation in Germany.

A large number of works have studied university-industry relationships from a qualitative point of view or by relying on a case study of a single university.[2] The aim of this current study is to provide some statistical evidence at the cross-country, cross-industry level to verify some of the hypotheses put forward in the qualitative literature. The analysis in this paper provides preliminary evidence of firm and industry characteristics that affect the contribution of Public Research Organisations (PROs, defined here as universities and other public research centres) to firms' innovative activities and that influence firms' involvement in R&D projects with PROs. 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). We examine two main issues: the contribution made by PROs to the innovative process within firms and the existence as well as the extent of co-operative R&D projects between firms and PROs.

The descriptive analysis aims at distinguishing the relationship between sources of knowledge and specific phases of the innovation process. Also, although PROs are rarely seen as being the most important source of innovation completion for firms, we examine what are the specific patterns

[1] See Arundel *et al.* (1995) and Arundel and Geuna (2004) for an analysis based on the PACE data. See, among others, Mohnen and Hoareau (2002) for an analysis based on CIS II.

[2] See, among others, Faulkner and Senker (1995) for a qualitative technology-specific study. Geuna *et al.* (2004), among others, for a university specific case (University Louis Pasteur of Strasbourg).

characterising PRO-firm relationships at sector level when PROs are considered the most important sources of knowledge.

The analytical part of this paper is based on direct measurement of the extent of collaborations between firms and PROs. Unlike previous studies we have information both on the importance of university research for the innovative process of firms and, most importantly, on the number of research and development projects conducted jointly with PROs in the three years before the survey (1997-2000). A two-equation econometric model evaluates the effect of firm-specific, sector-specific and country-specific factors (such as firm size, appropriation and signalling, searching knowledge sources, government support) upon both the probability of an R&D collaboration developing with PROs and the number of R&D projects developed by the firm in the previous three years. Particular attention is devoted to the role of firm size with measures of both total employment and R&D employment being used. Also, the idea that the openness of the firm to the external environment has an important effect on the development of collaboration with PROs is tested via a set of proxies for this phenomenon, such as the extent to which firms actively search for relevant scientific information in publications, hold patents and participate in government funded projects.

The paper is organised as follows. Section 2 briefly reviews the literature on university-industry relations. Section 3 presents the descriptive analysis of the contribution of PROs to the innovation process in firms. The propensity for and extent of PRO-firm collaborations is examined in Section 4 using an econometric model. Finally, Section 5 presents the conclusions and a brief examination of the limits of current policy actions.

2. University-industry cooperation: a review of the literature based on survey analysis

Since the eighties, many countries have implemented policies to facilitate the transfer of knowledge from universities to companies: establishment of legal frameworks, creation of technology transfer offices inside universities, increasing the mobility of researchers to industry, large cooperative R&D programmes, etc. Some analyses show that these policy measures have contributed greatly to increasing the number and the scope of links between the two worlds.[3] However, there is no clear evidence on their economic impact. The relationship between university and industry is a complex and heterogeneous phenomenon. Actually, the channels used by firms to draw on knowledge developed by PROs are diverse. The intensity of links varies across firms, sectors and countries.

[3] See, for instance, Link (1996), Hall *et al.* (2000), Cohen *et al.* (1998), Caloghirou *et al.* (2001).

The extensive literature on university-industry is empirical and based on case studies, patent and bibliometric analyses, or large surveys. Rather than being exhaustive, our literature review aims at linking our contribution to a specific approach: we will mainly present the results based on survey analysis and progressively focus on formal cooperation as the specific channel of interaction used by both worlds. On the basis of these criteria and according to our contribution, we will present five important and inter-connected issues addressed by this literature. One part of the literature analyses the impact of scientific results on the economic sphere regardless of which channel of interaction is used. A second issue concerns, from the firms' point of view, the relative importance of PROs as an external source of information for new ideas and innovation completion. Other contributions study the variety and importance of channels (i.e. publications, informal contacts, conferences, recruitment of students, formal collaborative contracts, etc.) used by both actors to exchange knowledge. We will give specific attention to the relative importance of formal collaborative agreements. Finally, a set of econometric models highlights the characteristics of firms, which draw upon the results of the research carried out in PROs to innovate. Very few analyses based on large surveys focus on formal agreements. One of our aims is to shed new light on this specific topic.

One strand of publications analyses the impact and influence of scientific research results on the economic system. Some of these studies are based on surveys of firms in different industry sectors. They show that without results developed by academics, many innovations could not have been realised or would have come much later (Mansfield 1991, Beise and Stahl 1999). Cohen *et al.* (1998) underline that academic research has positively influenced firms' sales, research productivity and patenting activity. These positive impacts are confirmed by studies based on bibliometric data and regression analysis. For instance, Narin *et al.* (1997) using citations in patents to non-patent literature (such as journal articles, books and abstracts) conclude that the knowledge flow between the two worlds increased threefold in the US between the end of the eighties and the mid-nineties. More generally, US studies highlight that geographical proximity between the university and industry increases the benefits of academic research. These studies conclude that PROs produce substantial R&D spillovers. They do not analyse the channels through which university research impacts on industrial innovation. This is the aim of the remaining part of the literature.

Using the Carnegie Mellon Survey on industrial R&D, Cohen *et al.* (2002) examine a broad range of information sources used by firms to innovate, of which one is the R&D conducted in PROs. They distinguish between the sources of information that contribute to innovative ideas and to the completion of innovation. With the exception of a few industries (pharmaceuticals, petroleum, etc.),

PROs do not play a central role in suggesting new ideas. Overall, PROs seem to be more important for innovation completion than for suggesting new ideas. 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) PROs are significant. The analysis highlights that different sectors behave differently too. In Europe, the CIS I, II and III found PROs were not considered to be a major source of information, but made no distinction between the different phases of innovation. The results of the KNOW survey used in this paper allow us to take account of both the innovation idea and the innovation completion phases and thus to make comparisons with the results of Cohen *et al.* (2002). Moreover, we attempt to identify, from the list of possible sources, the most important contributors to both phases of innovation.

What are the key channels through which PROs affect industrial innovation? Cohen *et al.* (2002) find that the channels of open science, especially publications, public meetings and conferences and also informal information exchange and consulting, are the most important in the US. Cooperative ventures do not seem to have been so important as other channels for industrial R&D. These results are controversial in relation to European contributions. For instance, based on a survey of firms and universities, Meyer-Krahmer and Schmoch (1998) find that collaborative research and informal contacts are the most important channels of communication. The significance of formal collaboration is confirmed by the CIS I and II surveys. These surveys show that firms consider universities to be important partners in technological cooperation. According to the EC benchmarking study, universities are increasingly involved in cooperative R&D. However, the results of the PACE survey highlight that large companies class recruitment of new graduates, informal contacts and contract research as the most important ways to access academic knowledge, and that 'low tech' sectors favour formal collaboration much more than do 'high tech' sectors (Arundel and Geuna, 2004).[4] The European evidence would lead one to conclude that formal collaboration is also becoming an important channel for accessing knowledge. In our sample, although PROs are not seen by firms as playing an important role in the innovation process, about half of the firms have nonetheless developed formal collaborations with PROs.

