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Determinants of R&D Cooperation in Small and Medium-Sized Enterprises

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Abstract

We investigate the determinants of R&D cooperation in small and medium-sized enterprises (SMEs). Using firm-level data from the 2002 Korean Innovation Survey and applying a probit model with sample selection, we find that incoming spillovers of knowledge have a significant and positive impact on SMEs' decisions to engage in cooperative R&D. In particular, the effect of knowledge spillovers on R&D cooperation is much larger for smaller firms. Despite the importance of external knowledge for SMEs, the estimation results suggest that SMEs may have a disadvantage in establishing external R&D linkages because of their absolute size limitations.

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1. Introduction

Most small and medium-sized enterprises (SMEs) have few formal R&D activities and depend heavily on external sources of knowledge (Acs, Audretsch, and Feldman, 1994). Thus, R&D cooperation with other firms, research institutions, or universities can be a viable way for SMEs to obtain new knowledge. In undertaking cooperative R&D activities, SMEs may have behavioral advantages over large firms; namely, SMEs might be able to respond more rapidly to external threats or opportunities and may have more efficient internal communication.[1] However, possible disadvantages for SMEs include insufficient resources for organizing successful R&D collaboration and the lack of absorptive capacity in gaining benefits from knowledge spillovers.

Using data from the 2002 Korean Innovation Survey (KIS), we examine the determinants of R&D cooperation in SMEs.[2] As determinants of cooperative R&D activities, we consider variables related to information flow (e.g., incoming knowledge spillovers and appropriability) and other factors (e.g., cost, risk, and technological complementarity). In particular, we focus on the differential effects of incoming knowledge spillovers and appropriability in R&D cooperation according to firm size. We also investigate whether SMEs have a disadvantage in R&D cooperation because of their absolute size limitations and lack of absorptive capacity.

We find that incoming spillovers have a significant and positive impact on SMEs' R&D cooperation. We also find that incoming spillovers have a larger effect on smaller firms, which suggests that obtaining external knowledge is a key determinant of SMEs' R&D

[1] For example, Link and Rees (1990) show that small firms utilizing university-based research relationships are as a result more efficient in their internal R&D because they avoid bureaucratic inefficiencies.
[2] See Acs and Audretsch (1990) for an overview of factors affecting innovation activities in SMEs. Using the 2002 KIS and the CIS2, Mun and Chun (2006) and Vaona and Pianta (2008) examine the relationship between firm size and innovation activities for Korean and European manufacturing firms, respectively.

cooperation. However, neither strategic protection nor industry-level legal protection is related to cooperative R&D. Among the traditionally considered factors, both risk and technological complementarity are significantly and positively related to SMEs' R&D cooperation, but sharing costs is not.

The estimation results for different types of partners suggest that incoming spillovers stimulate both cooperation with suppliers and customers (vertical cooperation) and cooperation with research institutions and universities (institutional cooperation). Incoming spillovers have a larger marginal effect on the probability of cooperation with research institutions and universities than with suppliers and customers. Risk sharing is particularly important for vertical R&D cooperation with suppliers and customers while seeking complementary knowledge is a key determinant for institutional R&D cooperation.

Correcting the sample selection bias is econometrically crucial in investigating SMEs' cooperative R&D activities. Similar to the Community Innovation Survey (CIS), the KIS questionnaires on R&D cooperation are restricted to innovative firms.[3] Excluding non-innovative SMEs, which make up more than half of the total number of SMEs, may lead to sample selection bias if participation in cooperative R&D is correlated with SMEs' decisions to innovate. To address this bias due to simultaneous decision, we apply a bivariate probit model with sample selection. Estimation results using the sample selection model suggest that SMEs may have a disadvantage in establishing external R&D linkages because of their absolute size limitations, while the results of the simple probit model do not.

The remainder of this paper is organized as follows. Section 2 provides a brief review of the literature on the determinants of cooperative R&D. Section 3 describes the 2002 KIS

[3] Cassiman and Veugelers (2002) and many others analyze only the subsample of innovative firms. If the two probit equations of innovation activity and R&D cooperation are separately estimated, the estimated coefficients could be biased unless the error terms are uncorrelated. To address this problem, Cassiman and Veugelers (2002) and others use instrumental variables in their studies.

dataset and the construction of variables. Section 4 presents empirical specification dealing with the simultaneity problem. Section 5 discusses the empirical results, and Section 6 presents our conclusions.

2. Related Literature on R&D Cooperation

The growing phenomenon of R&D cooperation has attracted both theoretical and empirical studies to identify the determinants of R&D cooperation. Here we briefly discuss the motives behind cooperative R&D examined in the previous studies.

The industrial organization literature has pointed to technological spillovers as one of the important factors influencing firms' incentives to engage in cooperative R&D (Katz, 1986; d'Aspremont and Jacquemin, 1988; Kamien, Muller, and Zang, 1992). R&D spillovers arise when new knowledge created by one firm is also beneficial to other firms. Theoretical studies suggest that a high level of R&D spillovers can increase firms' probability of internalizing the spillovers by participating in R&D cooperation.

