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R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing

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Abstract

Using Community Innovation Survey data for Belgium we analyze which firm and industry characteristics are conducive to cooperation with universities. We take into consideration that the decision to cooperate with universities cannot be analyzed in isolation from the overall innovation strategy of the firm. Cooperating with universities is complementary to other innovation activities such as performing own R&D, sourcing public information and cooperating with other partners. In the econometric analysis we fully account for the impact of these simultaneously determined other R&D strategies. In addition, we examine the theoretically conflicting effect of the appropriation conditions on the likelihood of cooperating with universities. Our analysis confirms that large firms and firms in the chemical and pharmaceutical industry are more likely to be actively involved in industry science links. Furthermore, we find that these cooperative agreements are formed whenever risk is not an important obstacle to innovation and typically serve to share costs. Consistent with the open science paradigm, we find no evidence for the importance of the capacity to appropriate the returns from innovation for explaining cooperative agreements with universities.

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Finally, the results are consistent with complementarity of these agreements with other innovation activities.

JEL classification: O32; O34; L13

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1. Introduction

Several macro-economic studies have indicated the importance of *basic*, *scientific*, *research* for technology, innovation and economic growth of nations (e.g. Jaffe, 1989; Adams, 1990; Griliches, 1998; Rosenberg and Nelson, 1994; Mansfield, 1995; Cohen et al., 2002). At the micro level the technology management literature documents, mainly on the basis of specific case studies and detailed surveys at the firm-level, how scientific knowledge feeds into successful innovations (e.g. project Hindsight, 1958, project TRACES, 1967; Allen, 1977; Tushman and Katz, 1980). Linking scientific knowledge is especially important for firms innovating in the fast developing technologies like biotechnology, information technology and new materials (Cockburn and Henderson, 2000; Zucker et al., 1998; Mowery, 1998).

Empirical studies have attempted to quantify these knowledge transfers from academic research to innovating firms through various proxies. Shane (2002) investigates the licensing of university generated innovations while Siegel et al. (2003a,b) examine the impact of university science parks and others study academic spin-off activities (DiGregorio and Shane, 2003; Zucker et al., 1998; Audretsch and Stephan, 1996). More indirect evidence comes from using firm patents. Henderson et al. (1998) and Mowery (1998) look at citations to academic patents, and Verbeek et al. (2001) and Branstetter (2003) use citations in corporate patents to scientific literature. However, most of the empirical firm level studies have concentrated on research partnerships as an important mechanism for firms to engage in industry science relations (Henderson et al., 1998; Hall et al., 2001).

On average the evidence suggests a positive effect of knowledge transfers from science to industry. Nevertheless there exists a strong indication of the inadequate scale and intensity of such transfers. The highly uncertain and non-codifiable nature of scientific know-how results in high transaction costs and systemic failures in the market for this know-how, explaining the difficulty of organizing these *Industry Science Links* (*ISLs*). In addition, *ISLs* are hampered by diverging objectives between the partners and conflicting reward structures within academia for promoting *ISLs* (Siegel et al., 2003a,b). Especially in Europe, there seems to be a gap between high scientific performance on the one hand and industrial competitiveness on the other hand. This gap, mainly attributed to low levels of Industry Science Links, is known as the “European paradox” (EC-DGECFIN, 2000). The evidence from the Community Innovation Survey for the EU shows that only a small fraction of innovative enterprises use science, i.e. universities and public research laboratories, as an important information source in their innovation process.[1] Furthermore, the survey shows that in 2000 less than 10% of innovative firms had cooperative agreements with universities (EU-NEWCRONOS-CIS III).[2] Similarly, Hall et al. (2001) report that in the United States the vast majority of research partnerships registered under the NCRA and NCRPA Act do not include a university. Although the trend is increasing, only a modest 15% of all research partnerships involved a university.

Because *Industry Science Links* seem to encounter severe obstacles, many countries have launched a variety of public promotion programmes supporting especially collaborative research between industry and public science institutions. Financial support for collaborative research receives the largest portion of public money for ISLs promotion and is still gaining in importance in most countries. The EU framework programmes also follow this line of ISL promotion and represent major additional funding for industry-science collaborative research. Likewise in the United States, the Advanced Technology Program (ATP), as well as the CRADAs (Cooperative R&D agreements between Federally Funded R&D laboratories and firms) and the IUCRCs (Industry University Cooperative Research Centers) provide support for pre-competitive generic industry-science cooperative research.

The aim of our paper is to contribute to a better understanding of the quality and extent of *Industry Science Links* by examining the industry demand for such links. More particularly, we want to uncover the drivers and barriers for firms to engage in cooperative agreements with scientific institutions. Using firm level EUROSTAT CIS-survey data for Belgium, we present an econometric analysis on the firm and industry characteristics most conducive to cooperation in R&D with universities.

Compared to the existing literature, we argue that beyond the traditionally considered firm size, and industry affiliation the appropriability issue needs to be dealt with. At a more fundamental level, however, we argue that cooperative agreements with universities are typically not the sole component in a firm's overall innovation strategy, which raises the issue of *complementarity* among the various components. To be more successful in commercializing inventions made from know-how developed in cooperative agreements with universities, firms engage in complementary internal R&D projects and external innovation activities, such as actively screening public information sources and organizing R&D projects joint with other firms.

In line with existing studies our results confirm that large firms and firms in the chemical and pharmaceutical industry are more likely to have cooperative agreements with universities. These agreements are formed whenever risk is not an important obstacle to innovation and typically serve to share costs. We do not find evidence that appropriation conditions affect the formation of cooperative agreements with universities. More interestingly, our results do (weakly) suggest the existence of complementarity between R&D cooperation with universities and other innovation activities of the firms, such as sourcing freely available public information and cooperative agreements with suppliers and customers.

[1] In the latest Eurostat-Community Innovation Survey CIS-III (1999–2000), of all reporting innovative EU firms (excl UK) 4.5% rated universities as important sources of information, while 68% indicated universities as not important at all (EU-Newcronos-CISIII).

[2] On average for all reporting EU countries (excl UK) 18% of innovative firms reported in CIS-III having cooperative agreements, of which 35% reported having cooperative agreements with national universities, which implies that only 6.3% of all innovative firms have cooperative agreements with national universities.

Section 2 describes the literature on R&D cooperation between industry and science, while Section 3 discusses our research approach.Section 4 presents the results on which firm and industry characteristics stimulate cooperation in R&D with universities and Section 5 concludes.

2. R&D cooperation between science and industry

In the absence of a well developed economics literature on the specific topic of R&D cooperation between industry and science, we start with the more abundant literature on R&D cooperation in general. We use these insights to discuss the specific issues posed by cooperation between industry and science in more detail.

A first approach to better understand why firms choose to cooperate in R&D is offered by *Transaction Cost Economics*. Pisano (1990) describes alliances as a hybrid form of organisation between hierarchical transactions within the firm and arm's-length transactions in the market place. Arm's-length technology transactions can have high (transaction) costs, especially when the technology transacted has a tacit and uncertain component. Own development within the firm, limits these transaction costs, but does not allow access to specialist know-how available externally. Collaboration allows access to this specialised know-how, but also the inherent reciprocity relationship and "hostage" exchange between complementary partners minimizes opportunism. However, also in this case, information asymmetries and the uncertain and tacit nature of R&D may endanger the exploitation of cooperative benefits. This may explain why firms view alliances as a learning experience and only gradually build up commitment (Mody, 1993) or enter into larger networks of alliances, selecting partners where reputation matters more and where complementary is maximized (Gulati, 1995).