What increases the propensity of firms to draw upon public research (all channels considered)? In a regression analysis, Cohen *et al.* (2002) take size and age of the firm as the two explanatory variables. Larger firms and start-ups have a higher probability of benefiting from academic

research. Other studies (Arundel and Geuna 2004, Schartinger *et al.* 2001) incorporate additional explanatory variables, such as level of R&D expenditure, degree of firms' innovativeness. A more recent study (Laursen and Salter, 2003) introduced the concept of 'open' search strategies of firms into this literature,. Firms that adopt open search strategies have a higher probability of considering the knowledge produced by universities as important for their innovation activities.

As cooperation is considered both by empirical studies and by policy makers to be a central channel, it seems important to analyse it more deeply. Paradoxically, studies based on surveys rarely focus on R&D cooperation. Hall *et al.* (2000) analyse Advanced Technology Programme (ATP) cooperative agreements and concentrate on those involving universities. Collaborative projects with universities are more innovative and risky than those not involving universities: they encounter more difficulties but they are more stable. Drawing on CIS II, Mohnen and Hoareau (2002) find that firms that cooperate with universities are generally large, are active in scientific sectors, patent and receive government support. Firms that are part of a group and cooperate, rely less on collaborations with universities than with independent firms. Mohnen and Hoareau hypothesised that in a conglomerate, collaborations with universities are established at the headquarters level.

Our econometric model focuses on cooperation and confirms the results obtained by Mohnen and Hoareau (2002). However, we go a step further and use the concept of openness of firms, first introduced by Laursen and Salter (2003). Their measure of the degree of openness depends on the number of external channels[5] of information used by firms to innovate. It is based upon the idea that the strategy regarding openness is a search strategy. Our concept of openness is based upon the idea that, beside different channels there might be different possible mechanisms for knowledge exchange. For instance, knowledge exchange may involve the combination of a screening strategy with a signalling activity. First, searching and screening actions correspond to the process of looking for knowledge outside the border of the firm. If the external knowledge is codified, the firm will devote resources to screening the information contained, for example, in publications databases. If the external knowledge is tacit, it becomes strategic to look for potential partners to increase the sharing possibilities. The participation in government funded R&D projects is an appropriate way to meet new partners (to learn about them, their competencies and their networks) and to open up new technological options (Matt and Wolff 2003). Since it often requires public

[4] It is important to note that the unweighted results of the PACE survey show that publications are the most important method for learning about public research output.
[5] They use 15 different external sources of information to construct the openness variable. The more firms use different external sources, the more open they are.

information disclosure, participating in public programmes also constitutes an important signalling strategy (Matt and Wolff 2003), the second important element of openness. The signalling activity has to be understood as the process by which firms inform the outside environment about their range of competencies. For example, patenting activity, especially for small firms, has the double property of protecting results and signalling domains of competences.

Finally, we use a direct measurement of the extent of collaborations between firms and PROs. In contrast to earlier work we have information both on the importance of PRO research and on the number of research and development projects with PROs. This allows us to study *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 R&D projects).

3. Descriptive analysis of the contribution of PROs to the innovation process

The relevance of external contributors for the innovation process may change depending on whether the early or the late stage of innovation is considered. In this section we present some descriptive statistics on the role of external information sources in the innovation process. The aim is to separate the relationship between the sources of knowledge and the particular phases of the innovation process and to see whether specific patterns characterising the role of PROs emerge at sector level.

The analysis is based on the results of the KNOW survey carried out in 2000. Covering seven EU countries, including the four largest,[6] the survey focussed 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 the maximum of 76% in Denmark. The average response rate was 25% and 33% not including the UK. Of the 675 firms that responded, 558 - all innovators - were retained for the following analysis (non-innovative firms were excluded).[7]

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

3.1 The external sources of information for innovative ideas and innovation completion

For each innovator firm, the assessment of the role of external information sources in different stages of the innovation process was made by distinguishing between the contribution in the early phase of ideas generation and in the late phase of finalisation. The analysis presented here is based on responses that refer only to the firm's most economically significant innovations introduced in the previous three years.

[Insert Figure 1 about here]

Figure 1 depicts the weighted percentages of respondents that answered positively to the question about whether a specific external information source had contributed to the *original idea* behind the innovation. Results by sector may sum to more than 100% because more than one answer was allowed.

The first thing suggested by the distribution of responses is the high relevance for all sectors of customers, competitors and suppliers as sources of innovative ideas (except for telecommunications services, percentages for these sources were higher than 20%), compared to consultants and PROs. In the case of the communications equipment sector, suppliers are reported as being the major contributors to ideas for innovation. The sector that relies more than any other on PROs as a source of ideas is the chemicals sector followed by communications equipment and food and beverages. Another peculiarity of the chemicals sector is that it relies very heavily on competitors, while all the sectors relied heavily on customers for ideas.

In the case of *innovation completion* the results tend to mirror those for innovative ideas with one major difference.

[Insert Figure 2 about here]

While customers and suppliers are still the most relevant categories (between 20% and 40% of the answers in each sector), competitors, PROs and consultants are considered relevant by less than for 20% of the respondents. Although a large number of respondents indicated that customers are important contributors to innovation completion, in this stage of the innovation process sector differences seem to dominate. It should be noted that the relevance of PROs as a source of

[7] See Arundel and Bordoy (2002) for a description of the KNOW survey's methodology and main results.

information for innovation completion is small in the case of food and beverages, but with respect to ideas, it is significant for the telecommunication services sector.

Our results are comparable to those of Cohen *et al.* (2002) for the US, with a small difference. Similar to their study, PROs never score higher than the actors in the vertical chain of production and sale (i.e. customers and suppliers in our case) for both phases of innovation. They are nevertheless comparable to other sources (i.e. consultants and competitors). We also confirm that rivals are a more important source for innovation ideas and PROs dominate competitors for innovation completion (except in chemicals). In Cohen *et al.* (2002) PROs are ranked higher than consultants in both phases, while according to our analysis, consultants are preferred in all sectors except chemicals.