The relationship between spillovers and R&D cooperation has also been analyzed using empirical studies. Cassiman and Veugelers (2002) measure firm-specific incoming spillovers in terms of the relative importance of publicly available information to the innovation process and estimate their impact on R&D cooperation.[4] They find that higher incoming spillovers increase the probability of cooperating with research institutions and universities but have no effect on cooperation with customers or suppliers. In a similar vein, Branstetter and Sakakibara (2002) examine the research productivity of a large number of Japanese firms participating in research consortia and show that research consortia outcomes as measured by the number of patents are positively associated with the level of potential R&D spillovers.

López (2008) also find that spillovers positively affect the probability of R&D cooperation with research institutions for Spanish manufacturing firms. Belderbos *et al.* (2004) distinguish the effects of spillovers from other sources on various types of cooperation: with competitors, with suppliers or customers, and with universities or research institutions. They report that spillovers from one type of R&D partner have a more significant impact on the probability of R&D cooperation with the same type of partner. They also find that knowledge spillovers from universities and research institutions facilitate all types of R&D cooperation.

Although empirical studies on the relationship between spillovers and R&D cooperation are expanding, there are few analyses focusing specifically on SMEs. It is critical for SMEs to use external knowledge to produce innovative products. Audretsch and Vivarelli (1996) show that not only are knowledge spillovers important for small firms to be able to innovate, but they are much more important for small firms than for larger firms. Thus, it is to be expected that R&D spillovers will positively influence SMEs' decisions on R&D collaboration.

The degree of spillovers from external knowledge depends heavily on a firm's ability to find, access, and exploit new information, or so-called absorptive capacity. According to Cohen and Levinthal (1989), absorptive capacity can be enhanced by investments by firms in their own innovative activities.[5] Therefore, increased internal R&D efforts can result in greater incentives for firms to engage in cooperative R&D.

Because data on R&D spending are not often available at the firm-level, many empirical studies have used other R&D-related measures to gauge absorptive capacity. For example, using the number of R&D employees to capture firms' absorptive capacity, Fritsch and Lukas

[4] In addition to R&D cooperation as inter-firm or inter-organization contacts, Simonen and McCann (2008) examine face-to-face knowledge spillovers from labor acquisition.
[5] Human resource and knowledge management are also crucial factors determining firms' absorptive capacity (Schmidt, 2005).

(2001) show that firms with higher shares of R&D employees are more likely to be engaged in cooperative R&D. Belderbos *et al.* (2004) include the share of R&D personnel and its square term in probit regressions. Their findings suggest that R&D intensity is positively related to the probability of R&D cooperation but that its marginal impact is decreasing. Tether (2002) and Miotti and Sachwald (2003) use dummy variables for whether or not a firm conducts R&D on a continuous basis. Their results suggest that firms that undertake R&D on a continuous basis are more likely to be involved in cooperative arrangements.

Firms' ability to control the outflows of knowledge can also have a distinct impact on decisions regarding cooperative R&D (Cassiman and Veugelers, 2002). If firms are not able to protect their knowledge successfully, the possibility of free-riding within and outside cooperative agreements increases (Kesteloot and Veugelers, 1995; Greenlee and Cassiman, 1999). Cassiman and Veugelers (2002) show that higher appropriability, as measured by the effectiveness of strategic protection of product and process such as secrecy, increases the probability of cooperating with suppliers or customers but has no significant impact on cooperation with research institutions. In contrast, López (2008) find that the effectiveness of strategic protection has a positive impact on cooperation with any type of partner.

The management literature often emphasizes firms' resource constraints as determinants of R&D collaboration (Hagedoorn, Link, and Vonortas, 2000). The resource-based perspective suggests that firms utilize R&D partnerships for accessing complementary knowledge, pooling risks, or sharing costs (Hagedoorn, 1993; Sakakibara, 1997). However, the empirical results on the effects of these factors on R&D cooperation are mixed. Miotti and Sachwald (2003) find that a lack of technological information within firms does not have an impact on the probability of R&D cooperation. However, Cassiman and Veugelers (2002) report that the probability of cooperation is higher for firms with more technological knowhow. They argue that a higher availability of technological knowledge implies that firms have a wider scope of innovation activities for potential cooperation.

In addition, the results of empirical studies on the hypothesis of cost and risk sharing as motivations for cooperative R&D do not point in the same direction. Bayona, García-Marco, and Huerta (2001) show that both risks and costs of innovation are significant determinants of cooperation. In contrast, Miotti and Sachwald (2003) find that neither influences the probability of cooperation. Cassiman and Veugelers (2002) show that sharing costs is an important factor affecting the decision to cooperate, whereas reducing risks is not. Distinguishing R&D cooperation by type of partner, Belderbos *et al*. (2004) find that risk constraints positively affect the probability of cooperation with rivals or suppliers, while cost sharing is only relevant for the decision of cooperating with research institutions.

