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R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium

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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 (Adam B. Jaffe, 1986; Jeffrey I. Bernstein and M. Ishaq Nadiri, 1988) and ultimately for economic growth (Paul M. Romer, 1990; Gene M. Grossman and Elhanan Helpman, 1991; Zvi 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.

While assessing spillovers, it is important to distinguish between *incoming spillovers,* which affect the rate of innovation of the firm, and *appropriability,* which affects the ability of the firm to appropriate the returns from innovation. The information sources for incoming spillovers are usually situated in the public domain, and their usefulness to the firm depend on the firm's ability to create information flows from this public pool of knowledge. But firms also 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 relevance of distinguishing between incoming spillovers and appropriability is revealed when we use these measures to analyze their impact on the decision of firms to engage in cooperative R&D agreements. The relationship between different knowledge flows (spillovers) and R&D 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. 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 noncooperating firms (Claude d'Aspremont and Alexis Jacquemin, 1988; Morton I. Kamien et al., 1992; Raymond 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., Carl Shapiro and Robert D. Willig, 1990; Katrien Kesteloot and Veugelers, 1995) and encourages free-riding on the R&D efforts of the research joint venture by outsiders to the cooperative agreement (Patrick Greenlee and Cassiman, 1999).

In most theoretical models of cooperation in R&D and spillovers, firms generate and receive spillovers to the same extent. Assuming symmetry between incoming and outgoing spillovers precludes 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 nonpartners, while at the same time minimizing spillovers

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to nonpartners. Several strands of literature have developed the notion that firms attempt to manage incoming information flows. First, firms try to increase the extent of incoming spillovers by investing in "absorptive capacity." Wesley M. Cohen and Daniel A. Levinthal (1989) argue that external knowledge is more effective for the innovation process when the firm engages in own R&D. 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 nonsharing harsher (Kesteloot and Veugelers, 1995; B. Curtis Eaton and Mukesh 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. A more narrow research approach improves appropriability but at the same time limits the usefulness of external information sources for its own innovation process (Kamien and Zang, 2000).

In this paper, we empirically explore the effects of knowledge flows on R&D cooperation, highlighting the distinction between two measures of knowledge flows, namely, incoming spillovers and appropriability. Incoming spillovers are measured by the importance of publicly available information for the innovation process of the firm, obtained from survey data on Belgian manufacturing firms. Using the same survey data, we also construct a measure of appropriability, which rates the effectiveness of different mechanisms for protecting the innovations of the firm. The advantage of our measures of incoming spillovers and appropriability is that they are direct and firm-specific, allowing for heterogeneity among firms. 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. A firm's effectiveness in protecting commercially sensitive information might be reduced by the knowledge flows created through participating in cooperative R&D agreements. The ability to protect valuable information from reaching other firms also depends on the firm's innovation activities such as own R&D, on the competitive environment of the firm and the appropriability conditions in the industry.

We find that there is a significant relation 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. Differentiating between incoming spillovers and appropriation proves particularly important when examining their effect on different types of cooperative agreements, such as agreements with suppliers and customers or agreements with research institutions. Furthermore, our results suggest that the level of knowledge in- and outflows is not exogenous to the firm. Through their innovation activities, firms affect their incoming spillovers and appropriation capabilities.

In Section I we describe the data. Section II develops an empirical model to analyze the relationship between the decision to cooperate and spillovers. Section III presents the results of our analysis while Section IV concludes.

I. 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. We restrict attention to the subsample of innovating firms from the Belgian manufacturing industry.[1] In the sample, 60 percent (439) of the firms claim to innovate. Due to

[1] A more detailed analysis of this data is reported in Veugelers and Cassiman (1999). Innovating firms are distinguished from those who do not innovate 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,

missing values we are left with 411 observations on actively innovating firms between 1990 and 1992. For these firms, the questionnaire provides information for the construction of measures of incoming spillovers and appropriability.[2]