The *Industrial Organisation* literature on R&D cooperation focuses on the effect of imperfect appropriability of results from the innovation process on the incentives to innovate, when the firms cooperate in R&D (e.g. Spence, 1984; D'Aspremont and Jacquemin, 1988; Kamien et al., 1992). On the one hand, imperfect appropriability increases the benefits from cooperative R&D agreements. When spillovers are high enough, i.e. above a critical level, cooperating firms internalizing these spillovers, are more profitable compared to non-cooperating firms (d'Aspremont and Jacquemin, 1988; Kamien et al., 1992; De Bondt, 1997). On the other hand, imperfect appropriability increases the incentive of firms to free ride on each other's R&D investments (e.g. Shapiro and Willig, 1990; Kesteloot and Veugelers, 1994) and encourages free-riding on the R&D efforts of the research joint venture by outsiders to the cooperative agreement (Greenlee and Cassiman, 1999). Recent extensions of these models, take into account that firms attempt to increase incoming spillovers, not only directly through information sharing in cooperative arrangements, but also indirectly by investing in own R&D. The notion of 'absorptive capacity' introduced by Cohen and Levinthal (1989) and further theoretically developed in Kamien and Zang (2000) stresses the importance of a stock of prior knowledge to effectively absorb spillovers, while cooperating. Also Mowery and Rosenberg (1989) stress that "cooperative research programs alone are insufficient. . .more is needed, specifically the development of sufficient expertise within firms to utilize the results of externally performed research."

Most theoretical IO research when discussing the effects of imperfect appropriation, focuses on cooperation between competing firms, stressing the importance of the degree of product market competition. Direct competition among partners ex post leads to less/more incentives to cooperate in R&D when spillovers are low/high. However, when firms are no direct competitors but market independent or complementary goods, these theories would predict that cooperation will lead to higher R&D investment levels for any level of spillovers (De Bondt et al., 1992; Röller et al., 1997). In a setting where partners are no direct competitors in output markets, there is no detrimental effect to the firm from knowledge spillovers that would strengthening the product market position of the rival.

To which extent can the results from the literature on cooperation in R&D be extended to collaboration between firms and universities? Since universities are no direct competitors in the output markets of the collaborating firm, not being able to appropriate exclusively the benefits from the new know-how generated is not an issue for firm-university cooperation, as it is in cooperation among firms competing in output markets, unless the know-how would leak out to competitors indirectly through common partners.

In addition, the specific nature of the know-how being transacted in Industry–Science cooperation generates a different profile of firms being engaged in these types of cooperation. Science institutions offer new technical knowledge which is mainly needed in innovation activities oriented towards developing new technologies and for products very new to the market. These innovation activities take place in the early stages of the innovation process characterized by high technological uncertainty and still low demand for the outcomes of innovation activities (a.o. Jensen et al., 2003). As a consequence, only a select set of firms within specific industries, using specific technologies (e.g., bio- and nano-technology), will have a strong interest in the scientific know-how offered by universities.

Given the specific characteristics of scientific knowledge, R&D cooperation between universities and industry is characterized by high uncertainty, high information asymmetries between partners, high transaction costs for knowledge exchange requiring the presence of absorptive capacity, high spillovers to other market actors (i.e. a low level of appropriation of benefits out of the knowledge acquired), and, restrictions for financing knowledge production and exchange activities due to risk-averse and short-term oriented financial markets. In addition, enforcing partner compliance in cooperative contracts will be more difficult when the technology is characterized by a large amount of uncertainty. Nevertheless, the more generic nature of research projects with universities and research institutes involves less intellectual property right issues. Hall et al. (2001) note that when research results are uncertain, neither party can define meaningful boundaries for any resulting Intellectual Property Rights, and hence appropriation is less likely to be an insurmountable issue.

Previous empirical studies on R&D cooperation between firms and science indicate the importance of firm size and own R&D as drivers for cooperation. This is reminiscent of the absorptive capacity idea which stresses the need to have in-house (technological) capabilities to optimally benefit from R&D cooperation. Leiponen (2001) obtains a positive size effect and also a positive research competence effect of R&D collaborations with universities on Finnish innovation survey data. A larger size and larger R&D effect are also reported for firms that are linked to federal laboratories via cooperative R&D in Adams et al. (2000) and in Adams et al. (2001) for firms engaged in IUCRCs (Industry-University Cooperative Research Centers). The importance of size and R&D intensity is very much in line with the results from the studies on R&D cooperation among firms. These studies also find strong evidence for the size and R&D orientation of firms to be beneficial to R&D cooperation (o.a. Röller et al., 1997; Kleinknecht and Van Reijnen, 1992; Colombo and Gerrone, 1996; Dutta and Weiss, 1997; Hagedoorn et al., 2000 for an overview). Nevertheless, Mohnen and Hoareau (2003) did not find R&D intensity to be significantly related to cooperation with universities. They do find that firm size, government support, patenting and scientific industry status contribute positively towards explaining R&D collaborations with universities relative to other types of cooperation. Capron and Cincera (2003) also confirm the importance of firm size and government support as significant drivers for R&D cooperation with universities.

None of these papers, when assessing causes and effects, properly accounts for the simultaneity between own R&D and R&D cooperation arising from complementarity.[3] Veugelers (1997) taking into account this simultaneous relationship, finds that firms who spend more on internal R&D have a significantly higher probability of co-operation in R&D and that once correction has been made for this, size (which typically positively influences internal R&D) no longer is relevant for explaining R&D co-operation. Cassiman and Veugelers (2002) provide evidence of a strong positive effect of own R&D activities on cooperation in R&D, but after controlling for endogeneity this effect is less significant.

Beyond the simultaneous relationship between own R&D and cooperation in R&D, there are few studies which consider the complementarity with other innovation activities for cooperating firms. Liebeskind et al. (1996) uncovered that for the biotech sector, companies that were engaged in joint research and publishing with academic institutions were more effective at externally sourcing new scientific knowledge. Arora and Gambardella (1990) examine the complementarity among external sourcing strategies of large firms in the biotechnology industry. They find evidence for complementarity between four types of external sourcing strategies for large chemical and pharmaceutical companies in biotechnology (agreements with other firms, with universities, investments in and acquisitions of new biotechnology firms). Furthermore, the correction for firm characteristics suggests that large firms with higher internal knowledge, measured by number of patents, are more actively involved in pursuing a combination of strategies of external linkages. Belderbos et al. (2004) jointly estimating various types of cooperative agreements–horizontal, vertical and with research institutes–, compare the relevant factors explaining the different types of cooperation and find evidence consistent with complementarity between the three types.

