R&D COOPERATION AND SPILLOVERS:
SOME EMPIRICAL EVIDENCE

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RESEARCH PAPER No 430
January, 2001

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Abstract

Different aspects of external information flows have typically been lumped together under the name "spillovers". We attempt to refine our understanding of external information flows through the construction of firm-specific measures of *incoming spillovers and appropriability* from survey data on Belgian manufacturing firms. *Incoming spillovers* measure the importance of publicly available information for the innovation process of the firm. *Appropriability* is defined as the effectiveness of several protection mechanisms for appropriating the benefits of successful innovations. The importance of this distinction between incoming spillovers and appropriability is revealed when contrasting their effects on different types of cooperative agreements. The decision to cooperate with *research institutes* is mainly affected by the level of incoming spillovers, while appropriability plays an important role for *cooperating with suppliers or customers.*

JEL: D21, L13, O31, O32.
Keywords: Research and Development; Cooperation; Spillovers; Appropriability

* The authors would like to thank Gary Charness, James Costain, Raymond De Bondt, Paul Geroski, Mort Kamien, Steve Martin, Marno Verbeek and, especially, an anonymous referee for their very helpful comments as well as the seminar participants at the London Business School, IESE Business School, Universidad Carlos III, Universitat Autonoma de Barcelona, Universidad de Zaragoza, Universidad Publica de Navarra, the Catholic University of Leuven and Paris I and Paris XII, and the participants in ASSET (Bologna), LASEM (Cancun) and EARIE (Turin). The DWTC and IWT generously provided the data for this research. The first author acknowledges support from DGES PB96-0302 and CIRIT 1997SGR00138, the second author from CNRS, Enjeux Economiques de l'Innovation and NFWO (G.0131.98). The paper was to a large extent written while the first author was assistant professor at the Universitat Pompeu Fabra in Barcelona and the second author was visiting the Universitat Autonoma de Barcelona and MIT (Sloan School (ICRMOT)).

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I. Introduction

Successful innovation depends on the development and integration of new knowledge in the innovation process. Part of this knowledge will reach the firm from external sources. Several authors have documented the existence of these external information flows and have commented on their importance for decisions at the firm level (Jaffe, 1986; Bernstein and Nadiri, 1988, 1989) and ultimately for economic growth (Romer, 1986, 1990; Krugman, 1991; Grossman and Helpman, 1991; Griliches, 1992). One challenge facing this literature has been the measurement of these information flows or "spillovers" between firms and gauging their effect on different innovation management decisions by the firm. The contribution of this paper is twofold. First, we attempt to clarify the concept of spillovers and their measurement. The second contribution of this paper is that we use measures of spillovers to empirically analyze the decision of firms to engage in cooperative agreements in R&D.

In order to clarify the concept of spillovers, one needs to distinguish between different measures of these *spillovers*. On the one hand, there are measures of the importance of external information flows for the rate of success of the firm's innovation process. These information sources are typically situated in the public domain and their usefulness to the firm depends on the firm's ability to generate *incoming spillovers* from this general pool of knowledge. Many things can be measured here: the total pool of external knowledge that is potentially available, the fraction of this pool that is accessible and relevant to the firm, the know-how that is effectively absorbed and used within the firm, or the effectiveness of this absorbed knowledge for the firm's innovative performance. On the other hand, firms attempt to appropriate the benefits of their innovations by controlling the information flows out of the company into the pool of publicly available information. The success of a firm's innovation strategy not only depends on the success of its innovation process, but is also a function of how proficient the firm is at appropriating any benefits from its successful innovation process. Typically, the protected information is commercially sensitive and the success or profitability of a firm's innovation strategy crucially depends on legal and strategic measures of protection to restrict these *outgoing spillovers*. Here as well different measures are possible: the usefulness and/or degree of difficulty to a firm of protecting its own knowledge, the fraction of know-how it can keep proprietary, the potential economic returns to a given firm's own knowledge that it manages to appropriate, or the potential social returns from the non-appropriated knowledge.

Throughout the paper, we will distinguish between incoming spillovers, which affect the rate of innovation of the firm, and outgoing spillovers which affect the ability of the firm to appropriate the returns from innovation. We will explore a direct measure of *incoming spillovers*, as measured by the importance of publicly available information for the innovation process of the firm, obtained from survey data on Belgian manufacturing firms. Alternative measures of incoming spillovers used in the literature require the construction of a pool of available and relevant knowledge (o.a. Jaffe (1986)). The estimated effect of this pool of available knowledge on the firm's decision variables is then the spillover effect. The advantage of our measure is that it avoids the construction of a pool of available knowledge by jointly measuring the extent of the pool of relevant knowledge and its productivity for the firm's innovation process.

Using the same survey data, we can also construct a direct measure of *appropriability* which rates the effectiveness of different mechanisms for protecting the innovations of the firm. Alternatively, one could use regression analysis to calculate the average gap between private and social rates of return (Bernstein and Nadiri, 1989). But as mentioned before, this requires the construction of a pool of general knowledge relevant to the firm. The advantage of our measure of appropriability is that it is direct and firm-specific. The disadvantage of both our measures of incoming spillovers and appropriability is that their construction relies on qualitative firm-level data, which requires the necessary caution in interpretation.

The second contribution of this paper is that we use these measures of incoming spillovers and appropriation to analyze their impact on the decision of firms to engage in cooperative R&D. The pervasiveness of cooperative agreements in R&D has become a significant feature in current innovation management practice. It offers firms more efficient access to new external information and allows them to integrate this information more effectively into their innovation process. However, cooperation in R&D carries more risks with respect to the loss of commercially sensitive information and hence might diminish the firm's ability to appropriate the benefits of successful innovations. To the best of our knowledge, this is the first study that empirically investigates the relation between cooperation in R&D and spillovers. This is surprising given the extensive theoretical literature which focuses on this relationship.

We find that there is indeed a significant correlation between external information flows and the decision to cooperate in R&D. Firms that rate generally available external information sources as more important inputs to their innovation process—the *incoming spillovers*—are more likely to be actively engaged in cooperative R&D agreements. At the same time, firms that are more effective in appropriating the results from their innovation process are also more likely to cooperate in R&D. The importance of distinguishing between measures of incoming spillovers and appropriability becomes even more apparent when analyzing the type of partner with which firms cooperate. Higher incoming spillovers positively affect the probability of cooperating with research institutes such as universities and public or private research labs, but have no effect on cooperation with customers or suppliers. Firms who find the publicly available pool of knowledge more important for their innovation process are more likely to benefit from cooperative agreements with other research institutes. Better appropriability of results of the innovation process, however, increases the probability of cooperating with customers or suppliers and is unrelated to cooperative agreements with research institutes. Commercially sensitive information, which is the result of these more 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.

Furthermore, we find evidence for a reverse effect of cooperation in R&D on incoming spillovers and appropriability. This effect, again, only becomes apparent when distinguishing between different types of cooperative R&D agreements. Cooperative agreements between research partners increase the usefulness of the publicly available pool of knowledge and the effectiveness of appropriation mechanisms for the firm's innovation process. Cooperative agreements with suppliers or customers, however, reduce the effectiveness of strategic protection measures. This suggests that the commercially sensitive information that firms might disseminate indirectly through cooperative agreements with suppliers and customers could be detrimental to the efforts of the firm to appropriate the returns from its innovation process. Hence, firms should take care to protect their proprietary information before engaging in these types of agreements. Our results, therefore, strongly suggest that the level of knowledge in- and outflows is not, as assumed in much of the theoretical literature, exogenous to the firm. But through their innovation activities, firms affect their incoming spillovers and appropriation capabilities.

In the next section we discuss the theoretical issues related to external information flows and cooperation in R&D; we describe the data and set up an empirical model to analyze the relationship between the decision to cooperate and spillovers. Section 3 presents the results of our analysis and section 4 concludes.

II. R&D Cooperation and Spillovers

Issues

The relationship between different knowledge flows –spillovers– and cooperation is complex. The theoretical literature has mainly focused on the effect of imperfect appropriability of results from the innovation process on the incentives to innovate, when the firm cooperates in R&D. On the one hand, imperfect appropriability increases the benefits from cooperative R&D agreements. Firms that cooperate in R&D choose their R&D investments to jointly maximize profits. Hence, cooperation in R&D internalizes the positive externality created by involuntary knowledge transfers and investment in R&D is increasing in the level of the spillover. When spillovers are high enough, i.e. above a critical level, cooperating firms will spend more on R&D and are increasingly more profitable compared to non-cooperating firms (d'Aspremont and Jacquemin, 1988; Kamien, Muller and Zang, 1992). On the other hand, imperfect appropriability increases the incentive of firms to free ride on each other's R&D investments. First, partners may conceal their technological expertise while trying to absorb as much of the partner's knowledge as possible (e.g. Shapiro and Willig, 1990; Baumol, 1993; Kesteloot and Veugelers, 1994). Higher spillover levels increase partners' potential benefits from cheating. The second free riding problem results from firms that remain outside the cooperative agreement. Lower appropriability of results encourages free-riding on the R&D efforts of the research joint venture by an outsider to the cooperative agreement (Greenlee and Cassiman, 1999; De Bondt and Wu, 1997). Hence, cooperative ventures not only become more profitable, but also easier to sustain the better firms are at appropriating the benefits of their innovation process.