3.2 The most important contributors to innovative ideas and innovation completion

After identifying external contributors to innovation, we made an attempt to identify, from the options listed, the most important contributors to both ideas and innovation completion. In both phases, and in almost all sectors, customers were singled out as the most important source. Suppliers ranked second and competitors third as contributors to innovative ideas while they were the lowest ranked for contributors to innovation completion.[8] PROs generally were ranked immediately below consultants both in terms of contributing to ideas and in terms of contributors to innovation completion.

[Insert Figure 3 about here]

However, results did differ by sector. For instance, for chemicals firms suppliers and competitors play a major role in both phases of innovation. Results are similar for consultants in the case of telecommunication services in both phases. In the case of innovation completion, telecommunication services display the highest percentages for PROs, while food and beverages displays the highest percentages in the PROs category in the case of innovation ideas. Of particular note is that a higher share of chemical firms indicates PROs as ‘most important’ in innovation completion than considered PROs the most important for innovative ideas.

[Insert Figure 4 about here]

[8] The exception is the case of food and beverages for which competitors rank second in the case of innovation ideas. In the case of innovation completion suppliers are identified as the most important contributors to innovation by communications equipment firms.

3.3 Why and how do firms in chemical and food industries approach universities

The descriptive statistics presented in the previous section suggest that, for the firms included in our sample, PROs are not often considered to be important for innovation completion. Nevertheless, the subset of firms that consider PROs as the most important source for innovation completion may be characterised by a specific behaviour in the way they approached this source of external knowledge. Analysing whether there are differences in this respect will enable us to identify some of the determinants of this behaviour.

We divided the sample into two groups: G1 is made up of firms who identified PROs as the most important contributors to innovation completion and G0 is firms who identified other sources as the most important. We analysed whether the characteristics of G1 are different from those of G0 respondents based on the answers to questions in four modules: motivation for knowledge acquisition, mode of contact, communication methods and type of knowledge acquired. The sample involved five sectors, but only for two (chemicals and food and beverages) were there a sufficient number of observations to develop this analysis. The results are presented in Table 1.

[Insert Table 1 about here]

A YES in the cell indicates that more than 50% of the respondents in that group replied positively to the question, similarly a NO indicates a more than 50% negative response. For example, in the chemicals sector, for the first question more than 50% of the respondents who identified PROs as the most important contributors to innovation completion had decided to obtain knowledge from PROs in the interests of cost and risk reduction; less than 50% of the respondents who identified other actors as the most important contributors to innovation completion had based their decision on these aspects. So, if G1 answered in a significantly different way from G0 – i.e. moving from YES to NO, or vice versa - this would mean that G1 attributed a specific role to PROs compared to other possible partners (customers, suppliers, consultants, competitors).

When both G1 and G0 are both YES or are both NO, the sign between brackets indicates whether the response rate of the G1 group is 10% or more different from the response rate of G0. No sign means that the share of of the two groups' answers was approximately the same. In the remainder of this section we summarise the results of the chemicals and the food and beverages sectors.

Chemicals sector

Respondents from the chemicals sector who identified PROs as the most important contributors to innovation completion seem to adopt a knowledge sourcing strategy that specifically taps PROs. The motivation for chemicals firms to exploit PROs rather than other external partners is related to cost and risk reduction. The connection is generally based on long-term relationships (previous experience is important), which have become formalised via co-operative agreements. Informal contacts however still play a part in information exchange. Trade fairs and conferences tend to be the preferred places for chemicals firms to meet PROs. Chemicals firms mainly acquired technical and scientific knowledge from PROs. Other information from the 10 interviews that were conducted in each country involved in the survey also confirms that relationships with universities are established via public programmes and are reinforced by hiring university researchers.[9]

Food and beverages sector

In the case of the food and beverages sector, the importance of PROs when compared to other partners is much less clear. The main difference for this sector lies in the necessity to meet government regulations. Respondents who identified PROs as the most important contributors to innovation completion all seemed to have links with universities to enable them to meet the requirements of government regulation. G1 respondents gave more positive answers than G0s for motivations related to cost and risk reduction and updating of technical expertise. G1s have links with known partners (previous experience) but establish mainly informal contacts (formal R&D agreements are the exception rather than the rule). G1 food and beverage companies acquired technical and scientific information from their academic partners. The SMEs in the food and beverages sector regarded universities as the experts able to deal with many of the major issues they face: BSE, quality of food, safety constraints in food production, etc. These constraints are often established by government but can also be imposed by large distributors, which might require evidence, for instance, of the hygiene standards in the production process. The statistical evidence and the responses from the interviews seem to suggest that PROs have a specific role in the food and beverages sector. They provide reliable and up-to-date test facilities to show that various products meet regulations (imposed by government or other institutions). Such activities (testing and expert advice) do not necessarily involve formalised agreements.

[9] The minimum selection criteria were to cover the five sectors and in each sector to choose one large and one small company. The main questions tackled during the interviews concerned the competition strategy of the firm, their cooperative research behaviour, their patenting behaviour and the specific innovation detailed in the survey.

4. Identifying the factors explaining the propensity and the extent of PRO-firm cooperation

The analysis in the previous section has suggested that there are different reasons why firms interact with PROs. However, we did not consider a specific communication channel. In this section we look further into what determines the willingness of firms to establish formal cooperation with a university. More specifically, we provide a quantitative assessment of the propensity for and the extent of firms' engagement in collaborations with PROs. In section 4.1 we focus on identification and selection of the variables to include in an econometric model. In section 4.2 we estimate the model.

Consistent with the findings of 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. About 50% of them had had some co-operation with PROs in the three years before the questionnaire; of the 458 firms that responded 222 said they had been involved in one or more R&D cooperation with PROs in the previous three years.

Participation in co-operative projects varied depending on which industry 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 co-operate with PROs, although some have conducted a number of research and development projects with PROs (more than six in the last three years).[10] Table 2 shows a subdivision of the number of co-operative projects broken down by sectors.[11]

[Insert Table 2 about here]

Overall, the firms surveyed had an average of 1.6 research and development contracts with PROs; they had collaborated with PROs from a minimum of 0 to a maximum of 25 times and the distribution of their co-operation is very skewed (see Appendix 1 for the descriptive statistics). The population of firms carrying out R&D projects with PROs can be described as being composed of a large number of organisations co-operating in only a small way and a small group of firms involved in a large number of co-operative agreements. Although PROs are rarely the most important source

[10] The highest number of research and development projects with PROs reported is 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.