3. Data

Following the Oslo Manual (OECD and Eurostat, 1997), the Science and Technology Policy Institute in Korea started the KIS for manufacturing firms in 1997 and continued the survey in 2000, 2002, and 2005.[6] The first two waves are experimental, and data are not available for public use. The 2002 KIS includes both privately held firms and corporations, while the 2005 KIS includes only corporations. Since we focus on the cooperative R&D activities in SMEs consisting mainly of privately-held firms, we choose to use the 2002 KIS rather than the 2005 KIS. Data used in this study contains information about the innovation activities of 3,775 manufacturing firms with at least 10 employees.

To consider simultaneous decisions regarding innovation activity and R&D cooperation, we construct two dependent variables. The dummy variable of innovation activity is set equal to 1 if firms are engaged in either product or process innovation activities during the period of 2001–2002. Non-technological innovations such as changes in marketing strategy, organization, or product design are excluded. Product innovation includes both new and improved products. Moreover, firms are defined as innovative even if their innovation activities are not successful. Among innovative firms, the R&D cooperation dummy variable is set to 1 if firms are engaged in at least one cooperative R&D activity with any type of partner; otherwise, the variable is set equal to 0. Types of partners include suppliers, customers, private and public research institutions, and universities.[7]

Following Cassiman and Veugelers (2002), we consider incoming spillovers to measure the importance of publicly available information to a firm's innovation process. Publicly available information has three types of sources: patent information; specialist conferences, meetings, and publications; and trade shows and seminars. The appropriability variable measures the effectiveness of legal and strategic methods for protecting new products and processes. We use strategic protection through secrecy, complexity, or lead time as a firm-level measure for appropriability but define legal protection as that provided by patents, brand names, or copyrights. The legal protection variable is calculated at the three-digit industry-level. We also consider other motives for cooperative R&D, such as sharing cost and risk as well as accessing complementary knowledge. The variables of incoming spillovers, appropriability, legal protection, cost, risk, and complementarity are defined only for innovative firms. These variables are classified from 1 (unimportant) to 5 (crucial) and are rescaled from 0 (unimportant) to 1 (crucial).

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[6] The OECD Frascati Manual focuses on measuring R&D expenditures (input), whereas the Oslo Manual measures innovation activities (output).

[7] We exclude R&D cooperation within a business group (so-called Chaebol). Moreover, we use a business group dummy variable to estimate the determinants of R&D cooperation to control for possibly different behavior of firms affiliated with the business group.

Firms continuously involved in R&D can have higher absorptive capacity and thus obtain more benefits from R&D cooperation. The permanent R&D variable measures continuous R&D activity and is set to 1 if a firm has a permanent research department.[8]

To measure firm size, we construct three dummy variables according to the number of employees (10–49, 50–99, and 100–299).[9] Because firm size can be affected by innovation activities, we use the number of employees in 1999. Firm size dummy variables enable us to investigate the nonlinear effect of firm size on the probability of innovation activity and R&D cooperation. Other variables are also considered as determinants of R&D cooperation and/or innovation activity. The export dummy variable is set equal to 1 if a firm has exports in 1999. The big city variable is a dummy variable set equal to 1 if a firm is located in one of the seven largest cities (including Seoul) in Korea. The three-firm concentration ratio is the sum of the sales of the largest three firms at the four-digit level market.[10] The business group variable is set equal to 1 if a firm belongs to a domestic or foreign business group and is 0 otherwise.

Table 1 presents descriptive statistics for 2,190 sample firms consisting of 1,147 non-innovative firms (52.4%) and 1,043 innovative firms (47.6%). Among the innovative firms, approximately 40.7% are engaged in at least one cooperative R&D activity with any type of partner. About 34.1% of firms engage in R&D cooperation with suppliers and customers, whereas about 29.7% of firms cooperate with research institutions and universities. Thus, about 23.1% of firms have R&D cooperation with both types of partners.

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[8] Other proxies for permanent R&D may include continuous R&D expenditures and the number of full-time R&D workers. However, these variables are not available for a substantial number of firms in the sample.

[9] Under the Framework Act on SMEs in Korea, a company with fewer than 300 employees is classified as an SME.

[10] To obtain the four-digit level three-firm concentration ratio, we aggregate the five-digit level ratio published by the Korea Development Institute using the weights of the industry sales.

[Table 1 about here]

As expected, average firm size is bigger among innovative firms than non-innovative firms, which indicates possible sample selectivity according to firm size. For example, only about 40% of firms with fewer than 50 employees have their own innovation activities, while more than 65% of firms with more than 100 employees are involved in such activities. If firm size is associated with a firm's own innovative activity as well as cooperative R&D activity, the disproportionate inclusion of innovative and bigger firms could bias the estimated effect of determinants of R&D cooperation.

As discussed earlier, some variables are defined only for innovative firms, such as R&D cooperation, incoming spillovers, appropriability, cost, risk, and complementarity. However, firm size and other variables are defined for all firms. For example, the average of the permanent R&D variable is significantly different for innovative and non-innovative firms. Because the activities of innovation and R&D cooperation can be correlated with each other, an effect of variables such as permanent R&D, which is related to innovative activity, cannot be consistently estimated in an equation determining R&D cooperation.