Imperfect appropriability of innovation results leads to information flows that increase the stock of publicly available knowledge from which other firms draw information for their own innovation process. Firms attempt to manage these incoming information flows. First, they try to increase the extent of incoming spillovers by investing in "absorptive capacity". Cohen and Levinthal (1989) argue that external knowledge is more effective for the innovation process when the firm engages in own R&D. The direct effect of higher absorptive capacity is thus to increase the effectiveness of incoming information. Secondly, a firm might increase its incoming spillovers by voluntarily trading knowledge with partners, as in the research joint venture information sharing scenario of Kamien *et al.* (1992). Increasing the incoming spillovers between research partners is found to increase not only the profitability, but also the stability of cooperation in R&D, since it makes the potential threat of non-sharing harsher (Kesteloot and Veugelers, 1994; Eaton and Eswaran, 1997).

Finally, the choice of research approach by the firm influences the appropriability conditions it faces and the extent of incoming spillovers it enjoys. Kamien and Zang (2000) show that firms that cooperatively choose their R&D expenditures maximize information flows—their *incoming* spillovers—through the choice of very broad research directions for the research joint venture. If the firms cannot coordinate their R&D expenditures, they are more concerned about managing their *outgoing* spillovers by choosing a more narrow research approach which improves appropriability but at the same time limits the usefulness of external information sources for their own innovation process.

In most theoretical models on cooperation in R&D and spillovers, firms generate and receive spillovers to the same extent. Assuming symmetric incoming and outgoing spillovers makes it difficult to model the idea that firms manage these information flows. The aim of managing the external information flows is to maximize the incoming spillovers *from* partners and non-partners, while at the same time minimizing spillovers *to* non-partners and non-loyal partners. In our empirical analysis we will not be concerned with the equilibrium analysis as performed in most of the theoretical work. In the relationship between spillovers and cooperation, we want to highlight the distinction between two measures of knowledge flows, namely *incoming spillovers*, measured as the usefulness of external information as an input for the innovation process, and, *appropriability*, measured as the effectiveness in capturing value from a successful innovation. We allow for heterogeneity among firms along these dimensions. The ability to create incoming spillovers from the general pool of knowledge can be a function of other innovation activities of the firm such as own R&D, participation in cooperative agreements, the type of research the firm engages in, or the technological opportunities in the industry. At the same time, firms that cooperate pay special attention to protecting their proprietary knowledge. The ability to protect valuable information from reaching other firms also depends on the firm's innovation activities such as own R&D, the firm's competitive environment and the appropriability conditions in the industry. But a firm's effectiveness in protecting commercially sensitive information might be reduced by the knowledge flows created through participating in cooperative R&D agreements.

Data

The data used for this study are drawn from the Community Innovation Survey (CIS) conducted in several member states of the European Union in 1993. The survey intended to develop insights into the problems of technological innovation in the manufacturing industry and was the first of its kind organized in many of the participating countries (1). We will restrict attention to the subsample of innovating firms from Belgian manufacturing industry (2). These firms are distinguished from those who do not innovate

(1) A more detailed analysis of these data is reported in Veugelers and Cassiman (1999).

(2) The authors are grateful to DWTC and IWT for providing the data. These organizations were responsible for the collection of the Belgian subsample of the CIS, which was conducted by Eurostat. A representative sample of 1335 Belgian manufacturing firms was selected and a 13-page questionnaire sent out to them. The response rate was higher than 50% (748). The researchers in charge of collecting the data for the CIS also performed a limited non-response analysis and concluded that no systematic biases could be detected (Debackere and Fleurent, 1995).

based on their answers to the questions about whether they innovated between 1990 and 1992. Innovation is defined by introducing new or improved products, or new or improved processes, and, at the same time, firms needed to have specified a positive amount spent on innovation. In the sample, 60% (439) of the firms claim to innovate, while only 40% do not. This number is in line with the survey results from other EU countries (Eurostat, Statistics in Focus, 1996-2). Due to missing values we are left with 411 observations on actively innovating firms. For these firms, the questionnaire provides information that allows to construct measures for both incoming spillovers and appropriability (3).

Incoming spillovers: In the questionnaire, firms rated the importance for their innovation process of publicly available information from three sources on a 5-point Likert scale (from unimportant (1) to crucial (5)). These information sources were: patent information; specialist conferences, meetings and publications; trade shows and seminars. We aggregated these answers by summing the scores on each of these three questions and re-scaled the total score to a number between 0 and 1 to generate a firm-specific measure of incoming spillovers: *INSPILL* (4). To capture the exogenous nature of spillovers, determined by technology or market characteristics, we also construct the average industry score for *INSPILL*: *indINSPILL* (5). The questionnaire thus provides a direct measure of the importance of incoming spillovers for the innovation process. Studies relying on the indirect measurement of incoming spillovers require the construction of a pool of available and relevant knowledge for each firm in the sample. In order to assess which agents benefit more from a given knowledge stock, a measure of "distance" between technology receiver and generator needs to be included. Several approaches are used in the literature: input-output flows (Terleckyj, 1974), technology flows obtained from patent information (6), import or FDI flows for international channels (Coe and Helpman, 1988). Our measure avoids this by jointly measuring the extent of the pool of relevant knowledge and its productivity for the firm's innovation process.

Appropriability: Firms rated the effectiveness of five different methods for protecting products and processes respectively (10 different questions overall) on a 5-point Likert scale (from 1 (unimportant) to 5 (crucial)). The five methods were: patents; brand names and copyright; secrecy; complexity; and lead time. We distinguish between two types of protection: legal protection of products and processes through patents, brand names or copyright, and strategic protection of products and processes through secrecy, complexity or lead time. Again we aggregated answers on each of these questions by summing the scores on each of these questions and rescaled the total score to a number between 0 and 1 to generate a measure of legal and strategic protection. However, we will only use strategic protection, *PROTstrat*, as a firm level variable, assuming that legal protection is an industry, rather than a firm-specific characteristic. The industry averages *indPROTleg* and

(3) Only the innovating firms needed to fill out all questions in the survey. Restricting the sample to innovating firms might lead to sample selection if we believed that cooperation is an important way to innovate for firms that would otherwise not be innovation active. This is unlikely, however, given that all firms that cooperate do have some other innovation strategies, such as own R&D or some form of external knowledge acquisition (see Veugelers and Cassiman (1999)).

(4) See Table A1 in the Appendix for the definition of all variables used. The rescaling of a variable with Likert scores between 1 and 5 to a variable between 0 and 1 is done for each Likert score used in the analysis: rescaled score = (score - 1)/4. This allows the comparison of coefficients.

(5) The industry is defined at the NACE 2 digit sector level and the average is the average score from the firms responding in the sample.

(6) Various approaches have been pursued here: patent information on principal users in the Yale studies, supplementary technology codes in EPO (Verspagen, 1995), clustering techniques (Jaffe, 1986), citations (Jaffe, Henderson and Trajtenberg, 1993).

indPROTstrat capture the technology and market characteristics that determine the appropriability regime of the industry.

From the questionnaire we derive a direct measure of the beliefs of the firm's management about the effectiveness of various mechanisms to protect their innovations. In the literature, there exist two alternative ways of measuring appropriability by way of estimating the gap between private and social rates of return of innovation. Both have their own limitations (see Griliches, 1992). First, one can restrict attention to a specific innovation. This requires intimate knowledge of the innovation to track information flows. The limitation of this type of study is that it is not representative and only considers "important" innovations. Second, the results of regression based studies can be used to calculate the average gap between private and social rates of return for an industry (Bernstein and Nadiri, 1989). But as discussed before, this requires the construction of a pool of general knowledge which is relevant to the firm. The advantage of our measure of appropriability is that it is firm-specific and does not require detailed knowledge of the different innovations of the firm.

Although the use of survey data yields direct firm-specific measures for incoming spillovers and appropriability, it also introduces some subjectivity into the measurement of these firm-specific measures *INSPILL* and *PROTstrat*, which would lead to problems of measurement error. A first potential problem of measurement error is the aggregation of scores of different questions. However, the different questions on the importance of information sources for the innovation process and on the effectiveness of measures of protection were grouped in the same subsection of the questionnaire. Comparing the scores on the different questions should therefore have come naturally to the respondents. Nevertheless, we experimented with different measures and combinations of these variables and all lead to similar results. Second, individual respondents may also differ in their use of the 5-point scale. This would introduce a more serious problem of measurement error (7). Other studies, most notably Cohen and Levinthal (1989) and Levin (1988), have found that including industry means for the qualitative variables reduces the problems of using subjective measures. They use the data of the Yale Survey to construct measures of appropriability at the industry level and these variables have been widely used in related applications (8). However, the beliefs of management about the external environment are what drive a firm's decision about whether or not to engage in a cooperative agreement. As shown below, firm-specific measures capture these effects better than industry specific variables, since they increase the explanatory power of the empirical model considerably. Our data allow for alternative corrections for measurement error, avoiding industry aggregation. We indirectly attempt to control for measurement error problems by regressing *INSPILL* and *PROTstrat* on instruments available in the data set that are assumed to be exogenous and with uncorrelated measurement errors.