Incoming Spillovers.—In the questionnaire, firms rated the *importance* of publicly available information for their innovation process from three sources on a five-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 incoming spillovers, we aggregated these answers by summing the scores on each of these questions and rescaled the total score to a number between 0 and 1.[3] To capture the exogenous nature of spillovers, determined by technology or market characteristics, we also construct the average industry score for incoming spillovers.[4] The questionnaire thus provides a direct measure of the importance of incoming spillovers for the innovation process. Alternative measures of incoming spillovers have been proposed in the literature: the total pool of external knowledge that is potentially available, the fraction of this knowledge pool that is 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. 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.[5] 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 (ten 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 copyright, and *strategic* protection of products and processes through secrecy, complexity, or lead time. Again we sum the scores on each of these questions and rescale 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 as a firm-level variable on appropriability. Legal protection is an industry variable, rather than a firm-specific characteristic. The industry averages capture the technology and market characteristics that determine the appropriability regime of the industry.

While we derive a direct measure of the beliefs of the firm's management about the effectiveness of various mechanisms to protect their innovations, there exist in the literature alternative ways of measuring appropriability: the fraction of know-how the firm 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 nonappropriated knowledge (see Griliches, 1992; Paul A. Geroski, 1995). One can either restrict attention to a specific innovation or use the results of regression-based studies which requires the construction of a pool of general knowledge relevant to the firm (Bernstein and Nadiri, 1988). The advantage of our measure of appropriability is that it is firm-specific and does not

and at the same time, firms needed to have specified a positive amount spent on innovation.

[2] 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 innovative 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).

[3] See Table A1 in the Appendix for the construction and definition of all variables used. Table A2 in Appendix also provides a tabulation of the results from the original survey instruments for both incoming spillovers and appropriability and for cooperating and noncooperating firms.

[4] The industry is defined at the NACE two-digit sector level and the average is the average score from the firms responding in the sample.

[5] Several approaches are used in the literature: input–output flows, technology flows obtained from patent information (Jaffe, 1986; Jaffe et al., 1993), and import or FDI flows for international channels (David T. Coe and Helpman, 1995).

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 of incoming spillovers and appropriability, which would lead to problems of measurement error.[6] Other studies, most notably Richard C. Levin (1988) and Cohen and Levinthal (1989) have found that including industry means for the qualitative variables reduces the problems of using subjective measures. They use the Yale Survey data to construct measures of appropriability at the industry level and these variables have been widely used in related applications.[7] 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.[8] Our two-step empirical method allows an alternative correction for measurement error, avoiding industry aggregation.

R&D Cooperation.—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 cooperation variable equal to 1 when firms indicated that they had at least one cooperative agreement with any type of partner and 0 otherwise. 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).[9] In order to uncover common characteristics of the cooperation decision we first pool the data on cooperative agreements. Next, we perform our analysis for cooperative agreements with vertical partners and research institutes separately.[10]

II. Empirical Model

The focus of the analysis is on the effects of our measures of incoming spillovers and appropriability on R&D cooperation. 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.

The theoretical literature does not provide a clear-cut prediction 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 a cooperative R&D agreement. Distinguishing between different types of cooperative R&D agreements (vertical cooperation [i.e., cooperation with suppliers or customers] and 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 deal-

[6] Individual respondents might differ in their use of the 5-point scale. Unfortunately, our data set lacks a panel structure that would allow for simple fixed firm-effect corrections.

[7] See, among others, Levin et al. (1985), Cohen et al. (1987), Levin (1988), Levin and Peter C. Reiss (1988), Cohen and Levinthal (1989), and Alvin K. Klevorick et al. (1995).

[8] As Iain Cockburn and Griliches (1988), we find that within-industry variation in spillover and appropriability variables is much more important than between-industry variation.

[9] 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 nonpartners in cooperation.

[10] 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. This contrasts with the bulk of the theoretical literature, which mainly analyzes cooperative agreements between competitors.

ing with more commercially sensitive information in vertical cooperative agreements.