4. Empirical Specification

We use a bivariate probit model with sample selection. In the model, R&D cooperation (Y_2) can be observed only when another variable of innovation activity (Y_1) in the selection equation is equal to 1, given as follows:

$$Y_{2i} = \begin{cases} 1 & \text{if } X'_{2i}\beta_2 + u_{2i} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$Y_{1i} = \begin{cases} 1 & \text{if } X'_{1i}\beta_1 + u_{1i} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where Y_{2i} is observed only if $Y_{1i} = 1$, while Y_{1i} is always observed; and u_{1i} and u_{2i} have a standard bivariate normal distribution with the correlation coefficient, $\rho = corr(u_{1i}, u_{2i})$.

Constructing the log-likelihood function, we have three types of observations in the sample with unconditional probabilities: *Innovation and Cooperation* (*Y₂=1, Y₁=1*), *Innovation and Non-cooperation* (*Y₂=0, Y₁=1*), and *Non-innovation* (*Y₁=0*):

$$\begin{aligned} L = & \sum_{y_1=1, y_2=1} \ln[\Phi_2(X'_{1i}\beta_1, X'_{2i}\beta_2)] \\ & + \sum_{y_1=1, y_2=0} \ln[\Phi_2(X'_{1i}\beta_1, -X'_{2i}\beta_2)] \\ & + \sum_{y_1=0} \ln[1 - \Phi(X'_{1i}\beta_1)] \end{aligned} \quad (2)$$

where Φ and Φ_2 denote the univariate and bivariate normal cumulative distribution functions, respectively. Equation (2) is maximized with respect to the parameters of β_1, β_2, and ρ using the full information maximum likelihood method. If the error terms in the two equations are correlated ($\rho \neq 0$), a standard probit model using the subsample of innovative firms yields biased results.

In the estimation, we include two-digit level industry dummy variables to correct for possible endogeneity associated with industry-specific factors.[11] This assumes that the proportions of innovative firms, R&D cooperation, and other variables are substantially different across industries. In a similar vein, Cassiman and Veugelers (2002) and López (2008) use the industry averages of such variables as incoming spillovers and appropriability to control for endogeneity in explanatory variables in R&D cooperation equations.

5. Estimation Results

Main Results

Table 2 reports the estimation results for both the (simple) probit model and the bivariate probit model with sample selection.[12] The correlation coefficient between the residuals from the two equations in the bivariate probit model is significantly positive, which suggests a possible complementarity between a firm's own innovation activity and R&D cooperation.[13]

[Table 2 about here]

Results show that incoming spillovers have a significant and positive effect on the probability of firms' R&D cooperation in both the simple probit and bivariate probit with sample selection models. The positive effect of incoming spillovers on R&D cooperation is consistent with the findings of Cassiman and Veugelers (2002) using Belgian manufacturing firms and those of Lee and Choe (2006) using Korean manufacturing firms. Moreover, our results with a positive correlation coefficient also suggest an overestimated spillover effect in

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[11] Korean standard industry classification codes include 21 two-digit level manufacturing industries.

[12] The bivariate probit model corrects for the endogeneity problem and also provides more accurate estimates through the inclusion of non-innovative firms. In fact, the total sample size (2,190) is about twice as large as the number of innovative firms (1,043).

[13] However, in a study of cooperative R&D behavior in Italian manufacturing firms by Piga and Vivarelli (2004), estimation results of the bivariate model with sample selection show that the correlation coefficient is positive but not statistically significant. The simultaneity issue has also been examined in other studies on cooperative R&D activities. Using the multivariate probit model, Belderbos *et al*. (2004) show the complementarity (positive correlations) between types of R&D cooperation partners such as competitors, customers, and suppliers. In contrast, Piga and Vivarelli (2004) use a probit model with sample selection for a firm's decisions

the simple probit model due to sample selection. Consistently, both the coefficient estimate and marginal effect is smaller in the latter than in the former. This clearly indicates the possible endogeneity in the probit model associated with the inclusion of only innovative firms. For example, firms are more likely to innovate when they expect higher benefits of incoming spillovers through R&D cooperation.

In contrast to incoming spillovers, neither appropriability nor legal protection is associated with firms' R&D cooperation. Higher appropriability through strategic protection can have a positive effect on R&D cooperation because firms can control the outflow of commercially sensitive information. However, small firms often do not possess enough resources and market power to protect their technological knowledge (Arundel, 2001). Moreover, SMEs tend to have less bargaining power in cooperative agreements with large firms, which makes it difficult for SMEs to appropriate benefits from cooperative R&D. Our results suggest that the appropriability measured by the effectiveness of strategic protection is not relevant in SMEs' decisions on R&D collaboration. Legal protection has a negative sign but is not statistically significant. This variable is also not significant in Cassiman and Veugelers's (2002) findings but is negative and significant in the study by López (2008) only for cooperation with research institutions.[14]

Table 2 shows that sharing risk and technological complementarity seem to have positive effects on cooperation, while sharing cost does not. The marginal effects of the risk and technological complementarity variables in the bivariate probit model are 0.103 and 0.106, which is close to the marginal effect of incoming spillovers on R&D cooperation. The result indicates that not only obtaining complementary technology and knowledge through

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regarding internal (making) and external (buying) R&D and find a negative correlation, suggesting substitutability between internal and external R&D.