Closer examination of our knowledge flow variables, *INSPILL* on the one hand and *PROTstrat* on the other, shows that they do capture different effects. Correlation between *INSPILL* and *PROTstrat* is only 0.21 and there is a lot of variation in the ranking of the industries according to each of our measures (9). As could be expected, the chemical industry

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(7) Unfortunately, our data set lacks a panel structure that would allow for simple fixed firm effect corrections.

(8) See among others: Levin, Cohen and Mowery (1985), Cohen, Levin and Mowery (1987), Levin (1988), Levin and Reiss (1988), Cohen and Levinthal (1989), Klevorick, Levin, Nelson and Winter (1995).

(9) In addition, we performed a principal component analysis on the answers of the thirteen questions used for the construction of *INSPILL*, *PROTleg* and *PROTstrat*. Three principal components explain 60% of the variance and each question loaded most weight on one of the three principal components in line with our constructed measures. Not surprisingly, then, the principal components are strongly correlated with the constructed spillover and appropriability measures. The correlation between our constructed variables and the respective principal components was more than 0.92. We have performed the same analysis using the principal components. The qualitative results do not change, but interpretation is enhanced when using our constructed variables.

ranks high on the importance of incoming spillovers (ranked 2nd out of 19 industries) as well as on the effectiveness of patent protection (ranked 1st), but it is only ranked 8th in strategic protection. The apparel and textile industries score low on all measures. However, there are industries that score high on the importance of incoming spillovers, but low on appropriability such as the electronics industry which is ranked 4th on the importance of incoming spillovers, but only 13th for legal protection and 16th for strategic protection. As for the data of Levin *et al.* (1987), we find that within industry variation in the variables is much more important than between industry variation (see Cockburn and Griliches (1988)). This should not surprise us given the recent observation of substantial within industry heterogeneity of firm characteristics (Haltiwanger et al, 1999).

The cooperation variable: In the questionnaire the firms were asked to reveal whether they had cooperative agreements in R&D and to indicate the type of partners they cooperated with. Cooperation was understood to imply an active participation of the partners in a joint R&D project. We set the variable *COOP* equal to 1 when firms indicated that they had at least one cooperative agreement with any type of partner and 0 otherwise (10). In our data set there are 185 firms that have at least one type of cooperative agreement in R&D. The data also allow us to distinguish different types of cooperative partners: competitors (33), vertically related firms, i.e. suppliers or customers (135) and universities or other research institutes (135) (11). In order to uncover common characteristics of the cooperation decision we first pool the data on cooperative agreements *(COOP)*. Next, we perform our analysis for cooperative agreements with vertical partners *(COOPVERT)* and research institutes *(COOPRES)* separately (12). The nature of the partners is important in understanding the differential effect of incoming spillovers versus appropriability on the decision of firms to cooperate in R&D: incoming spillovers affect the decision to cooperate with research institutes. Appropriability, in contrast, is intimately related to the decision of the firm to cooperate with customers or suppliers.

In Figures 1 and 2 we plot the cumulative distributions of the importance of incoming spillovers for the firm's innovation process *(INSPILL)* and the effectiveness of strategic protection *(PROTstrat)* for cooperating and non-cooperating firms. These figures provide some first indication of the correlation between higher incoming spillovers and more effective protection, and the propensity of firms to cooperate. The cumulative distribution of cooperating firms always lies below the cumulative distribution of the non-cooperating firms, indicating a higher rating of cooperating firms of the importance of incoming spillovers as well as a higher rating on the effectiveness of protection of know-how (13).

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(10) Most studies of the determinants of R&D cooperation use the frequency of occurrence of R&D cooperation to assess which characteristics are more likely to lead to R&D cooperation (Röller *et al.*, 1997; Kleinknecht and Van Reijnen, 1992; Colombo and Gerrone, 1996).

(11) The questionnaire only contains information on whether firms cooperate or not, but not on budgets spent. Several firms do have cooperative agreements with different types of partners. But within one partner category, we have no information on the number of cooperative agreements. Information on the partner is also not available. Therefore, the data do not allow us to identify spillover flows to and from partners versus non-partners in cooperation.

(12) The limited number of cooperative agreements between competitors does not allow us to do a similar analysis with this latter group. However, it is already interesting to note that most of the cooperative agreements are vertical or with research institutes (see Robertson and Gatignon (1998) for similar results). This contrasts with the bulk of the theoretical literature, which mainly analyzes cooperative agreements between competitors.

(13) For eight out of the nine questions used for the construction of the spillover and protection variables, the mean answer for cooperating firms was significantly higher, at the 1% level of significance, than the mean answer for firms that did not cooperate. For the importance of trade shows and seminars the mean answers were not significantly different, although the cooperating firms had a higher mean score.

Figure 1. Cumulative distribution of importance of incoming spillovers for cooperating and noncooperating firms

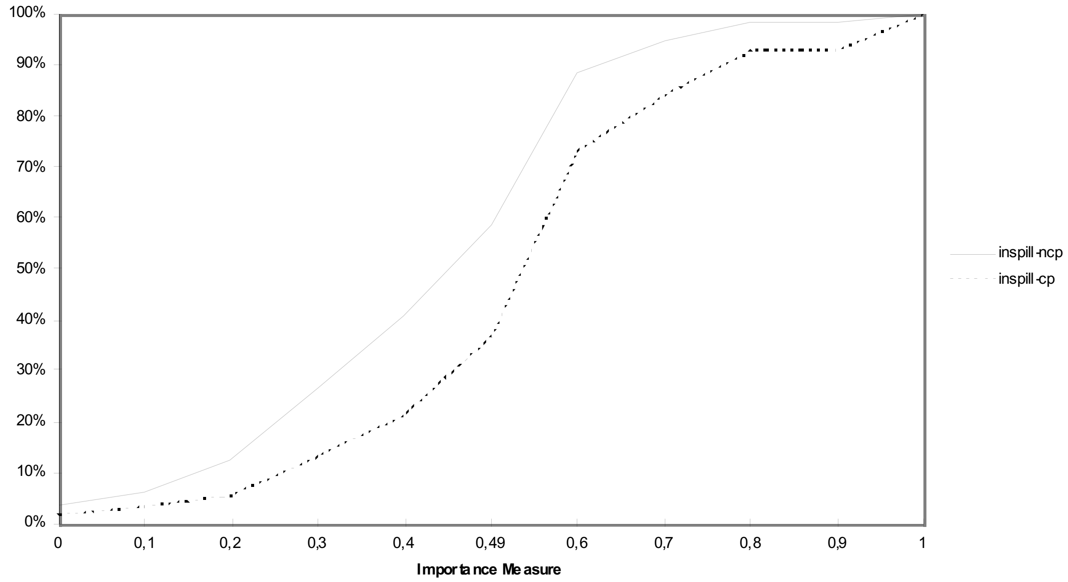
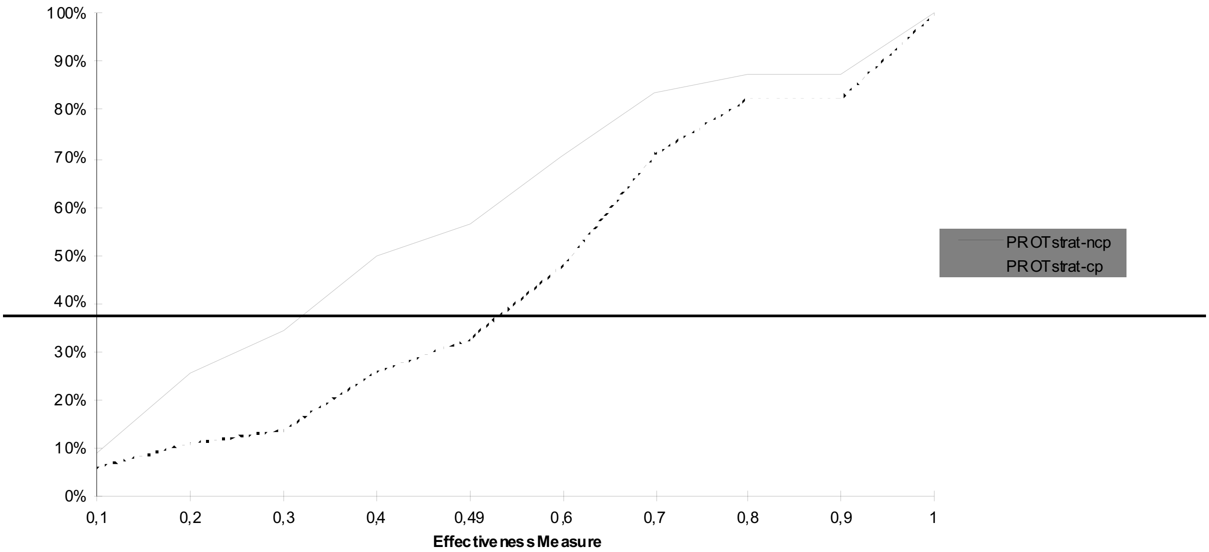


Figure 2. Cumulative distribution of effectiveness of strategic protection for cooperating and noncooperating firms



Model

The focus of the analysis is on the effects of our measures of incoming spillovers *(INSPILL)* and appropriability *(PROTstrat)* on R&D cooperation. Differentiating between incoming spillovers and appropriation will prove particularly important when examining their effect on different types of cooperative agreements. Following the literature, we expect that higher incoming spillovers increase the scope for learning within cooperative R&D agreements. Because of an improved technological competence of the partners, the marginal benefit of forming a research joint venture is higher, implying a higher probability of cooperation. Henderson and Cockburn (1996), in a related paper, show that knowledge flows between research groups in related therapeutical classes are an important determinant of research productivity in the pharmaceutical industry. These spillovers, measured as patent citations, thus impact the pharmaceutical firms' innovation process and determine whether different therapeutical classes will be integrated within the same firm.