[11] In Table 2 the following codification is employed. 0 = zero contracts; 1 = maximum of 1 contract; 2 = maximum 2 contracts; 3 = more than 2 contracts.

of information either for innovative ideas or innovation completion, they have developed co-operative relationships with firms with different frequencies. Two questions stand out. Why did certain firms collaborate with PROs during the three years before the questionnaire while others did not? And, what are the characteristics of the firms that might explain the different levels of co-operation with PROs?

4.1 The econometric model

To answer these questions we developed an econometric model that facilitates evaluation of the effect of firm-specific, industry-specific and country-specific factors upon the number of co-operations between firms and PROs. The aim of the regression analysis is twofold. The main purpose is to test for the *existence* of a relationship by analysing the propensity for firms to engage in R&D projects with PROs and identifying some firm-specific, industry-specific and country-specific characteristics. In addition, we aim to measure the *extent* of the relationship as proxied by the number of R&D projects that firms have been engaged in with PROs.

To highlight the determinants that could affect the relationship we focussed on firm characteristics. In particular we identified four broad classes: (1) firm size, (2) openness of the firm, (3) firm activity, (4) type of innovation process. From the questionnaire, specific questions designed to glean information regarding each of these classes were selected in order to construct independent variables. In this section we discuss the choice of these variables. Descriptive statistics are reported in Appendix 1.

Accounting for firm size

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 (Arundel and Geuna 2004; Mohen and Hoareau 2002; Cohen *et al.* 2002; Laursen and Salter 2003). The rationale underlying the role of firm size in affecting the progress of R&D collaboration is that big firms have more resources which can help them to establish their relationships with PROs, whereas, the smaller the firm, the less the resources that are available to develop multiple relationships.[12] As a measure of firm size we have considered the number of employees *(EMPLOYEES)*. Beside this measure we have relied also on another measure of size:

[12] 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 Ress (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 benefits deriving from interactions with PROs. Cohen and Klepper (1996) argue instead that the lower productivity of big firms is not related to R&D efficiency linked to firm size but is rather the consequence of the presence of high fixed costs.

R&D employment *(R&D)*. This is an indicator of the research size of the firm rather than of its overall size, which is accounted for instead by the number of employees.

Openness of the firm

We define openness as the attitude of firms to establish a relationship with PROs. As mentioned in Section 2, the concept of openness we propose focuses on the mechanisms through which knowledge can be imported from outside the firm rather than on the different channels used. These mechanisms can be proxied by different 'enablers'. For instance, to get access to external knowledge firms have also to activate an in-depth screening activity. Screening entails selection among sources of codified as well as tacit knowledge. In our contribution, the screening activity involves both the analysis of publication databases and participation in public funded R&D programmes. Moreover, firms may combine the screening activity with a strategic signalling of their range of competencies to the external world. By signalling their competencies, firms will attract potential partners and thus open new opportunities for collaboration. Both patenting and participation in publicly funded R&D programmes are part of the signalling strategy of the firm.

Firms regularly tap different sources to obtain ideas for innovation. Indeed, it seems that public research plays only a minor role in suggesting new ideas for innovation projects. This was one of the most important findings of the Yale Survey (Levin *et al.* 1987). More recently, these findings have been confirmed by other investigations. Surveying a sample of US firms included in the Carnegie Mellon R&D survey of industrial manufacturers, Cohen *et al.* (2002) found that sources of information more directly linked to the production and sales chain, such as suppliers and customers, are regarded as most important by firms.

On the basis of the findings of CIS III for UK firms, Swann (2002) argues that the extent to which firms rely on external information channels other than private and public research institutes is the consequence of the type of innovative activity in which the firms are engaged. Firms engaged in process innovations for instance are more likely to collaborate with universities and PROs than use them only as sources of information. This suggests that additional external sources of information are complements to rather than substitutes for collaboration with PROs.

Among the external channels of information usually considered, there is participation in trade fairs and conferences, searching patent databases and reading scientific and business publications. As a determinant of the propensity for collaboration with PROs, publications as a source of ideas seem to be particularly important since reliance on them indicates the relevance of academic research for the

innovative process. Thus we have 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. We expect this variable to positively affect participation in collaborative projects with PROs.

Secrecy and lead time are generally considered to be the preferred methods used to exploit the benefits from process innovation. Patenting is required to protect product innovations from imitation (Levin, Klevorick *et al.* 1987). However, patents constitute a way both of protecting innovations from imitation and of 'conveying public research to industry' (Cohen *et al.* 2002). In this respect the possibility of patenting should induce firms to engage more in collaborations with PROs in order to implement and bring to market novel ideas based on the knowledge developed within universities and public research. However, as it is the outcome of a research process, patenting also provides a way for firms to communicate the extent of their engagement in research, to *signal* their competencies. Czarnitzki and Frier (2003) offer an example of this latter proposition. They compare the number of patents applied for by publicly funded R&D consortia and by privately funded ones in Germany. They find that firms in publicly funded networks are more likely to apply for patents than firms in private networks. One of their interpretations is that firms want to impress the government and other actors and gain reputation to influence future grants or partnerships. Patents are thus used as a deliberate signalling strategy.

We would expect that appropriation and signalling strategy affect the existence and the extent of R&D projects with PROs. Specifically, the use of patents to protect innovation and signal competencies should have positive effects on participation in collaborative projects with PROs. A dummy variable *(PATENT)* has been employed to capture this effect.

Government policies are also likely to positively influence both the propensity of firms to develop R&D collaborations with PROs and the intensity of collaboration. The influence is obviously direct in the case of policies that entail subsidies specifically targeted to the setting up of projects with PROs. Empirical evidence in support of this relationship has come from both CIS I and CIS II (Arundel *et al.* 2000). However, it should be noted that government policies too could affect the propensity of firms to engage in collaborations with PROs in two indirect ways. Matt and Wolff (2003) show that participating in public programmes allows firms to acquire complementary knowledge, and *screen* partners by learning about their environment and their technological competence to enter a broader network. From this viewpoint, participating in public research

programmes is also an indicator of the extent of openness of the firm. More open firms should be more likely to engage in collaborative agreements with PROs.

Participating in public research programmes constitutes a signalling strategy for firm too. Very often these programmes impose limits on disclosure of information about the partners and the research topic. To account for both the direct and the indirect influence, we have 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.

Firm activity and relationship with PROs

Activity of the firm in terms of scientific intensity can influence both the existence and the extent of its relationships with PROs. 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 larger the firm the higher the probability of a relationship with a PRO being established and the greater the number of collaborative R&D projects.

R&D intensive firms might be more likely to develop R&D co-operations 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 a variable for R&D intensity of the firm *(R&DINT)*, based on the ratio between R&D employment and total employment. We also recognise that firm activity may be influenced by the 'legal status' of the firm. It is generally recognised that R&D activities tend to be concentrated at a 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 (2002) found that firms that collaborate with PROs and are part of large units rely less on this collaboration than do independent firms. To explain this result, they hypothesised that lower levels of involvement are a consequence of the fact that within big firms collaboration is mediated by the headquarters.