[14] The negative effect found in the study by López (2008) suggests that stronger legal protection may hamper the internalization of knowledge flows and therefore decrease the probability of R&D cooperation.

incoming spillovers but also sharing risk are key determinants of SMEs' cooperative R&D activities. Although cost is an important barrier impeding SMEs' innovation activities, it does not seem to be a critical factor influencing cooperation decisions. Collaborative R&D can be beneficial for both small and large firms because it enables firms to overcome their disadvantages in innovation (Rothwell and Dodgson, 1991). However, engaging in cooperative R&D is a cautious decision because SMEs undertake fewer R&D projects, which are the core of the firms' activity. Our results suggest that SMEs do not participate in cooperative R&D simply for the purpose of sharing the cost of innovation.

As pointed out in the study of Cohen and Levinthal (1990), a firm's R&D has the dual role of generating new knowledge and enhancing absorptive capacity. The estimation result suggests that SMEs with more absorptive capacity as measured by the continuity of R&D activities are more likely to involve R&D cooperation. The absolute size of firms turns out to be an important determinant of cooperative R&D. The firm size dummy variables are strongly significant in the sample selection model but are not significant in the simple probit model.[15] Because R&D cooperation is defined only for innovative firms, which are generally larger in size, the sample selection bias from more observations of bigger firms can mitigate the firm size effect on R&D cooperation. Correcting for sample selection, we find that small firms have a disadvantage in establishing external R&D cooperation because of size limitations, which may be associated with SMEs' lack of human resources, funding for long-term R&D, and risk spreading (Rothwell and Dodgson, 1991).

Table 3 presents the differential effects of spillovers and appropriability according to firm size tertile (10–49, 50–99, and 100–299). The importance of incoming spillovers as

[15] Instead of the firm size dummy variable, our models include the firm size variable (the number of employees in hundreds) together with the size-squared variable. The size variable is not significant at the 10% level in the simple probit model but is highly significant in the selection model. Firm size is reported to be significantly

measured by marginal effect decreases as the firm size becomes larger. In particular, we do not find a statistically significant effect of incoming spillovers on R&D cooperation for firms with more than 100 employees. The higher spillover effect indicates greater learning through R&D cooperation, and thus potentially higher marginal profit from cooperation is expected for smaller firms than for larger firms. Again, knowledge flow is a crucial factor determining cooperative R&D agreements. This knowledge flow is much more important for smaller firms' decisions to engage in R&D cooperation, which is consistent with the findings of previous studies that knowledge spillovers through R&D cooperation are a key determinant for SMEs' decisions on innovation activities.[16]

[Table 3 about here]

Results for Different Types of Partners

Table 4 shows the estimated results for R&D cooperation with different types of partners. We find positive and significant effects of incoming spillovers on cooperation with suppliers and customers as well as with research institutions and universities. The marginal effect is almost two times greater for cooperating with research institutions and universities than with suppliers and customers. Our finding is also consistent with those of Cassiman and Veugelers (2002) and López (2008), who report that incoming spillovers have a significantly positive effect on cooperation with research institutions but not on cooperation with suppliers and customers or competitors. In a similar vein, Oh (2006) find that Korean firms prefer research institutions to other types of firms as their R&D partners because they expect greater

positive in Cassiman and Veugelers (2002) for Belgium and in Lee and Choe (2006) for Korea, but not in Abramovsky *et al*. (2005) for France, Germany, and the U.K.

[16] Consistently, Chun, Mun, and Yoon (2007) find that incoming spillovers constitute a significant factor in determining cooperative R&D for firms in high-tech industries, but not in low-tech industries.

knowledge spillovers from research institutions.[17] Appropriability as measured by the effectiveness of strategic protection shows a significant and positive sign for cooperation with research institutions or universities but not for vertical cooperation. This indicates that firms that are good at controlling the outflow of commercially sensitive knowledge are more likely to engage in cooperative R&D with research institutions and universities.

[Table 4 about here]

In addition to spillovers and protection of knowledge, risk sharing is an important factor in cooperating with suppliers and customers, although its effect on cooperation with research institutions is smaller and marginally significant. Technological complementarity is positive and significant only for cooperating with research institutions, not with other firms. Firms sharing complementary technologies may compete in the market, which may weaken incentives for R&D collaboration among those firms. In this respect, Branstetter and Sakakibara (2002) show that research consortia outcomes are negatively associated with the degree of product market competition among consortia members. The marginal effect of incoming spillovers in cooperation with research institutions and universities is the largest of all variables, whereas the effect in vertical cooperation is closer to those of risk and other variables.

Overall, the results in Table 4 suggest that obtaining and protecting new knowledge is a key factor in determining R&D cooperation of SMEs, especially with research institutions

[17] In addition, Oh (2006) emphasizes trust among partners as an important factor determining the performance of R&D collaboration and shows that the free-riding problem is significantly reduced as firms' amount of investment in a project increases.

and universities, while strategic business decisions such as sharing risk or obtaining and protecting new knowledge can be important drivers of vertical R&D cooperation.