Also with respect to the appropriability issue, there is little explicit empirical evidence. While the effects of the Bayh–Dole act accentuate the importance of intellectual property rights for universities for effective transfers to occur (e.g., Link et al., 2003), there is also the issue of importance of the effectiveness of IPR for firms to engage in ISL (see Dechenaux et al., 2003). Hall et al. (2001) using survey evidence from a small subset of ATP funded projects, demonstrate that Intellectual Property Rights issues between firms and universities do exist and in some cases those issues represent an insurmountable barrier preventing R&D cooperative agreements to be formed in the first place. However, such situations are more likely to occur for short-term, well defined research contracts

[3] Adams et al. (2001) present a simultaneous equation analysis of the joint decision to patent and to join the IURC, but ignores the simultaneity with own R&D.

where there is more certainty in terms of the characteristics of the research findings (e.g. screening test in biomedical research contracts).

Cassiman and Veugelers (2002) find that firms who can better appropriate the results of the innovation process to have a higher probability of cooperating with customers or suppliers, but this does not affect cooperative agreements with research institutes. Commercially sensitive information, which is the result of these vertical, applied research projects, often leaks out to competitors through common suppliers or customers. Hence, only firms that can sufficiently protect their proprietary information are willing to engage in this type of cooperative agreements.

3. R&D cooperation between science and industry: complementarity with other innovation activities of the firm and appropriation

We present an econometric analysis on firm and industry characteristics most favourable to cooperation with universities. The decision to cooperate or not is analyzed with a probit model. In line with the existing literature, as reviewed in the previous section, we include the standard explanatory variables like firm size, innovative profile and industry affiliation. But in addition, we take into account the presence of complementary innovation activities and add appropriability conditions. Before presenting the empirical research methodology and data to test our hypotheses, we first sketch the arguments behind our main hypotheses.

A first specific focus of our analysis is the consideration of other complementary innovation activities. To successfully commercialize inventions, firms need to develop R&D capabilities, both basic and applied. These R&D capabilities are developed through the use of own R&D inputs as well as through external sourcing. External sourcing requires that the firm has the necessary in-house capability to effectively absorb external know-how. Hence a firm's portfolio of potential innovation activities typically includes own R&D, joint R&D with other actors and sourcing of public information. ISL and cooperative agreements with science institutions develop in particular the firm's basic R&D capability. This basic R&D capability increases the efficiency of other innovation activities: own development activities conducted within the firm, as well as other external sourcing strategies.[4] Hence, firms being engaged in other innovation strategies will have a larger incentive to engage in industry–science cooperation. We therefore include the own R&D activities of the firm in our analysis for industry–science cooperation. We expect firms that have more own R&D activities, both basic and applied, to benefit more from the basic R&D capabilities developed through R&D cooperation with universities. In addition, own basic R&D activities may be an important driver for R&D cooperation with universities as absorptive capacity.

When we view basic R&D capabilities in their capacity to absorb external information efficiently into the in-house innovation activities, basic research will also act as an

[4] Cassiman et al. (2002) develop a model on the complementarity between basic and applied research. They provide an explanation for why larger firms with larger applied R&D budgets will be more inclined to be engaged in basic R&D. Also Aghion and Howitt, 1996, provide a model on the choice between basic and applied research, favoring larger firms for basic research.

important driver for complementarity with other external sourcing strategies. Rosenberg (1990) stresses the importance attached to performing *basic research* by companies that see it “as a ticket of admission to an information network”. Knowledge disseminated through publications, conferences and patents is a stock of knowledge that can be used by the firm as a (public good) input into its innovative activities. The effective transfer of this know-how typically requires a basic research capability by the receiving party, which can be built through cooperative agreements with science institutions. Hence, when free spillovers improve the basic R&D competence of the firm, the marginal benefit of forming a research joint venture with science institutes is higher, implying a higher probability of industry–science cooperation when firms are also sourcing public information.

We also include cooperating with suppliers and customers as another external innovation activity of the firm. These types of vertical cooperative agreements typically involve development activities. With applied R&D capacities complementary to basic R&D capacities that are developed in cooperative agreements with universities, we expect both types of cooperation to be mutually reinforcing. A higher applied technological capability developed through inter-firm cooperation will again increase the marginal benefit of cooperating with universities.

In order to address the possible endogeneity problems with the complementary strategies, we will use an instrumental variables estimation procedure. The procedure identifies next to the set of *assumed* exogenous variables, instruments specific for the complementary strategies (see below).

A second specific focus of our analysis is the impact of the *appropriation regime*. Following the suggestions from the economics literature, the more generic nature of research projects with universities and research institutes should involve less appropriation issues, as compared to the more commercially sensitive cooperation with customers/suppliers or competitors. Nevertheless, clear intellectual property regimes will facilitate industry science technology transfer. We test whether the appropriation regime is a significant characteristic for firms cooperating with universities. We distinguish *legal* protection of products and processes through patents, brand names or copy right, and *strategic* protection of products and processes through secrecy, complexity or lead time.

Beyond the two specific issues, complementarity with other innovation strategies and appropriation issues, we also include more standard firm and industry characteristics. A typical hypothesis of the literature is that absorptive capacity is required to benefit from R&D cooperation, especially with university partners (e.g. Leiponen, 2001). In most other empirical research absorptive capacity is proxied by own R&D, which we already included as a complementary innovation activity (see above). We expect however that even when controlling for any given level of own R&D, larger firms may still be more likely to possess the necessary in-house capability to effectively interact with science, since this capability extends beyond what is captured by R&D budgets (e.g. separate R&D departments, university-trained employees, available time and financial resources for establishing and maintaining science links). While most empirical evidence suggests that larger firms, ceteris paribus, are more likely to be engaged in R&D cooperation, some small high-tech firms may nevertheless be better placed to interact with science, particularly when they have sprung off from university research.

A high share of foreign-owned enterprises in the economy may be a restricting factor to ISLs, as the local affiliates of multinational enterprises may not carry out the type of basic research which strongly relies on new scientific knowledge. This basic R&D is typically done centrally at headquarter level, leaving industry–science cooperation more a headquarter than a subsidiary type of activity (von Zedwith and Gassmann, 2002).

As work by Mariti and Smiley (1983) a.o. has indicated, cost and risk sharing are in general important drivers for cooperative agreements. More specifically in industry–science collaboration, given the early stage of technology development, financial barriers to innovation may be strong given the imperfections of the financial markets for these early stage ventures. This is often a motive for why governments provide additional funding for industry–science collaboration. Although higher risk associated with high technological uncertainty induces risk sharing benefits from cooperation, at the same time it invokes higher transaction costs for cooperation, resulting in an ambiguous effect on the probability of cooperating with science.

Finally, we need to correct for the technology specific component of industry science links, since some industries, like pharmaceuticals and chemicals, are more "science-based", i.e. relying more heavily on advances in basic research for their innovative activities. We include an industry specific university cooperation variable and/or industry dummies.