In addition to our spillover measures we include variables previously shown to affect cooperation in R&D (Massimo G. Colombo and Paola Gerrone, 1996; Lars-Hendrik Röller et al., 1997). These prior studies provide strong evidence that firm size and R&D orientation of firms positively affect 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 nonlinear effect of firm size on the probability of cooperation in R&D and include a dummy variable for whether or not the firm performs R&D on a permanent basis.[11]

Other motives for cooperative R&D, such as cost and risk sharing as well as getting access to complementary knowledge, have also been found to be important (P. Mariti and R. H. Smiley, 1983; Beverly B. Tyler and H. Kevin Steensma, 1995; Mariko Sakakibara, 1997a, b). Our survey data allow 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 innovation, we expect to observe more cooperative R&D agreements for the purpose of cost sharing. We construct an aggregate measure of the responses to questions on the importance of costs as an obstacle to 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. Complementarities measure the availability of technological know-how within the firm, which increases the scope for complementarities between partners in a cooperative R&D agreement.[12] Finally, we include a variable on the level of cooperation in the industry, which we assume will pick up unobserved industry-specific attributes that contribute to the decision of a firm to engage in a cooperative R&D agreement.[13]

The level of incoming spillovers and the effectiveness of appropriation mechanisms might not only affect profitability and hence the decision to cooperate; 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 profitability as well as the stability of cooperation. Moreover, in response to free-riding, firms will want to limit *outgoing* spillovers to nonpartners. We expect that firms that are considering R&D cooperation have an incentive to become more successful at controlling information sharing with their partners, as well as limiting free-riding by nonpartners. 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 less effect on appropriation. Vertical cooperative agreements, on the contrary, might be more hazardous for appropriation given their commercially sensitive content.

In addition to the decision to cooperate, incoming spillovers depend on the firm's absorptive capacity. This is captured through permanent R&D. Furthermore, as generic research diffuses more easily, 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 (Kamien and Zang, 2000). These firms are expected to have a higher score on incoming spillovers. We proxy

[11] See 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.

[12] The construction of the variables on costs, risk, and complementarities 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 with the measurement error/subjectivity from the response to the importance of external sources of information and the effectiveness of measures of protection. This is consistent with the low correlation between incoming spillovers and appropriability on the one hand and costs, risk, and complementarities on the other.

[13] Dummy variables for the industry, when included, were not significant and did not affect the results.

the "basicness" of R&D performed by the firm in terms of 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.[14]

The competitive environment of the firm influences the strategic protection variable. More export-intensive firms typically face a more competitive environment. Moreover, firms with a higher internal technological capacity might be better both at absorbing incoming spillovers and at protecting their knowledge through secrecy, complexity, or lead time. Therefore, we include permanent R&D as an explanatory variable for appropriation. Also included as instruments are the industry averages for each of the endogenous variables. We assume that each of these industry variables picks up the effect of unobserved industry-specific attributes that contribute to that endogenous firm-specific variable. It is unlikely that many of these instruments are truly exogenous. Nevertheless, for the purpose of our investigation (uncovering the relation between cooperation and spillovers), they will be assumed to be exogenous. The only exception is the permanent R&D variable, for which there are strong a priori reasons identified in the literature to expect endogeneity (Colombo and Garrone, 1996; Veugelers, 1997). In order to address the possible endogeneity problems between R&D cooperation, spillovers, and permanent R&D, we will use a two-step estimation procedure. This procedure consists of first regressing the endogenous variables on all the *assumed* exogenous variables. In the second step, we use the predicted values of the endogenous variables as independent variables in the structural equations. This estimation procedure may also alleviate problems of measurement error arising from the use of qualitative measures of incoming spillovers and strategic protection by regressing these measures on exogenous instruments.[15,16]

Table 1 presents descriptive statistics on the variables. 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.[17]

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

A. *Spillovers and Cooperation*

We estimate a probit model of whether the firms decide to cooperate or not.[18] The coefficients in Table 2 present the marginal effect of the independent variables on the probability of cooperating, while keeping everything else con-

[14] 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.

[15] In addition to being computationally less demanding, using our two-step estimation procedure provides more robust estimates compared to simultaneous estimating the system by maximum likelihood (see Francis Vella and Marno Verbeek, 1999).