The level of detail provided by the KNOW survey enables us to test this hypothesis by checking whether there is a relationship between the legal status of the firm and the propensity for engagement in collaborations with PROs. In particular, a dummy variable *(HEADQ)* is used to take

into account whether the respondent is located within the central headquarters of the company. We expect this dummy to positively affect the development of R&D collaboration.

Types of innovative activities and processes

Typically firms carry out different types of activities which influence their opportunity to innovate. They can engage in product innovations, process innovations or both (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' collaboration with PROs, recent investigations provide mixed results concerning the direction and the extent of the relationship.

Using data from CIS II for a sample of European countries, Mohnen and Hoareau (2002) found a positive relationship between the introduction of radical product innovations and the extent of reliance on PROs. In the case of UK firms included in the CIS III, Laursen and Salter (2003) found only partial support for the hypothesis that the more innovative firms in terms of product innovations were those that rely more on public sources. Using the same UK data, Swann (2002) stressed that companies involved in process innovation are more likely to co-operate with PROs than those engaged in product innovation. 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 *(PROCINN)* and one focused on product innovation *(PRODINN)*. They are a test for the effects of different innovative processes on the development of collaboration with PROs.

In addition to the variables described so far, we decided to include in the regressions two additional dummy variables. First, a dummy variable *(COUNTRY)* that accounts for country fixed effects and second, a control dummy *(SECTOR)* for sector-specific effects.

4.2 Model estimation

We model the participation and level of participation in co-operative projects with PROs using a Probit and a Truncated regression model. The Probit model enables estimation of the probability of occurrence of a certain phenomenon in terms of a binary dependent variable. Our specification includes the decision to participate in R&D projects with PROs as a discrete dependent variable that takes the value 1 when the firm has participated in a project and the value 0 when it has not. The Truncated regression model allows the level of participation for the non-limit observations – that is, the number of R&D projects greater than zero – to be estimated. The advantage of a two-equation

model is that it separates the analysis of collaboration with PROs or not, from the analysis of multi-collaboration. The Probit model reveals the relevance of the factors considered to the selection, while the Truncated model explains the different levels of co-operation.

Before turning to analyse the factors that affect the development of co-operative R&D projects with PROs it should be noted that the above two separate equation model may give rise to inconsistent results because of the 'problem of truncation' (Greene 1993). This problem arises because the Truncated regression describes the number of R&D projects between firms and PROs but the actual number is observable only if firms decide to engage in the R&D process. The dependent variable in the truncated equation is therefore incidentally truncated according to the values taken by the Probit equation which acts as a 'selection equation'. An estimation of the truncated equation based on observed data only may produce inconsistent estimates because a selection bias is introduced. Checking whether Probit and Truncated regressions can be run separately or must be run simultaneously to avoid giving rise to inconsistent estimates due to selection bias, can be done by applying the Heckman procedure (Heckman 1979). The Heckman procedure is a two-step method involving estimation of a Probit regression of the observations from the sample followed by an ordinary least squared (OLS) regression on both the observed values for the independent variables and the new values constructed from the previous estimates.

To establish whether simultaneous estimation is necessary or whether the two equations can be estimated separately, a significant value of the rho is required. In our case, the application of the Heckman procedure produced a ρ (rho) of -0.3098 with a value of 0.2815 for the standard error enabling us to reject the need for the two equations to be estimated simultaneously. Moreover, comparison between the values of the coefficients estimated with the Truncated regression and with the OLS in the Heckman procedure highlights the absence of substantial differences between the two estimates.

The Probit and Truncated equations have been estimated in the following forms:

$$
\begin{aligned}
(1)\quad & y = \alpha + \beta_1 \ln R\,\&\,DINT + \beta_2 \ln EMPLOYEES + \beta_3 PUBLICATIO\ NS + \beta_4 PATENTS \\
& + \beta_5 HEADQ + \beta_6 SUBSIDIES + \beta_7 PROCINN + \beta_8 PRODINN \\
& + \sum_{i=1}^{n} \beta_i SECTOR + \sum_{j=1}^{m} \beta_j COUNTRY + \varepsilon_1
\end{aligned}
$$

where Y=1 if No. of Projects >0 and Y=0 if No of Projects =0.

The second equation is a Truncated regression.

$$\ln(1+P) = \delta + \gamma_1 \ln R\&DINT + \gamma_2 \ln R\&D + \gamma_3 PUBLICATIONS + \gamma_4 PATENTS + \gamma_5 HEADQ + \gamma_6 SUBSIDIES + \gamma_7 PROCINN + \gamma_8 PRODINN + \sum_{I=1}^{n} \gamma_i SECTOR + \sum_{j=1}^{m} \gamma_j COUNTRY + \varepsilon_{21} \quad (2)$$

where P is observed when No. of Projects >0.

Table 3 presents the results of the parsimonious estimations.[13]

[Insert Table 3 about here]

All the chosen independent variables, excluding PRODINN, have a positive effect on the propensity for firms to engage in R&D projects with PROs and all the coefficients of the variables are significantly different from zero. There is a 'size effect' on the propensity for firms to engage in projects with PROs as represented by the positive coefficients for EMPLOYEES, our proxy for firm size. R&D employment does not significantly affect the propensity to be involved in R&D projects with PROs and therefore it was not included in the final estimation model. R&DINT also positively affects the propensity to engage in R&D projects with PROs. These results suggest that larger firms that are heavily engaged in R&D activities (high R&D intensity) have a higher propensity than small firms to become involved in projects with PROs. However, the R&D size of the firm, proxied by R&D employment, does not affect this propensity.[14]

There are differences in both the influence and the significance of the independent variables present in the Truncated regression when compared to the Probit regression. The main difference between the two regressions is that in the Truncated regression, R&D employment exhibits a positive and significant coefficient while EMPLOYEES, which is a proxy for the 'absolute size' of the firm,

[13] All the estimations have been corrected for heteroschedasticity with the STATA robust estimation procedure.