4. R&D cooperation between science and industry: empirical evidence from Belgian manufacturing

4.1. The data

The data used for this research are innovation data on the Belgian manufacturing industry that were collected as part of the Community Innovation Survey conducted by Eurostat in different member states in 1993 (CIS-I). The survey contained questions characterizing the innovation strategies of firms: whether they innovate or not, do internal R&D and/or buy technology, as well as cooperate or not.[5] In addition to some quantitative information such as sales, exports and employment, the data allow us to identify obstacles to innovation, sources of technological information and mechanisms used to protect the results from innovation.[6]

The sample used in this study is restricted to the firms that innovate. These firms are distinguished from those who do not innovate based on their answer on the question whether they were actively engaged in innovation in the last two years, by introducing new or improved products or processes AND returned a positive amount spent on innovation: 60%

[5] A representative sample of 1335 Belgian manufacturing firms was selected. The response rate was higher than 50% (748). A limited non-response analysis was conducted, where no systematic bias could be detected with respect to size and industry affiliation. Veugelers and Cassiman (1999) contains more descriptive statistics results on the Belgian CIS-I sample.

[6] The CIS-II survey was unfortunately less rich in terms of qualitative variables, most notably on the appropriation of the results from innovation. In addition, since the Belgian CIS-II uses a different sampling methodology and innovation definitions, the results are less consistent across time with CIS-I and CIS-III and less comparable with other EU countries. The CIS-III Belgian firm level data were not yet available for research.

(439) of the firms in the sample claim to innovate, while only 40% do not. The non-innovating firms did not provide information about several variables, used in the analysis. In our regression analysis we correct for sample selection using the two-step Heckman correction.[7]

The phenomena of interest are the cooperative agreements in R&D which innovative firms may have with universities. Our dependent variable, CPuniv, indicates if firms responded that they cooperate with universities.[8] Due to missing values or too few observations per sector, we are left with 325 firms that innovate of which 87 (or 27%) have a cooperative agreement with universities. Most of these cooperative agreements are with local universities. 80 out of the 87 university cooperating firms have a Belgian university partner. Only 7 firms report cooperative agreements with international universities, without being engaged simultaneously in cooperation with national universities.[9]

To get an idea of the idiosyncrasies that might be present in the Belgian subsample, we compare Belgian innovative firms at the aggregate level with innovative firms from other EU countries using the CIS-III results.[10] While on average 6.3% of the innovative firms in the EU cooperate with national universities,[11] Belgium, with 9%, scores somewhat higher than the EU average. This is comparable to countries like France (7.7%), Germany (7.8%), and Austria (8.6%); higher than countries like Italy (2.3%), Spain (5%) and the Netherlands (5.2%); but still considerably below Sweden (13.5%) and Finland (28.2%).[12,13,14]

7 Sample selection with respect to innovating firms is rejected and does not significantly affect our results (see below).

8 The questionnaire only contains information on whether firms cooperate or not. No information on the importance and the number of cooperative agreements was available.

9 The results are not sensitive to excluding these 7 firms.

10 EUROSTAT NEW CRONOS provides international comparisons at the aggregate population level for CIS-II and CIS-III. These results exclude UK data. Although there is some international standardization in CIS methodology, results comparing countries are nevertheless plagued by differences in sampling and surveying design across countries. Similarly, comparisons over time across different versions of CIS need to be handled with care, given structural breaks in the methodology and survey design in several countries.

11 Also at the EU level, firms with cooperative agreements with international universities represent less then 1% of innovative firms.

12 The results for CIS-II are similar. In 1996, 33% of innovative firms with cooperative agreements reported having cooperative agreements with universities. This implies that 8.3% of all innovative firms in the EU have cooperative agreements with universities, which is also exactly the figure for Belgium. The different waves of CIS surveys hence do not seem to pick up a positive trend in industry science cooperation over time (from 8.3% to 9%).

13 When moving from population averages, as reported in NEWCRONOS to samples not weighted to population, restricted to manufacturing, cleaned for missing observations on firm characteristics and with innovators more narrowly defined as reporting positive innovation budgets, as in the sample used in the analysis reported here, the percentages of firms cooperating with universities are typically higher. Abramovsky et al. (2004), analysing firm level CIS-III data from 4 European countries, report for samples which are similarly composed as ours, for France 26.7% of cooperative firms engaged in cooperation with research institutes and 27.8% for Germany, very closely in line with the Belgian average sample number (27%).

14 A similar ranking of countries prevails when looking at how important innovative firms rate universities as source for their innovative activities. While on average for the EU 68% indicated universities as not important at all, Belgium scores close to this EU average (62%), in line with countries as France (57%), Germany (59%), and Austria (65%); higher than countries such as Italy (85%), the Netherlands (77%) and Spain (77%), but considerably lower than Finland (45%) and Sweden (49%).

With respect to structural characteristics of the Belgian Innovation System relevant for ISL, Belgian R&D expenditures as a percentage of GDP is slightly below the EU average, both in terms of what the private and public sector is spending. Belgium has a less pronounced high-tech orientation of its industry, but rather specializes in the higher segments of medium-tech industries, such as engineering and machinery, chemicals, motor vehicles, electrical machinery and metals. Another possible drawback in terms of industry structure for fostering ISLs is the large percentage of small to medium sized firms in Belgium. Furthermore, the large enterprise sector is concentrated in affiliates of multinational firms. Nevertheless, the small sized firms seem to be more innovation active as compared to their typical EU counterparts. On the supply side, Belgium has a well performing science base, at least in terms of the quality of the publications generated by Belgian scientists. Public promotion of ISLs is less significant, both in volumes and influence upon ISLs. The federal–regional political system in Belgium introduces a high complexity which impedes the development of a consistent policy promoting ISL (Polt, 2001).[15]

4.2. *The explanatory variables*[16]

As independent variables we include the typical factors shown in previous literature to affect the decision to cooperate. We include SIZE, measured by the logarithm of firm employment. Taking logarithms allows accounting for a non-linear size effect. A dummy variable FOR is included which takes the value of 1 if the firm is a local subsidiary of a foreign headquarter.

In addition, the survey information analyses the importance of cost and risk sharing motives for cooperation with science in particular. The firms rated the importance of different obstacles to innovation on a scale of 1 (unimportant) to 5 (crucial). We construct an aggregate measure of the responses to questions as lack of suitable financing, high costs of innovation, long pay-back period or difficult to control cost of innovation: COST. Similarly RISK is the response to importance of high risks as a barrier to innovation. To correct for “science-based industries”, we include an industry level variable for scientific cooperation.[17] Alternatively, we use the standard industry dummies.

A specific focus of our analysis is the consideration of other complementary innovation activities. First we include the *own R&D capacity*, which could also be picking up absorptive capacity as suggested by the literature. The CIS-I survey for Belgium does not provide reliable data on R&D budgets. In the absence of this, we have to revert to other proxies. In the questionnaire, firms rated the importance of internally available information for their innovation process on a 5-point scale from unimportant (1) to crucial (5). The

[15] See Capron and Meeusen (2000) for more on the Belgian Innovation System and Debackere and Veugelers (in press) for Belgian Industry Science Link structures in particular.

[16] Table A1 in the Appendix provides a detailed description of all the variables used in the analysis.