[16] 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 the permanent R&D variable, we estimate the first-step equation for permanent R&D as a linear probability model and use the predicted value of the latent variable in the second step of the estimation (James J. Heckman and Thomas E. MaCurdy, 1985).

[17] For eight out of the nine questions used for the construction of the incoming spillovers and appropriability variables, the mean answer for cooperating firms was significantly higher, at the 1-percent 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 (see Table A2 in the Appendix).

[18] Logit estimations give similar results.

TABLE 1—DESCRIPTIVE STATISTICS

Variable	Sample mean (N = 411)	Mean, noncooperating firms (N = 226)	Mean, cooperating firms (N = 185)	Mean, cooperation with suppliers and customers (N = 135)	Mean, cooperation with research institutions (N = 135)
Incoming spillovers	0.457	0.413	0.511**	0.528**	0.535**
	(0.193)	(0.183)	(0.511)	(0.194)	(0.192)
Appropriability	0.513	0.464	0.572**	0.59*	0.573**
	(0.251)	(0.262)	(0.572)	(0.219)	(0.215)
Industry-level legal protection	0.144	0.135	0.154**	0.155**	0.155**
	(0.036)	(0.035)	(0.034)	(0.036)	(0.029)
Size	0.604	0.190	1.11**	1.34**	1.21**
	(2.31)	(0.72)	(3.28)	(3.79)	(3.35)
Permanent R&D	0.737	0.602	0.903**	0.904**	0.933**
	(0.441)	(0.496)	(0.297)	(0.296)	(0.25)
Cost	0.456	0.426	0.494**	0.486†	0.514*
	(0.183)	(0.189)	(0.168)	(0.16)	(0.155)
Risk	0.441	0.429	0.455	0.465†	0.467*
	(0.243)	(0.254)	(0.228)	(0.235)	(0.222)
Complementarities	0.725	0.723	0.727	0.744	0.715
	(0.194)	(0.191)	(0.198)	(0.171)	(0.198)

Note: Standard deviations are in parentheses.
† Difference in means between cooperating and noncooperating firms. Significant at the 10-percent level.
* Significant at the 5-percent level.
** Significant at the 1-percent level.

stant. 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)].[19] Incoming spillovers have a positive and significant effect on the probability of firms cooperating. Cooperating firms, because of the improved technological competence of the partners, better tap the existing base of know-how. This increases the expected profitability of cooperative agreements and hence makes them more likely to occur.

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

Regressions (4) and (5) demonstrate that the correction for the endogeneity does not change our findings on the signs and significance of the coefficients of the spillover effects, but significantly increases the estimated coefficients.[20]

[19] The overall predictive power of the estimated cooperation model is high: for instance, for the exogenous model of regression (2), more than 74 percent of all cases are predicted correctly where randomly assigning firms would only classify 55 percent correctly.

[20] See Table A3 in the Appendix for the first-step regressions from which the predicted values for incoming spillovers, appropriability, and permanent R&D have been constructed. The two-step estimation procedure used to correct for endogeneity regresses the endogenous variables on all the assumed exogenous variables in the first step: size, size squared, industry-level legal protection, cost, risk, complementarities, basicness of R&D, export intensity, industry-level cooperation (industry-level cooperation with suppliers and customers, industry-level cooperation with research institutions), industry level of incoming spillovers,