[14] Several attempts to include other variables in the list of independent variables have been made. In particular we checked for the influence that strategic alliances might have on the propensity for firms to engage in projects with PROs. Developing external formal R&D collaborations and partnerships with other firms is one of the possible strategies followed by firms to establish collaborative relationships. Firms involved in strategic alliances may also have a higher propensity for participation in R&D co-operative projects with PROs. One of the possible reasons for this is that, once they have developed the skills needed to manage cross boundary relationships, firms become more willing to co-operate with external partners in the development of a core strategic activity for the firm. To analyse the possibility that firms involved in strategic alliances are more likely to participate in R&D co-operative 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 research joint venture and 0 when it is not. While the effect of this variable on propensity is generally positive, the coefficient of the variable was not significant.

does not affect the level of participation. Other things being equal we can argue that while there is indeed an ‘absolute size’ effect determining the propensity for a firm to engage in R&D projects with PROs, there is a significant ‘relative size’ effect, as captured by R&D employment, in explaining the extent of participation in the projects. R&D intensity, which is a proxy for the position of the firm with respect to the technological frontier rather than being a proxy for firm size, is still a significant explanatory variable, though with a lower probability than in the Probit regression.

In terms of the effect of the other independent variables, the positive influence of subsidies as an incentive to engage in R&D activities is confirmed to be as significant in determining the level of collaboration as it was for determining the propensity to collaborate. PUBLICATIONS, PATENTS and HEADQ variables change in significance between the Probit and the Truncated regression. Other effects being equal, searching in scientific or business journals for ideas has a positive impact on the propensity to engage in R&D projects with PROs, while it is not significant in explaining the level of participation in R&D projects. Similarly, patenting, which had a positive and significant effect in the Probit estimation, is no longer significant in the Truncated regression. Respondents located in the headquarters of a firm have a higher propensity to develop R&D collaborations with PROs compared to other respondents, but this characteristic does not affect the level of co-operation. Finally, process innovation does not significantly affect the extent of the collaboration.

The introduction of sector fixed effects does not change the significance of the Probit estimation except with regard to propensity to engage in projects with PROs, which is not affected by the firm’s being a process innovator once country dummies are included. Instead, sector dummies affect the estimates of the Truncated model. When sector dummies are included, R&D intensity is no longer significant. We can argue that, since sectors differ in terms of R&D intensity, the presence of these differences affects the level of co-operation with PROs. The inclusion of sector dummies makes patents significant and positive. This result can be interpreted as capturing the effect of signalling and, thus, firm openness, on the extent of collaboration rather than appropriation because sectoral dummies account, at least partially, for appropriability regimes. When country dummies are introduced, the relevance of both R&D intensity and the dummy variables for subsidies is affected. Country specific factors related to both the scientific profile of innovating firms and their reliance on subsidies influence the level of interaction between firms and PROs.

Some of our findings can be summarised as follows. The propensity of firms to engage in collaborations with PROs is positively affected by their size and openness. We define openness as the attitude of firms to establish a relationship with PROs. Large firms with a high absorptive capacity have a higher propensity to engage in R&D cooperation with the academic world. However, absorptive capacity loses its significance if the firm does not proactively screen the scientific and technological environment in which it works. In other words, the mechanisms through which firms can import knowledge from outside their boundaries are important explanatory variables of R&D cooperation. As mentioned above, there are different 'enablers' of these mechanisms. Seeking information in scientific and business journals and also participating in government-funded projects are two proactive means used to relate to the socio-economic environment. Patents and public programmes can be a way to signal in which domains the firm has 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. These three variables positively affect the propensity for firms to collaborate with PROs. In other words, larger firms with higher learning abilities and proactive screening and signalling strategies are the most likely partners for universities. Openness affects the level of cooperation to a lesser extent.

5. Conclusions

The focus of the KNOW questionnaire on small and medium sized firms provides a unique data-set for the researcher to base analysis of the impact of internal and external knowledge sources upon the innovative process of SMEs. This study has analysed the contribution of PROs to the innovative process of SMEs and has examined the firm-specific, sector-specific and country specific factors that explain the existence and extent of co-operative R&D projects between SMEs and PROs.

The descriptive results provide direct evidence that PROs are among the less important sources of information for both innovative ideas and innovation completion for the most important innovations developed during the three years prior to the survey for SMEs from the food and beverages, chemicals, communications equipment, telecommunications services and computer services sectors in seven EU countries. Surprisingly, the contribution of PROs to the phase of completion of the innovation (time period during which an innovation is being developed up to finalisation) is similar to the innovative ideas phase. If the most important external source of information is considered, for certain sectors PROs are contributing more to the completion phase than to the innovative ideas phase. In general, significant sectoral differences were found. For example, respondents from the

food and beverages sector assign particular importance to government regulation as a driver of relationships with PROs.

The interviews confirmed the results of the descriptive analysis pointing to the fact that most firms do not have spare resources (they are not big enough) to develop relationships with PROs although a few firms have periods of intensive interaction with PROs to satisfy specific needs.

Although PROs do not play a central role in the innovative process of SMEs, about half of the firms in the sample had developed R&D co-operative projects with PROs. The econometric model developed allows estimation of the impact of firm-specific factors, controlling for sector and country fixed effects, upon both the probability of developing an R&D project with PROs and the number of R&D projects developed by the firm in the previous three years. The results of this analysis point to two major phenomena. The first concerns the relationship between the probability of forming R&D collaborations with PROs and firm size. Our results suggest that the probability depends on the 'absolute size' of the firm. Larger firms have a much higher probability of R&D collaboration. This result is consistent with a large number of previous empirical investigations of determinants of university-industry relationships (Arundel *et al.* 2000; Mohen and Hoareau 2002; Cohen *et al.* 2002; Laursen and Salter 2003). However, the number of R&D co-operations is not affected by the 'absolute size' of the firm but rather by the 'relative size' as measured by R&D employment. This aspect has not been highlighted in previous contributions. R&D intensity affects both the propensity for and the extent of engagement in R&D projects.

The second phenomenon concerns the openness of firms, that is, their willingness to search, signal and screen the outside world by searching publications databases, by patenting and by participation in programmes subsidised by government. Our findings suggest that the reliance on publications for acquiring knowledge affects the probability of entering into a collaboration with a PRO but not the level of collaboration developed. Instead, firms that patent to protect innovation (and signal competencies) also have a higher probability of collaborating and a higher level of collaboration. In addition, the results of the estimation suggest that those firms that have received public subsidies have both a higher probability of developing R&D co-operation with PROs and a larger number of collaborations, although the impact of subsidies on the extent of the collaboration is mediated by country specific effects. This means that screening is an important precondition for the development of relationships between SMEs and PROs but that other factors should be taken into the account

when the focus is on the extent of the relationships. In both equations sectoral and country fixed effects are significant and important.

Overall, the results of this analysis support the view that relationships between firms and PROs are characterised by a high degree of heterogeneity. To speak about university-industry relationships in a general way and develop policies on the basis of such generalisation will lead to unintended inter-sectoral differences. Indeed, 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 forcing PROs into these types of relationships with no acknowledgement that without 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) is very important in explaining their probability of collaborating with PROs. Without willing partners satisfaction will not be achieved.