Table 5 reports the differential effects of spillovers and appropriability according to firm size tertile (10–49, 50–99, and 100–299) for two types of partners. R&D cooperation effects of incoming spillovers for both types of partners are negatively related to firm size. For each cross-product of size tertile and spillovers, the effect of spillovers is greater in cooperation with research institutions than in vertical cooperation. The findings are consistent with the results shown in Tables 3 and 4 and highlight the fact that incoming spillovers and appropriability are crucial factors in determining R&D cooperation for smaller firms, especially cooperation with research institutions and universities.

[Table 5 about here]

6. Conclusion

In this paper, we show that incoming spillovers, absorptive capacity, risk, and technological complementary are important determinants of Korean SMEs' decisions regarding R&D cooperation. Moreover, incoming flow of knowledge is a key factor for smaller firms' cooperation, particularly their cooperation with research institutions and universities rather than with other firms.

We also find that SMEs face size limitations in R&D cooperation. However, this does not imply that all SMEs have a disadvantage in R&D cooperation. For example, SMEs in technology-intensive industries may have a comparatively greater advantage in R&D cooperation than bigger firms because of their flexibility and ability to respond rapidly.

Identifying the sources of SMEs' size-related barriers to collaboration can help clarify their external knowledge linkages. These sources may be related not only to firm size itself but also to qualitative aspects of the SMEs such as their human capital and internal organization. Future data on these variables as collected by the KIS can help researchers to further analyze and understand such relationships.

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Table 1. Descriptive Statistics

	Total	Non-innovative firms	Innovative firms
R&D cooperation			
Cooperation	N/A	N/A	0.407
			(0.492)
Cooperation with suppliers and customers	N/A	N/A	0.341
			(0.474)
Cooperation with research institutions and universities	N/A	N/A	0.297
			(0.457)
Spillovers and other factors			
Incoming spillovers	N/A	N/A	0.454
			(0.288)
Appropriability	N/A	N/A	0.447
			(0.288)
Industry-level legal protection	N/A	N/A	0.449
			(0.127)
Cost	N/A	N/A	0.575
			(0.220)
Risk	N/A	N/A	0.595
			(0.259)
Complementarity	N/A	N/A	0.321
			(0.186)
Permanent R&D	0.423	0.146	0.729
	(0.494)	(0.353)	(0.445)
Firm size (Number of employees in hundreds)	0.065	0.053	0.078
	(0.057)	(0.047)	(0.064)
Firm size dummy			
Size < 50	0.540	0.623	0.449
	(0.498)	(0.485)	(0.498)
50 ≤ Size < 100	0.253	0.240	0.267
	(0.435)	(0.427)	(0.442)
100 ≤ Size < 300	0.207	0.137	0.285
	(0.405)	(0.344)	(0.452)
Other variables			
Big city	0.422	0.441	0.401
	(0.494)	(0.497)	(0.490)
Export	0.432	0.321	0.553
	(0.495)	(0.467)	(0.497)
Three-firm concentration ratio	0.374	0.356	0.393
	(0.224)	(0.223)	(0.224)
Business group	0.057	0.049	0.065
	(0.231)	(0.216)	(0.247)
Sample size	2,190	1,147	1,043

Note: Numbers in parentheses are standard deviations.

Table 2. Estimation Results for R&D Cooperation

	Probit model		Sample selection model		
	Cooperation Eq.		Cooperation Eq.		Innovation Eq.
	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient
Incoming spillovers	0.538***	0.208***	0.400***	0.096***	
	(0.158)	(0.061)	(0.131)	(0.035)	
Appropriability	0.114	0.044	0.085	0.020	
	(0.153)	(0.059)	(0.114)	(0.027)	
Industry-level legal protection	0.431	0.167	–0.264	–0.063	
	(0.431)	(0.166)	(0.334)	(0.081)	
Cost	–0.259	0.100	–0.179	–0.043	
	(0.255)	(0.099)	(0.193)	(0.047)	
Risk	0.589***	0.228***	0.429**	0.103**	
	(0.217)	(0.084)	(0.179)	(0.046)	
Complementarity	0.590**	0.228**	0.444**	0.106**	
	(0.250)	(0.097)	(0.202)	(0.051)	
Permanent R&D	0.385***	0.144***	0.291***	0.071***	
	(0.103)	(0.037)	(0.087)	(0.023)	
Firm size (50 ≤ Size < 100)	0.067	0.026	0.184**	0.046**	0.281***
	(0.101)	(0.039)	(0.085)	(0.022)	(0.068)
Firm size (100 ≤ Size < 300)	0.119	0.046	0.381***	0.101***	0.618***
	(0.103)	(0.040)	(0.095)	(0.026)	(0.078)
Big city	–0.100	–0.039	–0.099	–0.024	–0.055
	(0.085)	(0.032)	(0.070)	(0.017)	(0.059)
Export	0.143*	0.055*	0.353***	0.087***	0.461***
	(0.086)	(0.033)	(0.078)	(0.018)	(0.061)
Three-firm concentration ratio					0.451***
					(0.169)
Business group					–0.137
					(0.112)
LR test of Rho = 0:				0.880*	
Rho [Chi-squared(1)]				[2.97]	
Log-likelihood	–664.5			–1,993.9	
Sample size	1,043			2,190	

Notes: Numbers in parentheses are standard errors. Marginal effects are calculated at the mean values of the regressors. Cooperation, spillovers, appropriability, legal protection, cost, risk, and complementary variables are defined only for innovative firms. For permanent R&D, firm size, big city, and export dummy variables, marginal effects are in discrete changes from 0 to 1. All equations include two-digit level industry dummy variables.