TABLE 2—RESULTS OF PROBIT REGRESSIONS FOR COOPERATION

Variable	(1)	(2)	(3)	(4) (2-Step)	(5) (2-Step)	(6) Cooperation with suppliers and customers (2-step)	(7) Cooperation with research institutions (2-step)
Incoming spillovers	—	0.472**	0.523**	0.968†	0.878*	0.0966	1.567**
		(0.155)	(0.15)	(0.52)	(0.44)	(0.47)	(0.46)
Appropriability	—	0.195†	0.302**	0.75†	0.66†	0.62†	0.523
		(0.11)	(0.11)	(0.42)	(0.35)	(0.37)	(0.39)
Industry-level legal protection	−0.116	−0.297	−0.159	−0.945	−0.908	−0.791	−0.953
	(1.03)	(1.08)	(1.09)	(1.20)	(1.19)	(1.09)	(1.01)
Permanent R&D	0.325**	0.288**	—	−0.0775	—	0.0482	−0.108
	(0.055)	(0.059)		(0.22)		(0.19)	(0.21)
Size	0.149*	0.143*	0.161*	0.149†	0.146†	0.095*	0.128**
	(0.076)	(0.072)	(0.08)	(0.08)	(0.08)	(0.049)	(0.046)
Size squared	−0.0058†	−0.00577†	−0.0067†	−0.0065†	−0.0062†	−0.00333	−0.00621**
	(0.0034)	(0.0032)	(0.0035)	(0.0035)	(0.0035)	(0.0022)	(0.0021)
Cost	0.831**	0.756**	0.792**	0.56*	0.577**	0.341†	0.546**
	(0.20)	(0.20)	(0.20)	(0.22)	(0.22)	(0.20)	(0.20)
Risk	−0.232†	−0.281*	−0.25†	−0.275†	−0.272†	−0.014	−0.316*
	(0.13)	(0.13)	(0.14)	(0.14)	(0.14)	(0.13)	(0.13)
Complementarities	0.30†	0.369*	0.407*	0.412*	0.395*	0.442**	0.241
	(0.17)	(0.17)	(0.17)	(0.17)	(0.16)	(0.15)	(0.15)
Industry-level cooperation	0.916**	0.930**	0.954**	0.961**	0.946**	—	—
	(0.21)	(0.21)	(0.21)	(21)	(21)		
Industry level of vertical cooperation	—	—	—	—	—	0.804**	—
						(0.26)	
Industry level of cooperation with research institutions	—	—	—	—	—	—	0.977**
							(0.17)
χ^2:	98.72**	106.51**	99.80**	85.87**	84.65**	77**	104.1**
LL:	−218.48	−211.76	−221.81	−228.09	−228.14	−225.18	−199.18
N:	411	411	411	411	411	411	411

Notes: Robust standard errors are in parentheses. The coefficients are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus. For permanent R&D, it is the effect of a discrete change from 0 to 1.
† Significant at the 10-percent level.
* Significant at the 5-percent level.
** Significant at the 1-percent level.

The increase in the estimated coefficients might not only indicate an endogeneity problem, but could also reflect a problem of measurement error with incoming spillovers and appropriability, in which case the uncorrected estimates are biased towards zero.[21] The permanent R&D variable shows up insignificant once corrected for endogeneity and does not significantly affect the point estimate of incoming spillovers and appropriability. One disadvantage of our two-

industry level of appropriability, industry level of permanent R&D.

[21] 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 exogenous variables such as costs, risk, and complementarities is uncorrelated with the error in incoming spillovers and appropriability (see footnote 12). Nevertheless, estimating the model without these other qualitative variables did not change our results on the coefficients of incoming spillovers and appropriability significantly. Moreover, we could not reject the null hypothesis for no endogeneity of a Hausman test for this case.

step procedure is that it introduces multicollinearity between the predicted values of the endogenous variables, reducing significance of the estimated coefficients.[22]

Next, we discuss the nonspillover 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 highly significant, with evidence of a nonlinear, concave, relation. 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. 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. 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.

B. *Spillovers and Cooperation with Different Types of Partners*

Some interesting differences emerge between the effect of incoming spillovers and strategic protection depending on the type of partner one cooperates with: customers/suppliers or research institutes. Regressions (6) and (7) in Table 2 present the results of a similar exercise as performed in the previous subsection, but for the separately estimated (two-step) probit models.[23] 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. All this seems to suggest that outgoing spillovers between industrial partners are more critical than spillovers to nonindustrial 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 costs and low risks 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 agreement entails higher costs and thus scope for cost-sharing and higher risks with an increasing probability of opportunism by partners. The search for external know-how and complementarities, however, is only significant for vertical cooperative agreements.