[17] For the industry level variables we define the industry at the NACE 2 and 3 digit sector level and the industry average is the average score from the firms responding in the sample in the same sector. We only retain those sectors were we have at least 5 observations.

importance of internal information to innovation is included to proxy for internal know-how capabilities (INTSourcing).[18]

Second, we include the impact of complementary *external sourcing* strategies. A first external sourcing strategy is the use of publicly available information. In the questionnaire, firms rated the importance of publicly available information for their innovation process from three sources on a 5-point scale from unimportant (1) to crucial (5). The information sources were: patent information; specialist conferences, meetings and publications; trade shows and seminars. To generate a firm-specific measure of public sourcing, we construct the mean of the answers on these questions (PUBSourcing). Finally, we also include other cooperative strategies of the firm, more particularly whether the firm cooperates with clients and/or suppliers (CPvert).[19]

Finally, the survey data allows analysis of the extent to which appropriation and, more specifically, the capacity of firms to protect the rents from their innovative efforts shape their cooperative activities. In CIS-I, firms had to rate the effectiveness of five different methods for protecting products and processes respectively (10 different questions overall) on a scale from 1 (unimportant) to 5 (crucial). We distinguish between two types of protection: *legal* protection of products and processes through patents, brand names or copy right, and *strategic* protection of products and processes through secrecy, complexity or lead time. We construct a variable with the mean score for these questions to generate a measure of legal and strategic protection. We will use strategic protection only as a firm level variable on appropriability (PROTstrat), while legal protection is used only as an industry variable. The industry average captures the technology and market characteristics that determine the effectiveness of the legal appropriability regime of the industry (IndPROTleg).

4.3. The model specification

Our basic equation on CPuniv to be estimated includes the following set of right hand side variables:

$$X_{\mathrm{BASE}}^{\mathrm{CPuniv}} = \{\mathrm{SIZE},\ \mathrm{FOR},\ \mathrm{COST},\ \mathrm{RISK},\ \mathrm{PROTstrat},\ \mathrm{IndPROTleg},\ \mathrm{IndCPuniv}\} \tag{1}$$

To check the impact of complementary innovation activities we extend the basic set of control variables (1) with INTSourcing and the two external sourcing strategies: sourcing of publicly available information (PUBSourcing) and cooperation with vertically related companies (CPvert). Using a complementary innovation activity should stimulate

[18] The problem with the measure for econometric purposes is its low variance, since almost all firms in our sample indicate internal sources to be important. An alternative question, namely whether firms were engaged in own R&D activities, allowed to construct a dummy variable. But since all firms that cooperated with universities scored positively on this dummy, we could not use this information. Similarly, the question on the presence of *permanent* R&D activities only yielded 5 non-positive observations.

[19] We did not include cooperation with competitors, since we had too little positive observations here.

cooperation with universities.[20] Therefore, we expect a positive effect of these (instrumented) strategies in the probit for CPuniv.

$$X_{\text{EXT}}^{\text{CPuniv}} = \left\{X_{\text{BASE}}^{\text{CPuniv}}, \text{INTSourcing}, \ \text{PUBSourcing and CPvert}\right\}. \tag{2}$$

Because of complementarity, the innovation activities INTSourcing, PUBSourcing and CPvert are unlikely to be exogenous. Therefore, when included in the regression for CPuniv, they will be correlated with the error term, whenever we have not been able to include all common drivers of these innovation activities in the set of independent variables for CPuniv. Moreover, this correlation could occur only because of common measurement error or omitted variable bias. To tackle this problem we will use an instrumental variables estimation procedure. We regress the complementary strategies on a set of *assumed* exogenous variables and instruments in a first step. In the second step, we use the predicted values of the complementary strategy variables as independent variables in the probit estimation of the cooperation decision with universities (see also Maddala, 1983):[21]

$$X^{\text{INTSourcing}} = \left\{\text{OBSTEXTERNAL}, \ \text{OBSTRESOURCE}, \ \text{IndINTsourcing}, X_{\text{BASE}}^{\text{CPuniv}}\right\} \tag{3}$$

$$X^{\text{PUBSourcing}} = \left\{\text{BASICRD}, \ \text{IndPUBsourcing}, \ X_{\text{BASE}}^{\text{CPuniv}}\right\} \tag{4}$$

$$X^{\text{CPvert}} = \left\{\text{TECH}, \ \text{IndCPvert}, \ X_{\text{BASE}}^{\text{CPuniv}}\right\} \tag{5}$$

Included as specific instruments for the complementary strategies are the industry averages for each of the endogenous innovation activities (IndINTsourcing, IndPUBsourcing, IndCPvert). We assume that each of these industry averages picks up the effects of unobserved industry-specific attributes that contribute to that endogenous firm-specific variable.

When instrumenting for INTSourcing, we include in addition to IndINTsourcing, obstacles that are preventing firms from innovating: lack of internal resources and information OBSTEXTERNAL, and lack of external resources OBSTRESOURCE.[22]

It is often argued that generic research diffuses more easily (Vonortas, 1994; Kamien and Zang, 2000). Hence, firms that find sources of basic R&D more important for their innovation process, relative to information sources of applied R&D, are more likely to benefit from free public information and hence are expected to have a higher score on PUBSourcing. The variable BasicRD measures the importance for the innovation process of information from research institutes and universities relative to the importance of

[20] Since we are only interested in assessing the impact of complementary strategies on the probability of cooperative agreements with universities, we will not be testing complementarity as such. See Cassiman and Veugelers (2004) for testing complementarity between innovation activities, using information on performance.

[21] The ivprob-STATA program estimates the endogenous variables as a linear function of the exogeneous and instrumental variables and corrects the second step standard errors. The procedure, thus, avoids inconsistent estimates for the second step estimation in the case of cooperation with suppliers and customers, which is a dichotomous endogenous variable in a probit equation (Heckman and Macurdy, 1985).

[22] For a full specification of the instruments, see also Tables A1 and A2 in the Appendix.

suppliers and customers as an information source. We use this variable to proxy for the "basicness" of R&D performed by the firm (see also Mohnen and Hoareau, 2003).[23] For PUBSourcing the literature seems to suggest that absorptive capacity through internal technological capabilities is important to optimally benefit from external information flows. This effect should be captured by our assumed exogenous measure for absorptive capacity: firm size.

As specific instruments for vertical cooperation, we include next to our industry measure for vertical cooperation, IndCPvert, a measure for the lack of technological information as an obstacle to innovation, TECH. This variable measures the absence of potential for synergies in cooperative agreements and should work negatively on the likelihood to cooperate. In contrast to cooperation with universities, appropriation is a key issue when dealing with more commercially sensitive information in vertical cooperative agreements (see Cassiman and Veugelers, 2002). Hence our measures for appropriation on the firm and industry level are expected to affect CPvert differently compared to CPuniv. Also for CPvert absorptive capacity is important, captured by our assumed exogenous firm size measure.

Finally, we use the Heckman correction procedure for sample selection, specifically designed for probit equations. We include as right hand side variables for the innovation equation, SIZE, FOR, COST from Eq. (1) and as specific identifiers, various barriers to innovate as identified by the responding firms: OBSTMARKET, OBSTTECHNOLOGY OBSTEXTERNAL, OBSTRESOURCE, the firm's export intensity and finally industry dummies.[24]

4.4. The results

Table 1 first presents some descriptive statistics. In panel (A) the mean values of all basic right hand variables (1) are significantly higher for firms cooperating with universities than for firms without similar cooperative R&D agreements. Larger firms, firms with foreign ownership and those impeded by cost constraints, have a higher frequency of cooperating with science. This holds also for firms that are better able to appropriate the returns from innovation, but not for firms facing a higher risk, where there is no significant difference. Panel (B) also confirms the industry specific nature of industry science cooperation with especially firms in Chemicals and Pharmaceuticals the most inclined to cooperate with universities. Finally panel (C) reinforces the result on the size effect in more detail.