[*] Significant at the 10 percent level

[**] Significant at the 5 percent level

[***] Significant at the 1 percent level

Table 3. Estimation Results for R&D Cooperation: Firm Size, Incoming Spillovers, and Appropriability

	Probit model		Sample selection model		
	Cooperation Eq.		Cooperation Eq.		Innovation Eq.
	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient
Incoming spillovers × Firm size (Size < 50)	0.839***	0.324***	0.618***	0.143***	
	(0.231)	(0.089)	(0.181)	(0.045)	
Incoming spillovers × Firm size (50 ≤ Size < 100)	0.610**	0.235**	0.432*	0.100*	
	(0.290)	(0.112)	(0.221)	(0.053)	
Incoming spillovers × Firm size (100 ≤ Size < 300)	0.012	0.005	–0.069	–0.016	
	(0.288)	(0.111)	(0.230)	(0.053)	
Appropriability × Firm size (Size < 50)	0.267	0.103	0.190	0.044	
	(0.227)	(0.087)	(0.163)	(0.038)	
Appropriability × Firm size (50 ≤ Size < 100)	–0.377	–0.146	–0.243	–0.056	
	(0.288)	(0.111)	(0.217)	(0.051)	
Appropriability × Firm size (100 ≤ Size < 300)	0.437	0.169	0.324	0.075	
	(0.291)	(0.112)	(0.230)	(0.054)	
Industry-level legal protection	–0.364	–0.141	–0.192	–0.045	
	(0.436)	(0.168)	(0.332)	(0.078)	
Cost	–0.260	–0.100	–0.176	–0.041	
	(0.256)	(0.099)	(0.189)	(0.044)	
Risk	0.599***	0.231***	0.429**	0.100**	
	(0.219)	(0.084)	(0.174)	(0.042)	
Complementarity	0.657***	0.254***	0.486**	0.113**	
	(0.252)	(0.097)	(0.200)	(0.048)	
Permanent R&D	0.380***	0.142***	0.285***	0.068***	
	(0.104)	(0.037)	(0.083)	(0.020)	
Firm size (50 ≤ Size < 100)	0.450**	0.176**	0.460***	0.119***	0.281***
	(0.225)	(0.088)	(0.172)	(0.049)	(0.068)
Firm size (100 ≤ Size < 300)	0.420*	0.164*	0.647***	0.179***	0.614***
	(0.229)	(0.089)	(0.181)	(0.055)	(0.078)
Big city	–0.104	–0.040	–0.104	–0.040	–0.055
	(0.085)	(0.033)	(0.085)	(0.033)	(0.059)
Export	0.157*	0.060*	0.157***	0.060***	0.459***
	(0.087)	(0.033)	(0.087)	(0.033)	(0.061)
Three-firm concentration ratio					0.461***
					(0.168)
Business group					–0.138
					(0.111)
LR test of Rho = 0:			0.899*		
Rho [Chi-squared(1)]			[3.41]		
Log-likelihood	–659.8		–1,989.0		
Sample size	1,043		2,190		

Notes: Numbers in parentheses are standard errors. Marginal effects are calculated at the mean values of the regressors. Cooperation, spillovers, appropriability, legal protection, cost, risk, and complementary variables are defined only for innovative firms. For permanent R&D, firm size, big city, and export dummy variables, marginal effects are in discrete changes from 0 to 1. All equations include two-digit level industry dummy variables.