C. *Incoming Spillovers and Strategic Protection*

In Table 3 we present the results of the second-stage regressions of incoming spillovers and appropriability respectively. We find only weak evidence for endogeneity, with respect to the cooperative decision. The pooled cooperation variable does not significantly affect incoming spillovers nor appropriability [regressions (1) and (2)].[24] 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-percent level, is consistent with an information-sharing explanation of cooperation where cooperating firms increase their incoming spillovers because there are more opportunities for information

[22] Incoming spillovers, appropriability, and permanent R&D are closely related to the same (assumed exogenous) variables such as costs, basicness of R&D, and export intensity. See Table A3 in the Appendix.

[23] A similar table with the first-stage regressions such as Table A3 in the Appendix is available upon request.

[24] The Hausman test for endogeneity rejects the null hypothesis for no endogeneity of incoming spillovers and appropriability at the 10-percent level of significance only for the case of cooperation with research institutes. For the other cases, the null hypothesis could not be rejected.

TABLE 3—INCOMING SPILLOVERS AND STRATEGIC PROTECTION: RESULTS OF SECOND-STAGE REGRESSIONS

Variable	(1) Incoming spillovers	(2) Appropriability	(3) Incoming spillovers	(4) Appropriability
Cooperation	−0.0063	0.0313	—	—
	(0.21)	(0.028)		
Cooperation with suppliers and customers	—	—	0.0013	−0.081*
			(0.029)	(0.036)
Cooperation with research institutions	—	—	0.0462†	0.05
			(0.028)	(0.031)
Permanent R&D	0.123*	0.075	0.0878†	0.099
	(0.054)	(0.084)	(0.052)	(0.092)
Basicness of R&D	0.214**	—	0.184**	—
	(0.046)		(0.049)	
Export intensity	—	0.118*	—	0.141**
		(0.048)		(0.049)
Industry level of incoming spillovers	0.671**	—	0.635**	—
	(0.25)		(0.24)	
Industry level of appropriability	—	0.748**	—	0.795**
		(0.19)		(0.21)
Constant	−0.0671	−0.0033	−0.021	−0.0452
	(0.10)	(0.094)	(0.10)	(0.098)
R^2:	0.145	0.126	0.153	0.133
F:	20.68**	14.88**	16.74**	12.37**
N:	411	411	411	411

Note: Robust standard errors are in parentheses.
† Significant at the 10-percent level.
* Significant at the 5-percent level.
** Significant at the 1-percent level.

sharing due to the more basic nature of research projects [regression (3)]. Furthermore, regression (4) demonstrates that there is a positive effect of these cooperative agreements on the effectiveness of protection, most likely through increased complexity of products and processes, or through gaining lead time on competitors.[25] 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. In sum, we only find weak evidence indicating that by engaging in different types of cooperative R&D agreements, firms can affect their knowledge in- and outflows.

Turning next to other determinants of incoming spillovers and strategic protection, we find that absorptive capacity as measured by the permanent R&D effort of the firm 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 (i.e., the basicness of the R&D performed) is also an important determinant of incoming spillovers. 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 endogeneizing spillovers through the choice of research design, where basic research projects are more susceptible to external information flows. Exporting

[25] This effect is marginally significant at 11 percent.

firms, which typically face tougher competitive environments, protect their know-how more effectively.

IV. Conclusions

Our results on the relationship between firm-specific spillovers and R&D cooperation suggest that *incoming* spillovers and appropriability have important and separately identifiable effects: firms with higher incoming spillovers and better appropriation have a higher probability of cooperating 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 whom 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 that 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 agreement.

Furthermore, we find some evidence for a reverse effect of cooperation in R&D on incoming spillovers and appropriability. This effect only becomes apparent when distinguishing between different types of cooperative R&D agreements. Cooperation with suppliers or customers reduces 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. Therefore, firms should take care of protecting their proprietary information before engaging in these types of agreements. Cooperative agreements with research institutes increase the usefulness of the publicly available pool of knowledge and the effectiveness of appropriation mechanisms for the firm's innovation process. The former result presents evidence of information sharing within these cooperative agreements, while the latter might be an indication of the product/process complexity and lead time achieved through cooperation with research institutes.