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Appendix I: Descriptive statistics

Descriptive Statistics for selected variables (all variables)

Variable	Obs	Mean	Std. Dev	Min	Max
No of Projects	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
PUBLICATIONS	552			0:99	1:453
PATENTS	551			0:354	1:197
HEADQ	554			0:241	1:313
PROCINN	543			0:95	1:448
PRODINN	553			0:22	1:531
SUBSIDIES	492			0:341	1:151

Table 1: Differences in responses between groups

	Chemicals		**Food**	
Motivation for knowledge. Acquisition	G1	G0	G1	G0
Cost and risk reduction	YES	NO	YES(+)	YES
Update of technical expertise	YES(+)	YES	YES(+)	YES
Building on others innovation	NO	NO	NO(+)	NO
Meet government regulation	NO(-)	NO	YES	NO
Mode of contact				
Previous experience	YES(+)	YES	YES(+)	YES
Business or professional associations	NO(-)	NO	NO(+)	NO
Trade fairs and conferences	YES	NO	YES	NO
Internet	NO(+)	NO	NO	NO
Communication methods				
Informal contacts	YES(-)	YES	YES(+)	YES
R&D cooperation	YES	NO	NO(+)	NO
Exchange of students	NO	NO	NO(+)	NO
Type of knowledge acquired				
Technical and scientific	YES(-)	YES	YES(+)	YES
Linked to the market	NO	YES	YES(+)	YES

Table 2: 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%

Table 3: Regression Summary - Probit and Truncated Regressions

	Probit (1) Discrete Variable		**Truncated (2)** No of projects with Universities	
	Coeff	Coeff	Coeff	Coeff
SUBSIDIES	0.625**	0.634**	0.143*	0.150*
	(3.95)	(3.58)	(1.78)	(1.79)
PUBLICATIONS	0.785**	0.859**	-0.037	-0.035
	(4.05)	(4.07)	(-0.24)	(-025)
PATENT	0.384**	0.388**	0.126	0.191**
	(2.40)	(2.22)	(1.41)	(2.00)
HEADQ	0.555**	0.494**	0.104	0.075
	(3.66)	(2.77)	(1.25)	(0.88)
LnEMPLOYEES	0.178**	0.162**		
	(2.82)	(2.44)		
LnR&D			0.124**	0.124**
			(3.18)	(2.86)
LnR&DINT	1.201**	1.327**	0.468*	0.198
	(2.23)	(2.27)	(1.79)	(0.72)
PROCINN	0.386*	0.226	0.131	0.149
	(1.84)	(0.29)	(1.11)	(1.19)
PRODINN	0.028	0.051	0.178	0.250**
	(0.08)	(0.14)	(1.57)	(2.47)
Intercept	-2.549**	-2.023**	0.508**	0.230
	(-4.96)	(-3.06)	(2.52)	(0.69)
Sector dummies	No	Yes	No	Yes
Country dummies	No	Yes	No	Yes
Log Likelihood	-205.503	-193.248	-129.982	-125.883
Wald Chisq	72.61**	77.87**	43.89**	66.88**
Pseudo Rsq	0.169	0.218		
No Obs	357	357	184	184

* indicates significant at 10% confidence interval.
** indicates significant at least at 5% confidence interval.
t-value between brackets