* Significant at the 10 percent level

** Significant at the 5 percent level

*** Significant at the 1 percent level

Table 4. Estimation Results for R&D Cooperation with Different Partners

	Cooperation with suppliers and customers			**Cooperation with research institutions**		
	Probit	**Sample selection**		**Probit**	**Sample selection**	
	Coop. Eq.	Coop. Eq.	Innov. Eq.	Coop. Eq.	Coop. Eq.	Innov. Eq.
Incoming spillovers	0.576***	0.433***		1.090***	0.846***	
	(0.162)	(0.133)		(0.172)	(0.134)	
Appropriability	0.177	0.138		0.415**	0.318***	
	(0.157)	(0.118)		(0.165)	(0.123)	
Industry-level legal protection	–0.515	–0.358		–0.249	–0.073	
	(0.438)	(0.337)		(0.450)	(0.341)	
Cost	–0.143	–0.105		–0.031	0.031	
	(0.261)	(0.198)		(0.277)	(0.208)	
Risk	0.591***	0.453**		0.394*	0.269	
	(0.223)	(0.178)		(0.236)	(0.174)	
Complementarity	0.396	0.310		0.559**	0.447**	
	(0.256)	(0.201)		(0.276)	(0.208)	
Permanent R&D	0.329***	0.256***		0.515***	0.397***	
	(0.106)	(0.085)		(0.115)	(0.089)	
Firm size (50 ≤ Size < 100)	0.088	0.197**	0.283***	0.017	0.143	0.280***
	(0.104)	(0.086)	(0.068)	(0.109)	(0.089)	(0.068)
Firm size (100 ≤ Size < 300)	0.145	0.388***	0.620***	0.072	0.325***	0.624***
	(0.105)	(0.092)	(0.078)	(0.109)	(0.091)	(0.078)
Big city	–0.106	–0.102	–0.057	–0.014	–0.033	–0.052
	(0.086)	(0.072)	(0.059)	(0.091)	(0.074)	(0.059)
Export	0.133	0.338***	0.464***	0.160*	0.365***	0.461***
	(0.088)	(0.078)	(0.060)	(0.093)	(0.076)	(0.060)
Three-firm concentration ratio			0.416**			0.399**
			(0.169)			(0.169)
Business group			–0.170			–0.142
			(0.114)			(0.115)
LR test of Rho = 0:		0.900*			0.962**	
Rho [Chi-squared(1)]		[3.19]			[4.24]	
Log-likelihood	–631.2	–1,960.5		–566.8	–1,895.6	
Sample size	1,043	2,190		1,043	2,190	

Notes: Numbers in parentheses are standard errors. Cooperation, spillovers, appropriability, legal protection, cost, risk, and complementary variables are defined only for innovative firms. All equations include two-digit level industry dummy variables.

* Significant at the 10 percent level

** Significant at the 5 percent level

*** Significant at the 1 percent level

Table 5. Estimation Results for R&D Cooperation with Different Partners: Firm Size, Incoming Spillovers, and Appropriability

	Cooperation with suppliers and customers			Cooperation with research institutions`		
	Probit	**Sample selection**		**Probit**	**Sample selection**	
	Coop. Eq.	Coop. Eq.	Innov. Eq.	Coop. Eq.	Coop. Eq.	Innov. Eq.
Incoming spillovers	0.781***	0.586***		1.431***	1.077***	
x Firm size (Size < 50)	(0.238)	(0.179)		(0.261)	(0.199)	
Incoming spillovers	0.636**	0.459**		1.172***	0.877***	
x Firm size (50 ≤ Size < 100)	(0.296)	(0.222)		(0.320)	(0.244)	
Incoming spillovers	0.236	0.111		0.579*	0.441*	
x Firm size (100 ≤ Size < 300)	(0.292)	(0.238)		(0.303)	(0.250)	
Appropriability	0.336	0.251		0.555**	0.399**	
x Firm size (Size < 50)	(0.234)	(0.169)		(0.251)	(0.183)	
Appropriability	–0.185	–0.120		0.263	0.212	
x Firm size (50 ≤ Size < 100)	(0.294)	(0.215)		(0.311)	(0.231)	
Appropriability	0.337	0.258		0.443	0.362	
x Firm size (100 ≤ Size < 300)	(0.295)	(0.234)		(0.302)	(0.245)	
Industry-level legal protection	–0.484	–0.311		–0.190	–0.035	
	(0.442)	(0.335)		(0.455)	(0.344)	
Cost	–0.147	–0.105		–0.031	0.020	
	(0.261)	(0.195)		(0.278)	(0.208)	
Risk	0.601***	0.456***		0.394*	0.277	
	(0.224)	(0.172)		(0.237)	(0.177)	
Complementarity	0.442*	0.345*		0.613**	0.481**	
	(0.258)	(0.198)		(0.278)	(0.212)	
Permanent R&D	0.322***	0.250***		0.506***	0.398***	
	(0.107)	(0.082)		(0.116)	(0.090)	
Firm size (50 ≤ Size < 100)	0.383	0.422**	0.281***	0.275	0.331	0.278***
	(0.233)	(0.179)	(0.068)	(0.270)	(0.213)	(0.068)
Firm size (100 ≤ Size < 300)	0.395*	0.616***	0.617***	0.553**	0.675***	0.617***
	(0.236)	(0.191)	(0.078)	(0.258)	(0.212)	(0.078)
Big city	–0.109	–0.103	–0.057	–0.016	–0.032	–0.052
	(0.087)	(0.072)	(0.059)	(0.091)	(0.075)	(0.059)
Export	0.145	0.350***	0.463***	0.167*	0.366***	0.462***
	(0.089)	(0.076)	(0.060)	(0.094)	(0.077)	(0.060)
Three-firm concentration ratio			0.419**			0.398**
			(0.168)			(0.171)
Business group			–0.172			–0.149
			(0.114)			(0.115)
LR test of Rho = 0:		0.925*			0.941*	
Rho [Chi-squared(1)]		[3.65]			[3.39]	
Log-likelihood	–629.0	–1958.0		–563.9	–1893.1	
Sample size	1,043	2,190		1,043	2,190	

Notes: Numbers in parentheses are standard errors. Cooperation, spillovers, appropriability, legal protection, cost, risk, and complementary variables are defined only for innovative firms. All equations include two-digit level industry dummy variables.

* Significant at the 10 percent level
** Significant at the 5 percent level
*** Significant at the 1 percent level