Our results provide some 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 separately identifiable effects on the firm's cooperation decisions. Moreover, our results clearly do 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. 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.

TABLE A1—DESCRIPTION OF VARIABLES

Variable	Definition
Cooperation	Cooperation = 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
Industry level of cooperation	Mean of cooperation at industry level. Industry level is defined at two-digit NACE
Cooperation with suppliers and customers	Cooperation with suppliers and customers = 1 if firms cooperate with (1) suppliers, or (2) customers
Industry level of cooperation with suppliers and customers	Mean of cooperation with suppliers and customers at industry level. Industry level is defined at two-digit NACE
Cooperation with research institutions	Cooperation with research institutes = 1 if firms cooperate with (1) public research institutes, or (2) private research institutes, or (3) universities
Industry level of cooperation with research institutions	Mean of cooperation with research institutions at industry level. Industry level is defined at two-digit NACE
Size	Firm sales in 1992 in 10^{10} Belgian francs
Size squared	Firm sales in 1992 in 10^{10} Belgian francs squared
Export intensity	Export share in total firm sales
Permanent R&D	Permanent R&D = 1 if the firm's research and development activities have a permanent character
Industry level of permanent R&D	Mean of *Permanent R&D* at industry level. Industry level is defined at two-digit NACE
Incoming spillovers	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)
Appropriability	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)
Industry level of incoming spillovers	Mean of incoming spillovers at industry level. Industry level is defined at two-digit NACE
Industry level of appropriability	Mean of appropriability at industry level. Industry level is defined at two-digit NACE
Industry level of legal protection	Mean of legal protection at industry level. Industry level is defined at two-digit NACE. Legal protection 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) payback 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]
Complementarities	Complementarities = 1 − Importance of lack of technological information as an obstacle to innovation [number between 1 (unimportant) and 5 (crucial), rescaled between 0 and 1]
Basicness of R&D	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, and (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

Appendix

The data comprise a cross-section of Belgian manufacturing firms in 1992. A representative sample of 1,335 Belgian manufacturing firms was selected and a 13-page questionnaire sent out to them. The response rate was higher than 50 percent (748). The researchers in charge of collecting the data for the CIS also performed a limited nonresponse analysis and concluded that no systematic biases could be detected (Koenraad Debackere and Ilse Fleurent, 1995). From the raw questionnaire data we constructed the variables for our analysis described in Table A1. For example,

$$\text{Incoming Spillovers} = \frac{\text{Score Patent Info} + \text{Score Specialized Conferences} + \text{Score Trade Shows} - 3}{12}.$$

In Table A2, we present descriptive statistics on the questionnaire instruments for incoming spillovers and appropriability, and in Table A3 we present results of first-step regressions (used for constructing the predicted values of incoming spillovers, appropriability, and permanent R&D of Table 2 [regressions (4) and (5)] and cooperation and permanent R&D of Table 3 [regressions (1) and (2)]).

Table A2—Descriptive Statistics on Questionnaire Instruments for Incoming Spillovers and Appropriability

Instrument	Sample mean (N = 411)	Mean, noncooperating firms (N = 226)	Mean, cooperating firms (N = 185)	Mean, cooperation with suppliers and customers (N = 135)	Mean, cooperation with research institutions (N = 135)
Incoming spillovers					
Patent information	2.23	1.85	2.70**	2.76**	2.86**
	(1.15)	(1.00)	(1.16)	(1.16)	(1.18)
Conferences, meetings, and publications	3.05	2.87	3.28**	3.31**	3.39**
	(0.95)	(0.93)	(0.92)	(0.93)	(0.92)
Trade shows and seminars	3.20	3.23	3.16	3.27	3.16
	(0.94)	(0.98)	(0.89)	(0.89)	(0.87)
Appropriability					
Product secrecy	2.98	2.76	3.26**	3.32**	3.29**
	(1.19)	(1.20)	(1.12)	(1.08)	(1.12)
Product complexity	2.93	2.72	3.19**	3.27**	3.18**
	(1.19)	(1.20)	(1.14)	(1.13)	(1.15)
Product lead time	3.71	3.58	3.86**	3.93**	3.87*
	(1.06)	(1.15)	(0.91)	(0.88)	(0.90)
Process secrecy	3.07	2.83	3.37**	2.93**	3.40**
	(1.18)	(1.22)	(1.06)	(1.06)	(1.09)
Process complexity	2.95	2.71	3.25**	3.27**	3.23**
	(1.31)	(1.34)	(1.21)	(1.23)	(1.22)
Process lead time	3.01	2.85	3.21*	3.31**	3.21†
	(1.56)	(1.59)	(1.51)	(1.49)	(1.48)