The theoretical literature does not provide clear-cut predictions about the sign of the appropriability variable. On the one hand, lower appropriability, increases the scope for the internalization of information flows between firms through cooperation in R&D. On the other hand, lower appropriability increases free rider problems related to R&D investments, which reduce profitability and threaten the stability of cooperative agreements in R&D. When the appropriation regime is tight, i.e. protection is more effective, firms can more easily enter into R&D cooperation, controlling knowledge flows to non-partners or non-loyal partners. Distinguishing between different types of cooperative R&D agreements –vertical cooperation, or, cooperation with research institutes– one would expect that more generic incoming spillovers affect cooperation with research institutes more. In contrast, appropriation is a key issue when dealing with more commercially sensitive information in vertical cooperative agreements.

In addition to our measures of spillovers we include variables that have been shown in previous studies to affect cooperation in R&D (Röller *et al.*, 1997; Kleinknecht and Van Reijnen, 1992; Colombo and Gerrone, 1996). These studies provide strong evidence about the size and R&D orientation of firms positively affecting R&D cooperation. This is reminiscent of the absorptive capacity idea which stresses the need to have in-house (technological) power to optimally benefit from R&D cooperation. We allow for a non-linear effect of size on the probability of cooperation in R&D (*SIZE, SIZEsq*) and include a dummy variable for whether or not the firm performs R&D on a permanent basis *(PermRD)* (14). By including *INSPILL* and *PermRD* in the same relation, we can test whether the effect of absorptive capacity on R&D cooperation, in addition, runs through its effect on the importance of external information sources. At the same time, internal R&D capacity is an intrinsic element of any strategy to protect know-how, adding another indirect effect of R&D capacity on R&D cooperation through *PROTstrat.*

As work by Mariti and Smiley (1983) and Tyler and Steensma (1995) has indicated, other motives such as cost and risk sharing as well as getting access to new technologies are important incentives for cooperation. Sakakibara (1997a,b) finds that access to complementary knowledge is one of the most important objectives for establishing government sponsored research corporations in Japan. Our survey information allows us to proxy for these motives. The firms rated the importance of different obstacles to innovation on a scale of 1 (unimportant) to 5 (crucial). When costs are an important obstacle to

(14) Reported budgets for R&D proved to be unreliable.

innovation, we expect to observe more cooperative agreements with the purpose of cost sharing. We construct an aggregate measure of the responses to four questions on the importance of costs as an obstacle to innovation *(COST)*. These obstacles were: a lack of suitable financing; high costs of innovation; a long pay-back period; and, difficult to control costs of innovation. Similarly, we expect that higher risks and uncertainty in the innovation process favor risk sharing through the organization of cooperative agreements in R&D. *RISK* measures the importance of high risks as a barrier to innovation. Finding suitable partners to cooperate with requires knowledge about technological opportunities in the market. *TECH* measures the availability of technological information for innovation within the firm. Although a lack of internal technological know-how may drive firms to cooperate in order to access missing technologies externally, it simultaneously reduces the scope for complementarities that could be exploited through cooperation. Hence, we use *TECH* as a measure of the potential for realizing complementarities with partners in a cooperative agreement in R&D (15). Finally, we include the industry variable *indCOOP*, which we assume will pick up unobserved industry-specific attributes that contribute to the decision of a firm to engage in a cooperative agreement (16).

The level of incoming spillovers and the effectiveness of appropriation mechanisms might not only affect profitability and hence the decision to cooperate, but, when firms use cooperative agreements as a vehicle to manage external knowledge flows, the decision to cooperate could also influence the actual level of incoming spillovers and the effectiveness of appropriation strategies. Cooperating firms may try to maximize *incoming* spillovers among partners through information sharing, which will enhance the profitability as well as the stability of cooperation. Related, Brandstetter and Sakakibara (1998) find that R&D cooperation positively affects the research productivity of the partners and attribute this to the increased incoming spillovers between partners (17). Moreover, in response to free-riding, firms will want to limit *outgoing* spillovers to non-partners. Although outgoing technology flows to partners are essential in information sharing agreements in search of synergies, such agreements could possibly reduce the effectiveness of measures of protection. Firms need to carefully manage this exposure of own know-how within the alliance in view of the threat of opportunistic partners. We expect that firms that are considering R&D cooperation have an incentive to invest in mechanisms increasing appropriability in general and becoming more successful at controlling information sharing with their partners, as well as limiting free-riding by non-partners. Again, we should expect that the effect of cooperation on external knowledge flows differs according to type of cooperative agreement. The more generic nature of research projects with universities and research institutes should affect the potential for incoming spillovers from the sharing of knowledge, but should have little effect on appropriation. Vertical cooperative agreements, on the contrary, might be more hazardous for appropriation given their commercially sensitive content.

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(15) See Data Appendix for a precise definition of all the variables. Note that our sample consists of innovating firms. Hence, we expect these variables to affect how they organize their innovation process, rather than whether they innovate or not. The construction of the variables *COST*, *RISK* and *TECH* might again introduce some measurement error/subjectivity because of the use of a subjective rating scale. However, we will assume that this measurement error is uncorrelated to the measurement error/subjectivity from their response to the importance of external sources of information and the effectiveness of measures of protection. This is consistent with the low correlation between *INSPILL* and *PROTstrat* on the one hand and *COST*, *RISK* and *TECH* on the other.

(16) Dummy variables for the industry, when included, were not significant and did not affect the results.

(17) See also Kleinknecht (1999) for a related result.

Since our main interest lies in uncovering the relation between cooperation and spillovers, we will focus the endogeneity discussion on *INSPILL* and *PROTstrat,* assuming all other variables to be exogenous. The only exception is the variable *PermRD*, for which there are strong a priori reasons identified in the literature to expect endogeneity. Not only will own R&D enhance the efficiency of cooperation, but external sourcing through cooperation may stimulate or discourage own R&D (Veugelers, 1997, Colombo and Garrone, 1996). In order to address the possible endogeneity problems, we will use a two-step estimation procedure. The two-step estimation procedure consists of regressing the endogenous variables on all the assumed exogenous variables in the first step. Unfortunately, it is unlikely that many of the variables available are truly exogenous. Nevertheless, for the purpose of our investigation –uncovering the relation between cooperation and spillovers– they will be assumed to be exogenous. In the second step, we use the predicted values of the endogenous variables as independent variables in the structural equations. Furthermore, this estimation procedure might alleviate problems of measurement error arising from the use of qualitative measures of incoming spillovers and strategic protection by regressing *INSPILL* and *PROTstrat* on exogenous instruments (18) (19). Included as instruments are the industry averages for each of the endogenous variables. We assume that each of these industry mean variables pick up the effects of unobserved industry-specific attributes that contribute to that endogenous firm-specific variable (20).

The structural equations for *INSPILL* and *PROTstrat* might be of independent interest for understanding the relation between our spillovers measures and cooperation and are hence reported and discussed explicitly. For incoming spillovers, *INSPILL*, the literature seems to suggest that absorptive capacity through internal technological capabilities is important to optimally benefit from external information flows. Therefore, firms that perform R&D on a permanent basis should attribute higher importance to incoming spillovers. As an explanatory variable we thus include the estimated *PermRD* variable. It is often argued that generic research diffuses more easily (Vonortas, 1994; Kamien and Zang, 1998). 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 incoming spillovers and hence are expected to have a higher score on *INSPILL*. The variable *BasicRD* measures the importance for the innovation process of information from research institutes and universities relative to the importance of suppliers and customers as an information source. We use this variable to proxy for the "basicness" of R&D performed by the firm (21) (22). The industry variable *indINSPILL* is included as well to capture the technological conditions of the industry influencing knowledge flows.