As suggested by our hypothesis of complementarity with other innovation activities, the mean importance of INTsourcing, PUBsourcing and CPvert is significantly higher for firms cooperating with universities compared to firms without these cooperative agreements [see Table 1, panel (A)]. Further evidence consistent with complementarity among innovation activities is offered by examining the correlation between these

[23] This is one of the variables that is likely to be endogeneous, but since the purpose of this paper is to study the decision to cooperate and the drivers of external knowledge flows, we will assume that the research approach chosen by the firm, i.e. the relative mix between basic and applied research, is exogenous.

[24] We have tried various alternative specifications of the selection equation, but all lead to the same conclusions. See Veugelers and Cassiman (1999) for a more elaborate analysis of the determinants of the innovation decision.

Table 1
Descriptive statistics

Panel (A): basic descriptives of firms with and without cooperative agreements

	Mean if CPuniv=0	Mean if CPuniv=1
SIZE***	4.81 (1.48)	6.19 (1.43)
FOR***	0.32 (0.47)	0.51 (0.50)
COST**	0.47 (0.20)	0.51 (0.19)
RISK	0.48 (0.29)	0.46 (0.25)
PROTstrat***	3.21 (1.00)	3.57 (0.62)
IndPROTleg***	1.85 (0.30)	2.04 (0.33)
INTsourcing***	3.79 (0.97)	4.16 (0.71)
PUBsourcing***	2.76 (0.73)	3.16 (0.63)
CPvert***	0.20 (0.40)	0.64 (0.48)

Panel (B): cooperative agreements by industry

Sector	Nace	*N*	% firms with CPuniv=1 (%)
Steel and mineral	22+23+24	28	28.5
Chemicals and pharma	25+26	39	56
Metals and metal products	31	35	17
Machinery and instruments	32+37	31	22.5
Electronics	33+34	29	34
Transport	35+36	17	41
Food and beverages	41+42	41	32
Textiles and clothing	43+44+45	41	12
Wood and paper	46+47	44	4.5
Total		325	27

Panel (C): cooperative agreements by firm size

Size class (employment)	*N*	% firms with CPuniv=1 (%)
<25	43	7
25–100	74	12
100–250	60	17
250–500	68	31
500–1000	35	46
>1000	45	62
Total	325	27

different innovation activities. Table 2 reveals that all these innovation activities are significantly positively correlated.

Table 3 presents the results from the probit regressions on CPuniv. Regression (1) shows our base regression without accounting for any complementary innovation activities. As expected and in accordance with previous studies, SIZE positively and highly significantly affects the likelihood of cooperating with universities. Foreign ownership, FOR, has a negative effect on cooperation with universities, once corrected for other characteristics. Our results therefore seem to suggest that foreign subsidiaries located in Belgium are less likely to be involved in ISL, all else equal. This is consistent with the view that they are typically involved in the more applied R&D activities while the basic R&D activities that are most associated with *ISLs*, are located abroad at the central R&D

Table 2
Pairwise correlations between innovation activities

	Cpuniv	CPvert	INTsourcing	PUBsourcing
CPuniv	1			
CPvert	0.42[a]	1		
INTsourcing	0.18[a]	0.11[b]	1	
PUBsourcing	0.25[a]	0.24[a]	0.24[a]	1

[a] Correlations significant at 1%.
[b] Correlations significant at 5%.

department.[25] The negative effect is however only significant at the 10% level and not very robust across specifications.

When costs are an important obstacle to innovation, innovating firms have a significant higher probability of engaging in cooperative agreements with universities (COST), which often offer the advantage of receiving government subsidies. While cost-sharing seems to be an important driver for ISL cooperation, risk-sharing is not. Firms for which risk is an important barrier to innovate are actually less likely to cooperate with universities (RISK). This result is consistent with the transaction cost perspective that higher risk makes it more difficult to specify and enforce contracts.

The results do not provide support for appropriation to preoccupy firms when cooperating with universities. Strategic protection at the firm level does not affect significantly the likelihood of engaging in cooperation with universities (PROTstrat). The industry level variable IndPROTleg is significantly positive, suggesting that a more efficient patent protection system clears the way for ISLs. The effect is however only significant at the 10% level and not very robust across specifications. Finally, the industry level variable IndCPuniv, which proxies for the science-based nature of the industry is highly significant.[26,27]

As we only have information for those firms that are innovation active, the coefficients in the CPuniv regression might be inconsistently estimated because of sample selection. Regression (2) corrects for sample selection following a two-stage Heckman correction procedure appropriate in the case of a probit regression. The absence of sample selection cannot be rejected by the data and our estimates are affected little by this selection.

In the following regressions we include different complementary innovation activities sequentially. We start with internal information sources as a proxy for own R&D capacity (INTsourcing) (3). Confirming previous studies, own R&D capacity positively affects the decision to cooperate with universities, although this is only significant at 10%. Correcting

[25] See Veugelers and Cassiman (2002) for a more elaborate analysis of the innovative strategies of foreign affiliates in Belgium.

[26] Including in the base specification industry dummies rather than IndCPuniv gives similar results on the base variables, except that IndPROTleg looses significance already in the base specification. The specification with IndCPuniv performed slightly better than the industry dummy specification in terms of overall explanatory power. When including both IndCPuniv and the industry dummies, it is only IndCPuniv which is highly significant while the industry dummies loose significance.

[27] Not surprisingly, the highest industry dummy coefficient shows up for the chemicals and pharmaceutical sector. Our results are not driven by the Pharmaceuticals sector, since we found little changes in the point estimates when adding a Pharma dummy variable or dropping the Pharma cases (8 observations).