Fig. 1: External sources of information for innovation ideas by NACE sector

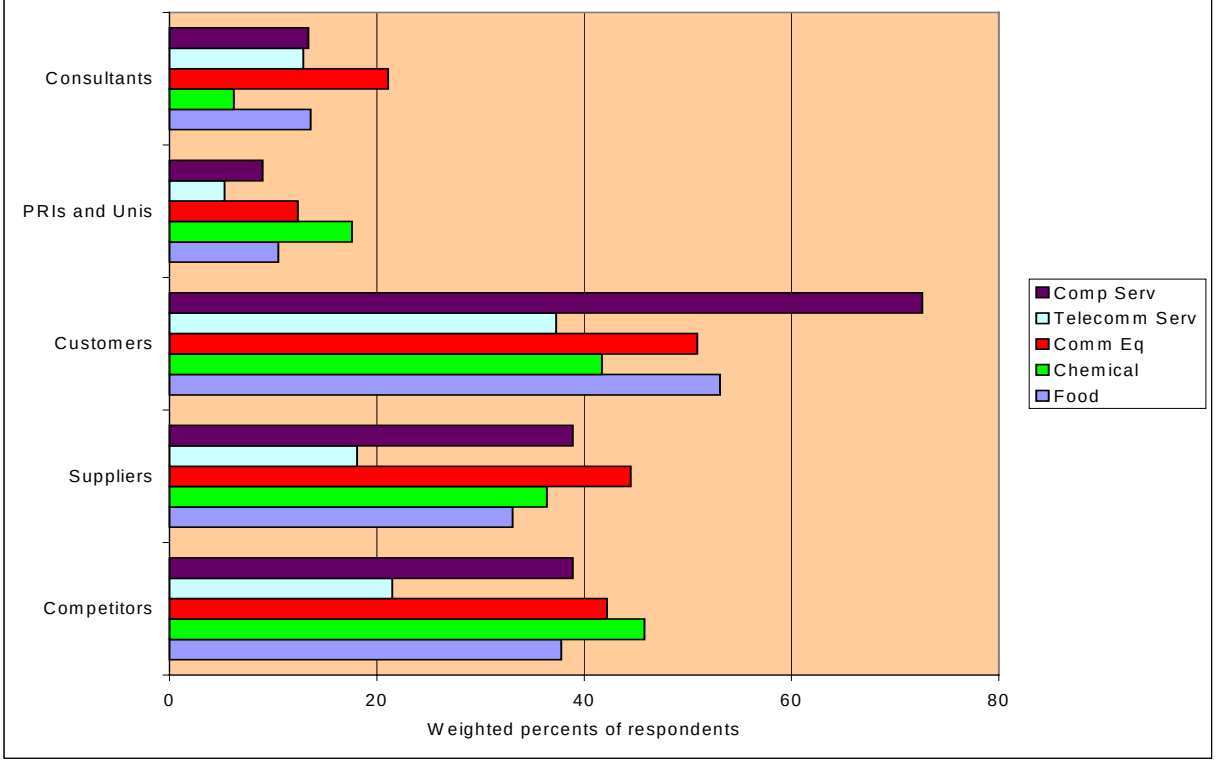

Fig. 2: External sources of information for innovation completion by NACE sector

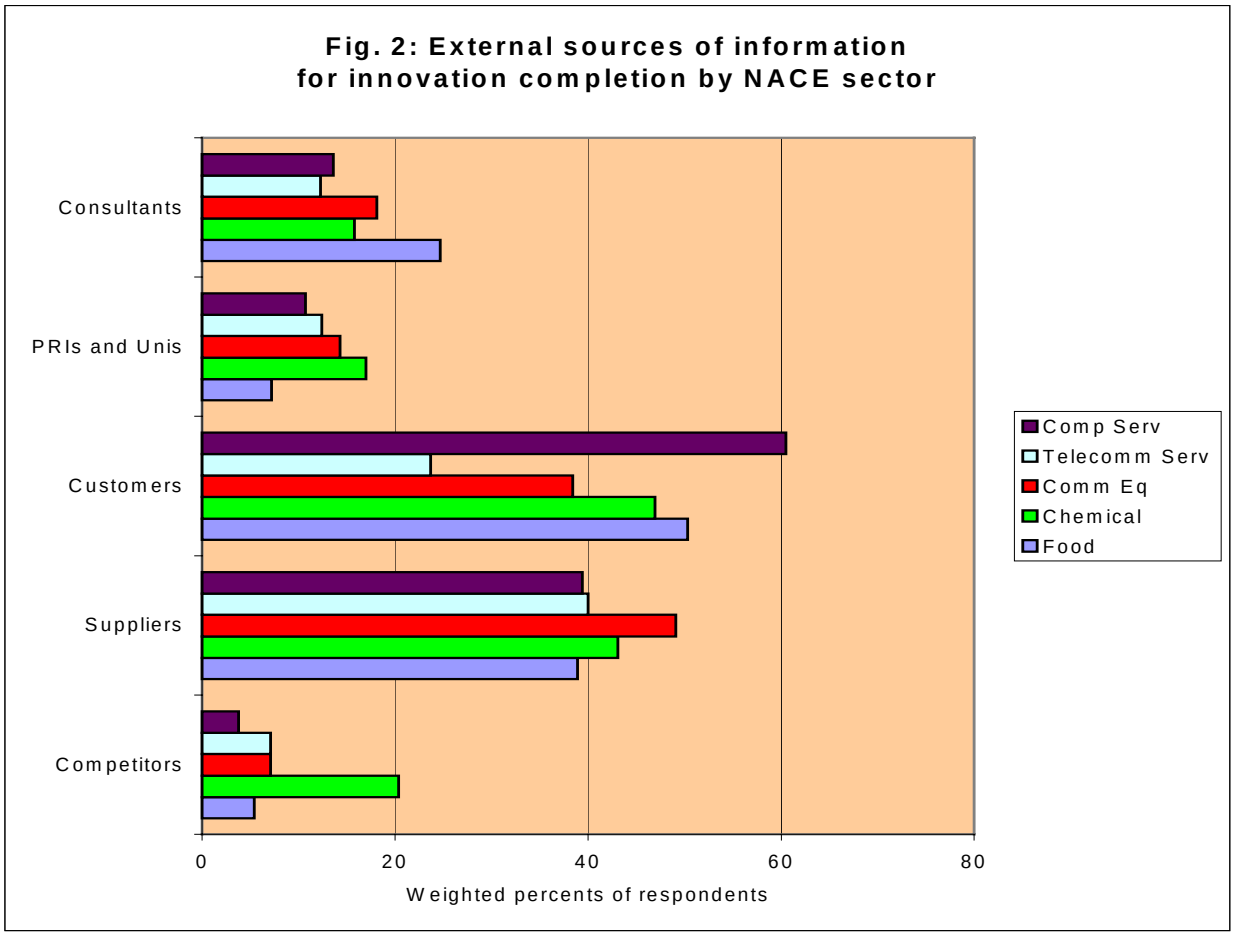

Fig 3: Most important external source of information for innovation ideas by NACE sector

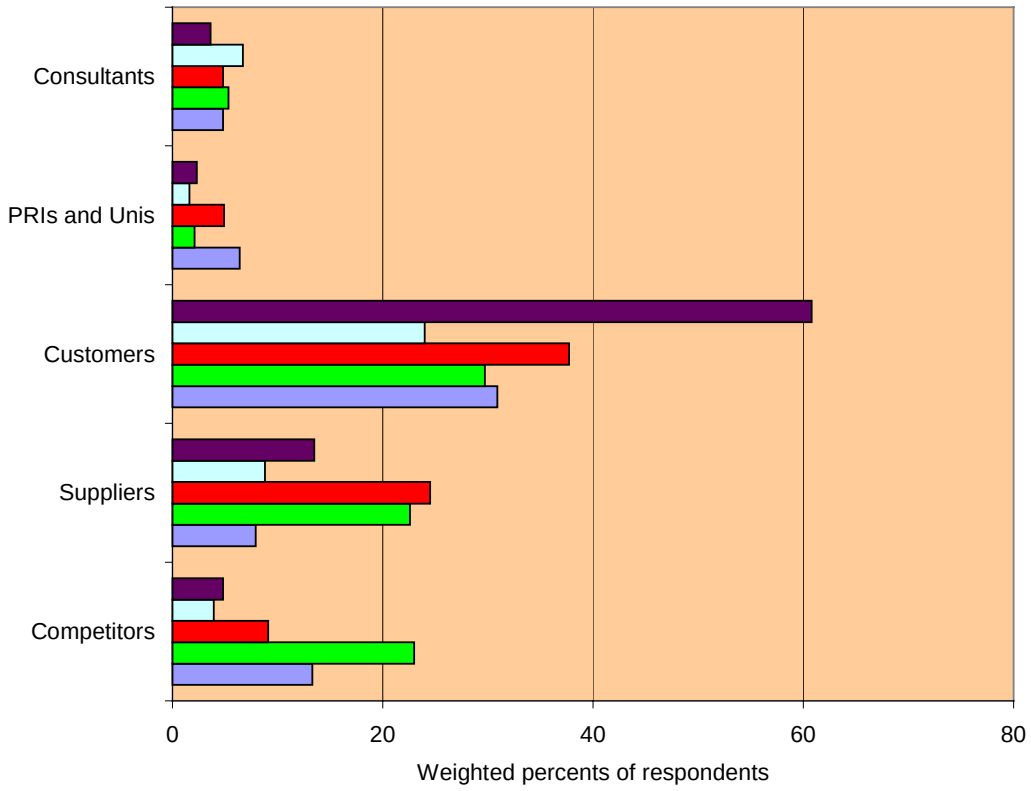

Fig 4: Most important external source of information for innovation completion by NACE sector