(18) In addition to being computationally less demanding, using our two-step estimation procedure provides more robust estimates compared to simultaneous estimating the system (*COOP*[Vert-Res], *INSPILL, PROTstrat, PermRD)* by maximum likelihood. Simultaneous estimation, requiring a full specification of all structural equations, might be plagued by biases arising from omitted variables in any of the individual equations, leading to inconsistent estimates for the whole system (see Vella and Verbeek (1999)).

(19) In order to avoid inconsistent estimates for the second step estimation in the case of a dichotomous endogenous variable in a probit equation, which is the case for *PermRD*, we estimate the *PermRD* first step equation as a linear probability model and use the predicted value of the latent variable in the second step of the estimation (Heckman and Macurdy (1985)). Note that the latent variable in this case, the R&D intensity of the firm, is the economic variable of interest underlying the variable *PermRD*.

(20) For a full specification of the model and the instruments, see also Appendix.

(21) The questionnaire grouped all the questions on the importance of different information sources for the innovation process in the same subsection. Scores of the same firms should be readily comparable. Note that by using this ratio of two scores, the potential problems of the subjectivity of these measures is reduced.

(22) 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.

The strategic protection variable *PROTstrat* will be influenced in particular by the competitive environment of the firm. The more competitive the environment, the more a firm is expected to invest in protecting any technological competence. More export intensive firms typically face a more competitive environment *(EXPint)*. Firms with a higher internal technological capacity might not only be better at absorbing incoming spillovers, but also be better at protecting their knowledge through secrecy, complexity or lead time. Therefore, we include the estimated *PermRD* as an explanatory variable. The variable *indPROTstrat* is included to capture technological conditions shaping strategic protection possibilities in the industry.

Table 1 presents some descriptive statistics about the variables used. Consistent with our model hypotheses, the mean values of all variables are higher for cooperating firms than for firms without cooperative R&D agreements. As suggested, the mean importance of incoming spillovers is slightly higher for firms cooperating with research institutes compared to firms that cooperate with customers or suppliers. This contrasts with the mean effectiveness of strategic protection mechanisms, where the reverse is true (23).

Table 1. Descriptive Statistics

	Sample Mean (N=411)	Mean *COOP*=0 (N=226)	Mean *COOP*=1 (N=185)	Mean VERT=1 (N=135)	Mean RES=1 (N=135)
INSPILL	0.457 (0.193)	0.413 (0.183)	0.511*** (0.511)	0.528*** (0.194)	0.535*** (0.192)
PROTstrat	0.513 (0.251)	0.464 (0.262)	0.572*** (0.572)	0.59** (0.219)	0.573*** (0.215)
IndPROTleg	0.144 (0.036)	0.135 (0.035)	0.154*** (0.034)	0.155*** (0.036)	0.155*** (0.029)
SIZE	0.604 (2.31)	0.190 (0.72)	1.11*** (3.28)	1.34*** (3.79)	1.21*** (3.35)
PermRD	0.737 (0.441)	0.602 (0.496)	0.903*** (0.297)	0.904*** (0.296)	0.933*** (0.25)
COST	0.456 (0.183)	0.426 (0.189)	0.494*** (0.168)	0.486* (0.16)	0.514** (0.155)
RISK	0.441 (0.243)	0.429 (0.254)	0.455 (0.228)	0.465* (0.235)	0.467** (0.222)
TECH	0.725 (0.194)	0.723 (0.191)	0.727 (0.198)	0.744 (0.171)	0.715 (0.198)
***difference in means between cooperating and not cooperating firms significant at 1%, **significant at 5%, *significant at 10% standard deviations in parenthesis					

Results

First, we discuss the importance of incoming spillovers and appropriability for the pooled cooperation decision of the firms, with and without correcting for endogeneity of the knowledge flow and permanent R&D variables. Next, we estimate the models for vertical cooperation and cooperation with research institutes separately. These results will contrast

(23) This difference is even more pronounced when comparing the means of *INSPILL* and *PROTstrat* for firms that exclusively cooperate with one type of partner.

our measures of incoming spillovers and appropriability. Finally, we discuss the structural equations for incoming spillovers and appropriability.

Spillovers and Cooperation

We estimate a Probit model of whether the firms decide to cooperate or not (24). The coefficients in Table 2 present the marginal effect of the independent variables on the probability of cooperating, while keeping everything else constant. Robust standard errors are estimated for these coefficients. Regression (1) does not include incoming spillovers and appropriability measures. Adding our firm-specific measures of incoming spillovers and strategic protection significantly increases the explanatory power of the regression (see regression (2)). Incoming spillovers have a positive and significant effect on the probability of firms cooperating (*INSPILL*). The existing base of know-how is better tapped by cooperating firms because of the improved technological competence of the partners. This increases the expected profitability of cooperative agreements and hence makes them more likely to occur.

Table 2. Results of Pooled Probit Regressions for Cooperation

	(1)	(2)	(3)	(4) (2-STEP)	(5) (2-STEP)
INSPILL	—	0.472*** (0.155)	0.523*** (0.15)	0.968* (0.52)	0.878** (0.44)
PROTstrat	—	0.195* (0.11)	0.302*** (0.11)	0.75* (0.42)	0.66* (0.35)
IndPROTleg	-0.116 (1.03)	-0.297 (1.08)	-0.159 (1.09)	-0.945 (1.20)	-0.908 (1.19)
PermRD	0.325*** (0.055)	0.288*** (0.059)	—	-0.0775 (0.22)	—
SIZE	0.149** (0.076)	0.143** (0.072)	0.161** (0.08)	0.149* (0.08)	0.146* (0.08)
SIZEsq	-0.0058* (0.0034)	-0.00577* (0.0032)	-0.0067* (0.0035)	-0.0065* (0.0035)	-0.0062* (0.0035)
COST	0.831*** (0.20)	0.756*** (0.20)	0.792*** (0.20)	0.56** (0.22)	0.577*** (0.22)
RISK	-0.232* (0.13)	-0.281** (0.13)	-0.25* (0.14)	-0.275* (0.14)	-0.272* (0.14)
TECH	0.30* (0.17)	0.369** (0.17)	0.407** (0.17)	0.412** (0.17)	0.395** (0.16)
INDCOOP	0.916*** (0.21)	0.930*** (0.21)	0.954*** (0.21)	0.961*** (21)	0.946*** (21)
	$\chi^2 = 98.72^{***}$ LL=-218.48	$\chi^2 = 106.51^{***}$ LL=-211.76	$\chi^2 = 99.80^{***}$ LL=-221.81	$\chi^2 = 85.87^{***}$ LL=-228.09	$\chi^2 = 84.65^{***}$ LL=-228.14

*** significant at 1%, ** significant at 5%, * significant at 10%, robust standard errors between brackets. The coefficients are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus. For *PermRD* it is the effect of a discrete change from 0 to 1 in (1) and (2).

(24) Logit estimations give similar results.

Similarly, higher appropriability through strategic protection has a positive effect on the probability of firms cooperating. The more effective strategic protection is, the better firms control the outflow of commercially sensitive information, and the more likely they are to engage in cooperative agreements *(PROTstrat)*. Hence, better appropriability reduces the potential for free riding within and beyond the cooperative agreement and improves the stability of these agreements. However, as regressions (2) and (3) show, the effect of incoming spillovers and appropriability is moderated by own R&D activities of the firm. Once controlling for permanent R&D, the coefficients of *INSPILL* and *PROTstrat* are reduced and *PROTstrat* loses some significance. This result suggests that the R&D capabilities of the firm and the effectiveness of appropriating returns from its innovation process are strongly interrelated.

As regressions (4) and (5) demonstrate, the correction for the endogeneity of *INSPILL*, *PROTstrat* and *PermRD* does not change our findings on the signs and significance of the coefficients of the spillover effects, but significantly increases the estimated coefficients (25). The increase in the estimated coefficients might not only indicate an endogeneity problem, but could also reflect a problem of measurement error with *INSPILL* and *PROTstrat*, in which case the uncorrected estimates are biased towards zero (26). Furthermore, *PermRD* shows up insignificant once corrected for endogeneity and does not significantly affect the point estimate of *INSPILL* and *PROTstrat*. One disadvantage of our two-step procedure is that it introduces multicollinearity between the predicted values of the endogenous variables, reducing significance of the estimated coefficients (27).

Next, we discuss the non-spillover determinants of cooperation. The signs and significance levels of all the coefficients of these variables remain fairly robust across the different regressions. Not surprisingly, larger firms are more likely to cooperate. The effect of firm size is very significant, with evidence for a non-linear concave relation. When costs are an important obstacle to innovation, innovating firms have a strongly significant higher probability of engaging in cooperative agreements (*COST*). While cost-sharing seems to be an important driver for cooperation, risk-sharing is not. On the contrary, firms for which risk is an important barrier to innovate are less likely to cooperate (*RISK*). Viewed from a transaction cost perspective, however, this result is not so surprising. Minimizing opportunistic partner behavior in cooperative contracts will be more difficult when the technology is characterized by a large amount of uncertainty. Therefore, it seems important to distinguish between costs and risks when analyzing the cooperation decision. Substituting *COST* and *RISK* with an independent variable that combines cost and risk factors, as is frequently done in the literature, results in an insignificant parameter estimate. As expected, the higher the availability of technological know-how for innovation, which increases the scope for complementarities to exploit through cooperation, the higher is the probability of cooperation (*TECH*) (28).