Table 3
Probit regressions Cpuniv

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SIZE	0.418*** (0.072)	0.454*** (0.082)	0.405*** (0.073)	0.436*** (0.081)	0.392*** (0.073)	0.198 (0.127)	0.326*** (0.077)	0.393 (0.294)
FOR	−0.367* (0.202)	−0.345* (0.203)	−0.338* (0.205)	−0.339 (0.212)	−0.343* (0.204)	−0.318 (0.311)	−0.353* (0.214)	−0.506 (0.416)
COST	1.257** (0.570)	1.231** (0.565)	1.226** (0.576)	1.298** (0.602)	1.240** (0.576)	1.004 (0.841)	1.164** (0.589)	1.431 (1.100)
RISK	−1.132*** (0.410)	−1.092*** (0.413)	−1.163*** (0.414)	−1.116*** (0.428)	−1.260*** (0.418)	−2.305*** (0.707)	−1.161*** (0.432)	−2.900*** (0.984)
PROTstrat	0.137 (0.113)	0.135 (0.113)	0.086 (0.118)	0.198 (0.162)	0.072 (0.118)	−0.355 (0.228)	0.042 (0.122)	−0.330 (0.292)
IndPROTleg	0.607* (0.337)	0.587* (0.335)	0.571* (0.340)	0.645* (0.362)	0.500 (0.344)	−0.470 (0.625)	0.387 (0.356)	−0.405 (0.831)
IndCPuniv	2.719*** (0.648)	2.700*** (0.648)	2.777*** (0.653)	2.546*** (0.710)	2.742*** (0.656)	3.258*** (1.015)	2.834*** (0.681)	4.269*** (1.430)
INTsourcing	–	–	0.186* (0.108)	−0.267 (0.448)	–	–	–	–
PUBsourcing	–	–	–	–	0.311** (0.143)	2.821*** (0.937)	0.245* (0.148)	3.436*** (1.176)
CPvert	–	–	–	–	–	–	0.780*** (0.189)	−2.420 (2.835)
Constant	−5.270*** (0.849)	−5.508*** (0.939)	−5.683*** (0.891)	−4.589*** (1.357)	−5.563*** (0.871)	−8.092*** (1.501)	−5.033*** (0.898)	−10.465*** (2.931)
	χ^2=105.18***	LL=−358.02***	χ^2=108.38***		χ^2=110.0***		χ^2=127.1***	
	LL=−136.2	N=480	LL=−134.68		LL=−133.79		LL=−125.23	
	N=325	159 censored	N=325		N=325		N=325	
		321 uncensored						
		ρ=0.291 (0.52)						

* Significant at 10 percent.

** Significant at 5 percent.

*** Significant at 1 percent.

for potential endogeneity, we find that there is no significant effect of own R&D capacity [regression (4)].[28] A problem is the poor measure we are using for internal R&D capacity, INTsourcing, which furthermore seems to be poorly instrumented.[29] Given the poor explanatory power, in the subsequent regressions, we therefore no longer include INTsourcing.[30] Note, however, that SIZE and PROTstrat are highly significant when instrumenting INTsourcing. Furthermore, SIZE continues to be a significant right hand side variable for CPvert in (4). Being a more continuous, correlated measure, SIZE rather than INTsourcing might be a better measure for absorptive capacity in our sample.

In regression (5)–(8) we add two other external sourcing strategies: PUBsourcing and CPvert to our base regression. The importance of publicly available information for the innovation process, PUBsourcing, is positively and significantly related with cooperation with universities [see regression (5)]. This result suggests complementarity between the different innovation activities. Obviously, this variable is plagued by endogeneity. When correcting for endogeneity in regression (6), the importance of PUBsourcing increases in significance. As Table A2 in the Appendix indicates, the specific instruments for PUBsourcing (BASICRD and IndPUBsourcing) are all significant and the overall explanatory power is higher than for the other complementary strategies. Note that also SIZE and PROTstrat is highly significant in explaining PUBsourcing, and that SIZE looses its significance in the corrected regression (6) for CPuniv.

Next to public sourcing, also cooperative agreements with customers and suppliers, CPvert, are found to be positively and highly significantly related with cooperation with universities [see regression (7)]. When we correct for endogeneity for the complementary strategies in (8), the effect of vertical cooperation no longer is significant and even negative. Again Table A2 in the Appendix indicates the poor predictive power of the first step regression for CPvert. In the absence of a good explanatory model, the predicted CPvert in Table 3 [regression (8)] is therefore a weak instrument, failing to provide any conclusive evidence on the impact of this complementary strategy.[31] An interesting result, nevertheless, is the positive and significant effect of SIZE and strategic protection PROTstrat for vertical cooperation in Table A2 in the Appendix, as was the case for the other complementary strategy PUBsourcing. All this seems to suggest that SIZE and PROTstrat are common drivers of the various innovation strategies, a result more thoroughly developed in Cassiman and Veugelers (2002).

While appropriation did not seem to affect the decision to cooperate with universities, the regressions for cooperative agreements with clients and suppliers, indicate that for the more applied R&D agreements with customers and suppliers, firms do take into consideration the potential loss of appropriability before engaging in such an agreement. This difference in results illustrates the importance of an open information environment in which cooperative agreements with universities take place, in contrast with other inter-firm cooperative agreements.

[28] See Table A2 in the Appendix for the instruments used. Alternative specifications gave very similar, insignificant, results.

[29] Although all specific instruments for INTsourcing are highly significant, the overall R2 for the INTsourcing first stage regression is low. (see Table A2 in the Appendix for the first step results).

[30] Reported results are not sensitive towards including INTsourcing or not.

[31] Again, alternative specifications gave very similar, insignificant, results.

5. Conclusions

This paper studies the demand side for Industry Science Links and more particularly which firms are more likely to be engaged in cooperative agreements in R&D with universities. We present an econometric analysis on the firm and industry characteristics most favourable to cooperation with universities, using EUROSTAT/CIS I data from Belgian manufacturing firms.

In line with previous studies, the results confirm the strong industry effect in industry science links, which tend to be agglomerated in specific science-based industries, most notably in chemicals and pharmaceuticals. In addition, firms impeded by costs to innovate are more likely to cooperate with universities, attracted by the often government subsidized cost-sharing in public–private partnerships. However risk sharing was not found to be associated with cooperation with universities. This could be related to the higher transaction costs for cooperative agreements in highly uncertain R&D projects. Furthermore, although only marginally significant, firms with foreign headquarters are less likely to be actively involved in industry science links in Belgium. Not surprisingly, we also find large firms to be more likely to have cooperative agreements with universities. Firm size may be related to the presence of the necessary resources to efficiently implement cooperation with scientific institutes as part of the innovation strategy of the firm. In the absence of a good proxy in our sample for own R&D capacity, firm size seems to be the better measure for absorptive capacity.

In line with the Industrial Organisation theory models on R&D cooperation, we also examine the impact of appropriation of know-how on the incentives to engage in R&D cooperation with universities. We find that a firm's capacity to effectively protect the returns from innovations is not a significant factor for cooperation with universities. This contrasts with other complementary external sourcing strategies, where the effectiveness of strategic protection mechanisms turned out to be a significant factor. The results are therefore consistent with the importance of a perspective of open, non-exclusive exchange when cooperating with scientists in basic exploratory cooperative research.

Finally, our study takes into account that cooperative agreements with universities are typically embedded in a wider innovation strategy of the firm. We find evidence consistent with a complementary relationship between cooperating with universities, and a sourcing strategy that uses public information as important information source for innovation. Likewise the data suggest positive correlation with other cooperative agreements with suppliers and customers, but we are not able to adequately instrument for this complementary strategy. A reason for the weak statistical significance lies in the two-stage method, adopted to control for endogeneity of the complementary strategies, which are often found to have multicollinearity problems as suggested by Maddala (1983). The complementary strategies do not seem to be fully controlled by the adopted instruments and other control variables. Hence there remains considerable measurement error and omitted variable bias. The analysis of the complementary innovation strategies nevertheless suggests that firms need to have internal absorptive and appropriation capacity for being able to exploit complementary strategies.

Overall the results seem to suggest that the low frequency of cooperative agreements with universities in Belgian manufacturing may be related to an industry structure that is focused on non-science based industries, characterized by a high share of small and medium sized firms, whose portfolio of R&D strategies is limited. Our results suggest some new avenues for S and T policy aimed at improving Industry Science Links from the industry's perspective. Beyond the classic subsidies for R&D cooperation with universities in order to reduce the financial risks for firms, policy makers should also consider ensuring the framework conditions for firms to develop a wider portfolio of innovation activities, such as other public sourcing strategies, which, in view of complementary, would stimulate firms to engage in cooperation with universities.

Our statistical results on the importance of assessing complementary innovation strategies for cooperation with universities, while consistent, are unfortunately not sufficiently strong to really confirm our claims. Hence, before we can translate these results into strong policy conclusions, we need more robust empirical results. Further research is needed both empirically and theoretically. Empirical work, replicating the results across countries and across time is needed. With the CIS methodology still maturing within EUROSTAT, more standardization across country and time will eventually emerge. This will permit more robust cross-country comparisons which would allow testing for the effect of different country conditions for industry-science cooperation. Cross time panel data analysis may provide more scope than the current cross-section approach for better instrumenting the complementary innovative strategies. But perhaps more importantly, we also need new insights from theory to better assess which capacities the firms need to master in-house to effectively engage in cooperation with science. This would allow finding better proxies for firm innovative capabilities and better controls for complementarity among innovation activities. Finally, the analysis should be extended beyond whether cooperation occurs or not, towards assessing the efficiency of such cooperation, and its impact on innovative performance and growth. We hope with this research to have incited future research on industry–science cooperation to properly account for the effect of other complementary innovation strategies.

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Appendix A.

Table A1
The variables

Dependent variables	
CPuniv	CPuniv = 1, if firms cooperate with Universities.
CPvert	CPvert = 1, if firms cooperate with (1) Suppliers, or, (2) Customers.
INTsourcing	Importance of internal information sources of the firm for innovation [number between 1 (unimportant) and 5 (crucial)].
PUBsourcing	Mean score of importance of following information sources for innovation process [number between 1 (unimportant) and 5 (crucial)]: (1) patent information, (2) specialized conferences, meetings and publications, (3) trade shows and seminars.
Independent variables [Base specification (1)]	
Size	Natural logarithm of number of employees in 1992 in 10.000.
FOR	FOR = 1, if the firm has foreign headquarters.
COST	Sum of scores of importance of following obstacles to innovation process [number between 1 (unimportant) and 5 (crucial)]: (1) no suitable financing available, (2) high costs of innovation, (3) pay-back period too long, (4) innovation cost hard to control. (rescaled between 0 and 1).
RISK	Importance of high risks as an obstacle to innovation [number between 1 (unimportant) and 5 (crucial), rescaled between 0 and 1].
PROTstrat	Average measure of effectiveness of secrecy, complexity and/or lead time as a protection measure of innovation [on scale 1 (unimportant) to 5 (crucial)].
IndProtleg	Average measure of effectiveness of patents or registration of brands as protection measure of innovation [on scale 1 (unimportant) to 5 (crucial)].
IndCPuniv	Mean of CPuniv at industry level. Industry level is defined at 2/3-digit NACE. Industries are steel, minerals, chemicals, pharmaceuticals, metals, machinery, electrics and electronics, ICT, electrical appliances, transportation equipment, precision equipment, food and beverages, textiles and clothing, wood and paper, rubber, other.
Specific instrumental variables INTsourcing: see specification (3)	
OBSTEXTERNAL	Mean of score of scores on Importance of lack of external technical services, lack of cooperation opportunities with other companies, and, lack of technological opportunities.
OBSTRESOURCE	Mean of score of scores on Importance of lack of innovation personnel, lack of technical personnel, lack of information about technologies, and, lack of market information as barrier to innovation [on scale 1 (unimportant) to 5 (crucial)].
IndINTsourcing	Mean of INTsourcing at industry level. Industry level is defined at 2/3-digit NACE, cf supra.
Instrumental variables PUBsourcing: see specification (4)	
BASICRD	Measure of importance for the innovation process of information from research institutes and universities relative to the importance of suppliers and customers as an information source.

(continued on next page)

Table A1 (*continued*)

Instrumental variables PUBsourcing: see specification (4)	
IndPUBsourcing	Mean of PUBsourcing at industry level. Industry level is defined at 2/3-digit NACE, cf supra.
Specific instrumental variables Cpvert: see specification (5)	
TECH	Importance of lack of technological information as an obstacle to innovation, [number between 1 (unimportant) and 5 (crucial), rescaled between 0 and 1)].
IndCPvert	Mean of CPvert at industry level. Industry level is defined at 2/3-digit NACE, cf supra.
Specific instrumental variables Heckman correction for INNOV	
EXP	Export intensity = sales from exports/total sales.
OBSTMARKET	Importance of lack of market information as a barrier to innovation [on scale 1 (unimportant) to 5 (crucial)].
OBSTTECHNOLOGY	Importance of lack of technological opportunities as barrier to innovation [on scale 1 (unimportant) to 5 (crucial)].
Industry dummies	Steel, mineral, chemicals and pharmaceuticals, metal, machinery, transportation equipment, food and beverages, textiles, rubber.

Table A2
Correction for selection bias and endogeneity

	(0) INNOV	(1) INTsourcing	(2) PUBsourcing	(3) CPvert
SIZE	0.327*** (0.059)	0.094** (0.036)	0.073*** (0.027)	0.088*** (0.018)
FOR	0.064 (0.199)	0.037 (0.117)	−0.024 (0.087)	−0.062 (0.058)
COST	0.851** (0.362)	0.158 (0.316)	0.048 (0.225)	0.188 (0.153)
RISK		0.083 (0.212)	0.448*** (0.160)	−0.090 (0.107)
PROTstrat		0.195*** (0.056)	0.166*** (0.041)	0.057** (0.027)
IndPROTleg		−0.067 (0.220)	0.167 (0.188)	0.076 (0.128)
IndCPuniv		−0.405 (0.371)	−0.407 (0.291)	−0.078 (0.247)
EXP	0.007*** (0.002)	–	–	–
OBSTTECHNOLOGY	−0.261** (0.102)	–	–	–
OBSTMARKET	−0.177*** (0.067)	–	–	–
OBSTEXTERNAL	−0.083 (0.146)	−0.205*** (0.076)	–	–
OBSTRESOURCE	0.317*** (0.108)	0.220*** (0.077)	–	–
IndINTsourcing		0.902*** (0.303)	–	–
BASICRD		–	0.489*** (0.134)	−0.012 (0.089)
IndPUBsourcing		–	0.640* (0.355)	0.110 (0.297)
TECH		–	–	−0.154 (0.109)
IndCPvert		–	–	0.556 (0.411)
Constant	−1.367*** (0.345)	−0.731 (1.021)	−0.654 (0.788)	−0.891 (0.659)
	Plus industry dummies	$F(10,314)=6.2$***	$F(9,315)=10.72$***	$F(11,313)=6.65$***
		Adj $R^2=0.14$	Adj $R^2=0.21$	Adj $R^2=0.16$
		$N=325$	$N=325$	$N=325$

Results on innovation selection from Heckman correction (0).
First stage results on endogeneous variables (1–3).

* Significant at 10 percent.
** Significant at 5 percent.
*** Significant at 1 percent.

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