Note: Standard deviations are in parentheses.
† Difference in means between cooperating and noncooperating firms significant at the 10-percent level.
* Significant at the 5-percent level.
** Significant at the 1-percent level.

TABLE A3—RESULTS OF FIRST-STEP REGRESSIONS USED FOR CONSTRUCTING THE PREDICTED VALUES OF INCOMING SPILLOVERS, APPROPRIABILITY, AND PERMANENT R&D OF TABLE 2, REGRESSIONS (4) AND (5), AND COOPERATION AND PERMANENT R&D OF TABLE 3, REGRESSIONS (1) AND (2)

Variable	Cooperation[a]	Incoming spillovers	Appropriability	Permanent R&D
Size	0.135**	0.00519	−0.0137	0.0457
	(0.049)	(0.013)	(0.017)	(0.029)
Size squared	−0.00551*	0.00003	0.00075	−0.00209
	(0.0025)	(0.00063)	(0.00083)	(0.0014)
Industry level of legal protection	0.602	−0.165	0.262	0.176
	(1.51)	(0.47)	(0.61)	(1.05)
Cost	0.972**	0.147*	0.323**	0.319*
	(0.21)	(0.64)	(0.083)	(0.14)
Risk	−0.223	0.115**	−0.0521	0.00425
	(0.14)	(0.044)	(0.058)	(0.099)
Complementarities	0.430*	0.0418	−0.07	0.148
	(0.17)	(0.053)	(0.069)	(0.12)
Basicness of R&D	0.392**	0.235**	0.0904[†]	0.284**
	(0.13)	(0.041)	(0.054)	(0.092)
Export intensity	0.190*	0.0438	0.183**	0.299**
	(0.086)	(0.028)	(0.036)	(0.062)
Industry level of cooperation	0.871**	−0.0526	−0.088	−0.206
	(0.23)	(0.073)	(0.095)	(0.16)
Industry level of incoming spillovers	−0.582	0.931**	−0.21	−0.173
	(0.86)	(0.265)	(0.35)	(0.59)
Industry level of appropriability	−0.089	0.0691	1.019**	−0.00044
	(0.70)	(0.22)	(0.29)	(0.49)
Industry level of permanent R&D	−0.0323	−0.0384	−0.071	0.876**
	(0.27)	(0.083)	(0.11)	(0.19)
Constant	—	−0.246[†]	−0.0846	−0.37
		(0.14)	(0.19)	(0.32)
	$\chi^2 = 113.94$**	$R^2 = 0.203$	$R^2 = 0.19$	$R^2 = 0.232$
	LL = −225.87	$F = 8.46$**	$F = 7.81$**	$F = 10.02$**
	$N = 411$	$N = 411$	$N = 411$	$N = 411$

Notes: A similar table for regressions (6) and (7) of Table 2 and regressions (3) and (4) of Table 3 is available upon request. Standard errors are in parentheses.

[a] The coefficients of the cooperation regression are the marginal effect of the independent variable on the probability of cooperation, ceteris paribus. Note that cooperation is a probit regression while incoming spillovers, appropriability, and permanent R&D are linear regressions.

[†] Significant at 10-percent level.

* Significant at 5-percent level.

** Significant at 1-percent level.

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