(25) See Table A2a in Appendix for the first-step regressions from which the predicted values for *INSPILL*, *PROTstrat* and *PermRD* have been constructed.

(26) In order to consider the regression of the endogenous variables on all exogenous variables as a correction for measurement error, we need to assume that the measurement error of the other qualitative exogeneous variables (*COST*, *RISK* and *TECH*) is uncorrelated with the error in *INSPILL* and *PROTstrat* (see footnote 15). Nevertheless, estimating the model without these other qualitative variables did not change our results on the coefficients of *INSPILL* and *PROTstrat* significantly. Furthermore, we could not reject the null hypothesis for no endogeneity of a Hausman test for this case.

(27) *INSPILL*, *PROTstrat* and *PermRD* are closely related to the same —assumed exogenous—variables such as *COST*, *BasicRD* and *EXPint*.

(28) Sakakibara (1997a,b) also finds that expected complementaries are one of the most important motives for forming government sponsored research consortia in Japan. Where Sakakibara (1997a, b) explicitly analyzed the motives for cooperation in R&D, the CIS questionnaire analyzed innovative behavior in general. The questions from which we derive our explanatory variables were never directly related to the decision of the firm to cooperate, but were rather related to the firm's innovative behavior. As a result, we expect our results to be less driven by what managers answering the questionnaire thought was the "correct" answer with respect to the cooperation decision.

The overall predictive power of the estimated cooperation model is good; for instance, for the exogenous model of regression (2), more than 74% of all cases are predicted correctly (29). There is however a tendency to underpredict the number of cooperative cases: only 69% of all cooperations were predicted correctly (30).

Spillovers and Cooperation with different types of partners

The importance of distinguishing between incoming spillovers and appropriability is highlighted when we distinguish between cooperation along the vertical chain, i.e. with suppliers or customers, and cooperation with research institutes. In our data set, 33% of the firms cooperate with customers or suppliers, while 33% cooperate with research institutes. Of the cooperating firms, 46% have cooperative agreements of both types. Tables 3 and 4 present the results of a similar exercise as performed in the previous section, but for the separately estimated probit models. For the sake of brevity, we will mainly restrict attention to the results of the two-step procedure, i.e. regressions (4) and (5) in Tables 3 and 4.

Table 3. Results of Probit Regressions for Cooperations with Customers and Suppliers

	(1)	(2)	(3)	(4) (2-STEP)	(5) (2-STEP)
INSPILL	—	0.449*** (0.13)	0.485*** (0.14)	0.0966 (0.47)	0.154 (0.40)
PROTstrat	—	0.252** (0.10)	0.319*** (0.11)	0.62* (0.37)	0.673** (0.31)
IndPROTleg	0.0372 (0.96)	-0.158 (0.98)	-0.184 (0.99)	-0.791 (1.09)	-0.821 (1.08)
PermRD	0.224*** (0.048)	0.183*** (0.053)	—	0.0482 (0.19)	—
SIZE	0.0882** (0.044)	0.0888** (0.041)	0.102** (0.045)	0.0.095** (0.049)	0.0974** (0.048)
SIZEsq	-0.00286 (0.0020)	-0.00311* (0.0019)	-0.0037* (0.0020)	-0.00333 (0.0022)	-0.00347* (0.0021)
COST	0.481*** (0.17)	0.381** (0.17)	0.414** (0.17)	0.341* (0.20)	0.331* (0.20)
RISK	-0.0168 (0.12)	-0.0671 (0.12)	-0.0498 (0.12)	-0.014 (0.13)	-0.0119 (0.13)
TECH	0.375*** (0.15)	0.445*** (0.15)	0.462*** (0.15)	0.442*** (0.15)	0.452*** (0.15)
INDCOOPVERT	0.728*** (0.24)	0.701*** (0.24)	0.755*** (0.25)	0.804*** (0.26)	0.818*** (0.25)
	χ^2 = 98.97*** LL=-219.31	χ^2 = 108.29*** LL=-209.76	χ^2 = 94.95*** LL=-214.7	χ^2 = 77*** LL=-225.18	χ^2 =77.16*** LL=-225.2

*** significant at 1%, ** significant at 5%, * significant at 10%, robust standard errors between brackets. The coefficients are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus. For *PermRD* it is the effect of a discrete change from 0 to 1 in (1) and (2).

(29) The naïve model would classify 55% correctly.
(30) The percentages for regression (4) are comparable: 72% and 62% respectively.

Table 4. Results of Probit Regressions for Cooperations with Research Institutes

	(1)	(2)	(3)	(4) (2-STEP)	(5) (2-STEP)
INSPILL	—	0.449*** (0.13)	0.485*** (0.14)	0.0966 (0.47)	0.154 (0.40)
PROTstrat	—	0.252** (0.10)	0.319*** (0.11)	0.62* (0.37)	0.673** (0.31)
IndPROTleg	0.0372 (0.96)	-0.158 (0.98)	-0.184 (0.99)	-0.791 (1.09)	-0.821 (1.08)
PermRD	0.224*** (0.048)	0.183*** (0.053)	—	0.0482 (0.19)	—
SIZE	0.0882** (0.044)	0.0888** (0.041)	0.102** (0.045)	0.0.095** (0.049)	0.0974** (0.048)
SIZEsq	-0.00286 (0.0020)	-0.00311* (0.0019)	-0.0037* (0.0020)	-0.00333 (0.0022)	-0.00347* (0.0021)
COST	0.481*** (0.17)	0.381** (0.17)	0.414** (0.17)	0.341* (0.20)	0.331* (0.20)
RISK	-0.0168 (0.12)	-0.0671 (0.12)	-0.0498 (0.12)	-0.014 (0.13)	-0.0119 (0.13)
TECH	0.375*** (0.15)	0.445*** (0.15)	0.462*** (0.15)	0.442*** (0.15)	0.452*** (0.15)
INDCOOPVERT	0.728*** (0.24)	0.701*** (0.24)	0.755*** (0.25)	0.804*** (0.26)	0.818*** (0.25)
	$\chi^2 = 98.97^{***}$ LL=-219.31	$\chi^2 = 108.29^{***}$ LL=-209.76	$\chi^2 = 94.95^{***}$ LL=-214.7	$\chi^2 = 77^{***}$ LL=-225.18	$\chi^2 = 77.16^{***}$ LL=-225.2

*** significant at 1%, ** significant at 5%, * significant at 10%, robust standard errors between brackets. The coefficients are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus. For *PermRD* it is the effect of a discrete change from 0 to 1 in (1) and (2).

Some interesting differences emerge in the effect of incoming spillovers and strategic protection depending of the type of partner one cooperates with. Incoming spillovers have a significantly positive effect on cooperation with research institutes. On the contrary, in vertical cooperation, the positive impact of incoming spillovers loses significance, once corrected for endogeneity. A different pattern emerges for appropriability through strategic protection. The effectiveness of strategic protection is not a significant factor when deciding about cooperating with research institutes. For vertical cooperation, however, the effectiveness of strategic protection is important to induce cooperation. Strategic protection remains significant across specifications. All this seems to suggest that outgoing spillovers between industrial partners are more critical than spillovers to non-industrial partners. This is reminiscent of the idea that competitors learn about their rivals through common suppliers or customers. Furthermore, firms want to avoid backward integration by customers or forward integration by suppliers because of what they learn through cooperative agreements.

For both types of cooperative agreements, firm size is an important determinant. It is interesting to observe that high cost *(COST)* and low risks *(RISK)* are relevant for cooperation with research institutes. These results are related to the more basic nature of joint R&D with research institutes. This type of agreements entails higher costs and thus scope for cost sharing and higher risks with an increasing probability for opportunism by partners. The search for external know-how and complementarities *(TECH)*, however, is only significant for vertical cooperative agreements, where the matching of existing technological capabilities is an important element of the cooperative agreement. High costs *(COST)* affect the organization of vertical cooperative agreements to a less significant extent than in the case of cooperative agreements with research institutes.

Incoming Spillovers and Strategic Protection

In Table 5 we present the results of the second-stage regressions of *INSPILL* and *PROTstrat* respectively. Regressions (1) and (2) use the predicted value for cooperative agreements of the pooled regression (31). Regressions (4) and (5) distinguish the type of cooperative agreement for the predicted value of the cooperative agreement (32). The results of Table 5 suggest that there is only weak evidence for endogeneity of *INSPILL* and *PROTstrat*, with respect to the cooperative decision (33). On the one hand, firms that cooperate with research institutes will have a higher rating of the importance of *incoming* spillovers for their innovation process. This positive coefficient, although only significant at the 10% level, is consistent with an information sharing explanation of cooperation where cooperating firms increase their *incoming* spillovers because there are more opportunities for information sharing due to the more basic nature of research projects (Regression (3)). Furthermore, regression (4) demonstrates that there is a positive effect of cooperative agreements on the effectiveness of protection, most likely through increased complexity of products and processes, or through gaining lead time on competitors (34). On the other hand, regression (4) suggests that vertical cooperative agreements would reduce the effectiveness of strategic protection. The commercially sensitive information that firms might disseminate indirectly through cooperative agreements with suppliers and customers could be detrimental to the efforts of the firm to appropriate the returns from its innovation process. Therefore, care should be taken to protect one's proprietary information before engaging in these types of agreements. In sum, our results indicate that by engaging in different types of cooperative R&D agreements, firms can affect their knowledge in- and outflows.

(31) See Table A2a in Appendix for the first-step regressions from which the predicted values for *COOP* and *PermRD* have been constructed.
(32) See Table A2b in Appendix for the first-step regressions from which the predicted values for *COOPVERT*, *COOPRES* and *PermRD* have been constructed.
(33) The Hausman test for endogeneity rejects the null hypothesis for no endogeneity of *INSPILL* and *PROTstrat* at the 10% level of significance only for the case of cooperation with research institutes. For the other case, the null could not be rejected.
(34) This effect is marginally significant at 11%.
(35) Note that *BasicRD* is an important—exogenous—regressor for *PermRD* (Tables A2a and A2b).

Table 5. Incoming Spillovers and Strategic Protection

	INSPILL (1)	*PROTstrat* (2)	*INSPILL* (3)	*PROTstrat* (4)
COOP	-0.0063 (0.21)	0.0313 (0.028)	—	—
COOPVERT	—	—	0.0013 (0.029)	-0.081** (0.036)
COOPRES	—	—	0.0462* (0.028)	0.05 (0.031)
PermRD	0.123** (0.054)	0.075 (0.084)	0.0878* (0.052)	0.099 (0.092)
BasicRD	0.214*** (0.046)	—	0.184*** (0.049)	—
EXPint	—	0.118** (0.048)	—	0.141*** (0.049)
IndINSPILL	0.671*** (0.25)	—	0.635*** (0.24)	—
IndPROTstrat	—	0.748*** (0.19)	—	0.795*** (0.21)
Constant	-0.0671 (0.10)	-0.0033 (0.094)	-0.021 (0.10)	-0.0452 (0.098)
	R^2=0.145 F=20.68***	R^2=0.126 F=14.88***	R^2=0.153 F=16.74***	R^2=0.133 F=12.37***
*** significant at 1%, ** significant at 5%, * significant at 10%, † significant at 15%, robust standard errors between brackets.				

Turning next to other determinants of incoming spillovers and strategic protection, we find that absorptive capacity as measured by *PermRD* positively affects the importance the firm attaches to incoming spillovers and the effectiveness of measures of appropriability, but this effect is only significant for the former. The R&D orientation of the firms *(BasicRD)* is also an important determinant of incoming spillovers (35). Firms involved in more basic R&D projects consider incoming spillovers as more important for their innovation process. This result is reminiscent of Kamien and Zang's (2000) approach to endogenizing spillovers through the choice of research design, where basic research projects are more susceptible to external information flows. Firms facing tougher competitive environments, such as exporting firms *(EXPint)*, will more effectively protect their know-how strategically. Not surprisingly, firms operating in industries characterized by easier external technology appropriation are more likely to rate incoming spillovers as important *(IndINSPILL)*. Similarly, technology or market characteristics favoring strategic protection will help firms to manage outgoing flows of information *(IndPROTstrat)*.

(35) Note that *BasicRD* is an important—exogenous—regressor for *PermRD* (Tables A2a and A2b).

Conclusions

Our results on the relationship between firm-specific spillovers and cooperation measured at the firm level seem to suggest that indeed *incoming* and *outgoing* spillovers have important and separately identifiable effects: firms with higher incoming spillovers and lower outgoing spillovers, i.e. better appropriation, have a higher probability of cooperating in R&D. Zeroing in on the type of partner in the cooperative agreements allows us to distinguish these effects more clearly. Incoming spillovers significantly affect the probability of cooperating with research institutes, while appropriability through the effectiveness of strategic protection matters for cooperative agreements in the vertical chain. This latter result does not support most of the theoretical models evaluating the relation between spillovers and R&D cooperation. These models would predict that firms are more likely to form cooperative agreements in R&D when the appropriation regime is loose.

Correcting for the endogeneity of spillovers and R&D cooperation is important in order to evaluate the magnitude of the effect of spillovers on the decision to cooperate. Although not affecting the direction of the effects of incoming and outgoing spillovers on cooperation, the correction suggests that the average cooperating firm weakly increases the importance of incoming spillovers. Our results therefore provide some support for information sharing, especially within cooperative R&D agreements with research institutes as partners. Furthermore, we find that cooperative agreements with vertically related firms can potentially diminish firms' ability to appropriate the results of the innovation process.

Additional empirical work is needed to verify the robustness of our results. The EUROSTAT/CIS data are a rich data set, allowing for the replication of this exercise for other European countries. However, the qualitative nature of most of the information limits the analysis in terms of quantifying R&D cooperation, R&D spillovers and their relation. Furthermore, in the absence of a panel data set it is very hard to control for unobserved firm heterogeneity. We hope that in the future alternative data sources will become available which allow for the construction of similar, more quantitative, measures of incoming spillovers and appropriability across a panel of firms. In addition, our results provide some interesting suggestions for further theoretical work on the issue of spillovers and R&D cooperation. First, the importance of the distinction between incoming spillovers and appropriability as a determinant of different types of cooperative agreements in R&D should be developed in more detail. Different spillover measures seem to have a separately identifiable impact on the firm's cooperation decisions. Second, the relation between spillovers and cooperative agreements should be analyzed in the broader context of the firm's innovation strategy. Firms that decide to be innovation active need to understand the complementarities that exist between own R&D programs, cooperative agreements in R&D and external technology acquisition in order to take advantage of publicly available information within the innovation process and to better appropriate the results of successful outcomes of the innovation process. We still have a poor understanding of these issues and hope that our results provide some useful directions towards improving theoretical modeling of these questions.

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DATA AND METHODS APPENDIX

The data are a cross-section of Belgian manufacturing firms in 1992. A representative sample of 1335 Belgian manufacturing firms was selected and a 13-page questionnaire sent out to them. The response rate was higher than 50% (748). The researchers in charge of collecting the data for the CIS also performed a limited non-response analysis and concluded that no systematic biases could be detected (Debackere and Fleurent, 1995). From the raw questionnaire data we constructed the variables for our analysis described in Table A1.

$$INSPILL = \frac{Score\ Patent\ Info + Score\ Specialized\ Conferences + Score\ Trade\ Shows - 3}{12}$$

For example:

Table A1: Description of Variables

COOP	*COOP*=1, if firms cooperate with 1. Suppliers, or, 2. Customers, or, 3. Competitors, or, 4. Public research institutes, or, 5. Private research institutes, or, 6. Universities.
INDCOOP	Mean of *COOP* at industry level. Industry level is defined at 2-digit NACE.
COOPVERT	*COOPVERT*=1, if firms cooperate with 1. Suppliers, or, 2. Customers.
INDCOOPVERT	Mean of *COOPVERT* at industry level. Industry level is defined at 2-digit NACE.
COOPRES	*COOPRES*=1, if firms cooperate with 1. Public research institutes, or, 2. Private research institutes, or, 3. Universities.
INDCOOPRES	Mean of *COOPRES* at industry level. Industry level is defined at 2-digit NACE.
SIZE	Firm Sales in 1992 in 10^{10} BEF.
SIZEsq	Firm Sales in 1992 in 10^{10} BEF squared.
EXPint	Export share in total Firm Sales
PermRD	*PermRD*=1 if the firm's research and development activities have a permanent character.
INDPERMRD	Mean of *PermRD* at industry level. Industry level is defined at 2-digit NACE.
INSPILL	Sum of scores 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. (rescaled between 0 and 1)

PROTstrat	Sum of scores of effectiveness of following methods for protecting new products/ processes (number between 1 (unimportant) and 5 (crucial)): 1. Secrecy for protecting products, 2. Complexity of product or process design for protecting products, 3. Lead time on competitors for protecting products, 4. Secrecy for protecting processes, 5. Complexity of product or process design for protecting processes, 6. Lead time on competitors for protecting processes. (rescaled between 0 and 1)
IndINSPILL	Mean of *INSPILL* at industry level. Industry level is defined at 2-digit NACE.
IndPROTstrat *IndPROTleg*	Mean of *PROTstrat* at industry level. Industry level is defined at 2-digit NACE. Mean of *PROTleg* at industry level. Industry level is defined at 2-digit NACE. *PROTleg* is Sum of scores of effectiveness of following methods for protecting new products/processes (number between 1 (unimportant) and 5 (crucial)): 1. Patents for protecting products, 2. Registration of brands, copyright for protecting products, 3. Patents for protecting processes, 4. Registration of brands, copyright for protecting processes. (rescaled between 0 and 1)
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).
TECH	*TECH* = 1 – *NOTECH* *NOTECH* = Importance of lack of technological information as an obstacle to innovation (number between 1 (unimportant) and 5 (crucial), rescaled between 0 and 1).
BasicRD	Ratio of between: 1. Sum of scores of importance of following information sources for innovation process (number between 1 (unimportant) and 5 (crucial)): a. Universities, b. Public research institutes, and c. Technical research institutes 2. Sum of scores of importance of following information sources for innovation process (number between 1 (unimportant) and 5 (crucial)): a. suppliers of materials, b. suppliers of equipment, and c. customers.

The two-step estimation procedure used to correct for endogeneity of *COOP (COOPVERT, COOPRES)* and *INSPILL*, *PROTstrat* and *PermRD*, regresses the endogenous variables on all the assumed exogenous variables in the first step: *SIZE*, *SIZEsq*, *IndPROTleg*, *COST*, *RISK*, *TECH*, *BasicRD*, *EXPint*, *IndCOOP (IndCOOPVERT, IndCOOPRES)*, *IndINSPILL*, *IndPROTstrat*, *IndPermRD*. In the second step, we use the predicted values of the endogenous variables of the first-step as right hand side variables in the specified regressions of Tables 2 to 5. Table A2 presents the regression results from the first step. Note that *COOP* (*COOPVERT, COOPRES*) are probit regressions while *INSPILL*, *PROTstrat* and *PermRD* are OLS regressions. The following equations are estimated in the second step estimation (36):

Probit Regressions

*COOP** = $\alpha_{11} + \alpha_{12}INSPILL + \alpha_{13}PROTstrat + \alpha_{14}\ IndPROTleg + \alpha_{15}PermRD + \alpha_{16}SIZE + \alpha_{17}\ SIZEsq + \alpha_{18}\ COST + \alpha_{19}RISK + \alpha_{110}TECH + \alpha_{111}\ IndCOOP$

*COOPVERT** = $\alpha_{21} + \alpha_{22}INSPILL + \alpha_{23}PROTstrat + \alpha_{24}\ IndPROTleg + \alpha_{25}\ PermRD + \alpha_{26}\ SIZE + \alpha_{27}\ SIZEsq + \alpha_{28}COST + \alpha_{29}RISK + \alpha_{210}TECH + \alpha_{211}IndCOOPVERT$

*COOPRES** = $\alpha_{31} + \alpha_{32}INSPILL + \alpha_{33}PROTstrat + \alpha_{34}IndPROTleg + \alpha_{35}PermRD + \alpha 36 SIZE + \alpha_{37}SIZEsq + \alpha_{38}COST + \alpha_{39}RISK + \alpha_{310}TECH + \alpha_{311}IndCOOPRES$

Linear Regressions

INSPILL = $\beta_{11} + \beta_{12}COOP + \beta_{13}PermRD + \beta_{14}BasicRD + \beta_{15}\ indINSPILL$

INSPILL = $\beta_{21} + \beta_{22}COOPVERT + \beta_{23}COOPRES + \beta_{24}PermRD + \beta_{25}BasicRD + \beta_{26}IndINSPILL$

PROTstrat = $\gamma_{11} + \gamma_{12}COOP + \gamma_{13}\ PermRD + \gamma_{14}\ EXPint + \gamma_{15}\ IndPROTstrat$

PROTstrat = $\gamma_{21} + \gamma_{22}COOPVERT + \gamma_{23}COOPRES + \gamma_{24}\ PermRD + \gamma_{25}\ EXPint + \gamma_{26}IndPROTstrat$

(36) The focus of the paper is on the relationship between spillovers and cooperation. Hence we do not discuss and specify a second step *PermRD* equation. The underlined variables are the assumed endogenous regressors and these coefficients are estimated using the predicted values for these variables from the first step regression results.

Table A2a: Results of First Step Regressions used for constructing the predicted values of *INSPILL, PROTstrat* and *PermRD* of Table 2, regressions (4) and (5), and *COOP* and *PermRD* of Table 5, regressions (1) and (2).

	COOP	*INSPILL*	*PROTstrat*	*PermRD*
SIZE	0.135*** (0.049)	0.00519 (0.013)	-0.0137 (0.017)	0.0457 (0.029)
SIZEsq	-0.00551** (0.0025)	0.00003 (0.00063)	0.00075 (0.00083)	-0.00209 (0.0014)
IndPROTleg	0.602 (1.51)	-0.165 (0.47)	0.262 (0.61)	0.176 (1.05)
COST	0.972*** (0.21)	0.147** (0.64)	0.323*** (0.083)	0.319** (0.14)
RISK	-0.223 (0.14)	0.115*** (0.044)	-0.0521 (0.058)	0.00425 (0.099)
TECH	0.430** (0.17)	0.0418 (0.053)	-0.07 (0.069)	0.148 (0.12)
BasicRD	0.392*** (0.13)	0.235*** (0.041)	0.0904* (0.054)	0.284*** (0.092)
EXPint	0.190** (0.086)	0.0438 (0.028)	0.183*** (0.036)	0.299*** (0.062)
INDCOOP	0.871*** (0.23)	-0.0526 (0.073)	-0.088 (0.095)	-0.206 (0.16)
INDINSPILL	-0.582 (0.86)	0.931*** (0.265)	-0.21 (0.35)	-0.173 (0.59)
INDPROTSTRAT	-0.089 (0.70)	0.0691 (0.22)	1.019*** (0.29)	-0.00044 (0.49)
INDPERMRD	-0.0323 (0.27)	-0.0384 (0.083)	-0.071 (0.11)	0.876*** (0.19)
CONSTANT	—	-0.246* (0.14)	-0.0846 (0.19)	-0.37 (0.32)
	χ^2 = 113.94*** LL=-225.87	R^2=0.203 F=8.46***	R^2=0.19 F=7.81***	R^2=0.232 F=10.02***

*** significant at 1%, ** significant at 5%, * significant at 10%, standard errors between brackets. The coefficients of the *COOP* regression are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus.

Table A2b: Results of First Step Regressions used for constructing the predicted values of *INSPILL*, *PROTstrat* and *PermRD* of Tables 3 and 4, regressions (4) and (5), and *COOPVERT*, *COOPRES* and *PermRD* of Table 5, regressions (3) and (4).

	COOPVERT	*COOPRES*	*INSPILL*	*PROTstrat*	*PermRD*
SIZE	0.0817** (0.037)	0.141*** (0.040)	0.00493 (0.013)	-0.0136 (0.017)	0.048 (0.03)
SIZEsq	-0.00263 (0.0021)	-0.0063*** (0.0019)	0.000038 (0.00064)	0.00074 (0.00083)	-0.00217 (0.0014)
IndPROTleg	0.478 (1.36)	-0.0207 (1.49)	-0.223 (0.46)	0.207 (0.60)	0.228 (1.04)
COST	0.597*** (0.18)	0.939*** (0.19)	0.147** (0.064)	0.321*** (0.084)	0.314** (0.14)
RISK	-0.0169 (0.12)	-0.185 (0.13)	0.116*** (0.044)	-0.0514 (0.058)	0.00335 (0.099)
TECH	0.437*** (0.15)	0.265* (0.15)	0.0434 (0.053)	-0.0685 (0.069)	0.151 (0.12)
BasicRD	0.10 (0.12)	0.558*** (0.12)	0.235*** (0.041)	0.0902* (0.054)	0.284*** (0.092)
EXPint	0.205*** (0.079)	0.0538 (0.08)	0.0439 (0.028)	0.184*** (0.036)	0.305*** (0.062)
INDCOOPVERT	0.786** (0.34)	-0.430 (0.32)	-0.0177 (0.11)	-0.0702 (0.14)	-0.253 (0.25)
INDCOOPRES	-0.0889 (0.20)	1.098*** (0.22)	-0.0405 (0.07)	-0.0416 (0.092)	-0.0828 (0.16)
INDINSPILL	-0.351 (0.76)	-0.181 (0.89)	0.949*** (0.27)	-0.189 (0.35)	-0.113 (0.6)
INDPROTSTRAT	-0.0341 (0.63)	0.284 (0.73)	0.0903 (0.22)	1.05*** (0.28)	0.0591 (0.49)
INDPERMRD	-0.0512 (0.24)	0.116 (0.26)	-0.0429 (0.083)	-0.0756 (0.11)	0.875*** (0.19)
CONSTANT	—	—	-0.26* (0.15)	-0.102 (0.19)	-0.42 (0.33)
	χ^2 = 72.7*** LL=-223.84	χ^2 = 131.34*** LL=-194.53	R^2=0.203 F=7.79***	R^2=0.19 F=7.18***	R^2=0.233 F=9.28***

*** significant at 1%, ** significant at 5%, * significant at 10%, standard errors between brackets. The coefficients of the *COOPVERT and COOPRES* regressions are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus.