The Contribution of R&D Outsourcing to Productivity Growth

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Abstract

Few studies have focused on the impact of R&D outsourcing on technological innovation and productivity despite the increased importance of R&D outsourcing. This study analyzes the productivity effects of investment in R&D outsourcing with a sample of Korean manufacturing industries from 2001 to 2009. The estimation results show a nonlinear U-shaped relationship between productivity and the share of R&D outsourcing capital for total R&D capital. This implies that the cost of R&D outsourcing outweighs its benefits in the early stages of R&D outsourcing. The U-shaped relationship is particularly pronounced in high-technology industries.

KEYWORDS: R&D outsourcing, productivity, R&D investment

1. INTRODUCTION

In recent years, we have observed important changes in R&D management strategies in the direction of increased reliance of companies on external sources of technology in highly industrialized countries as well as the trend toward greater R&D outsourcing (Chesbrough, 2003 and 2006). According to Howells (1999) and Howells, Gagliardi and Malik (2008), it is estimated that in 1993, Canadian and UK companies were spending 7% and 10%, respectively, of their total R&D budget on the external outsourcing of R&D. Expenditures on contracted research in Germany rose from 3.9 billion DM in 1987 to 9.6 billion DM in 1997 (Bönte, 2003). In a survey of US pharmaceutical companies, 56.6% of 105 companies responded that they outsourced at least some of their R&D in 1998, and this figure increased to 72.4% by 2003. Over the same period, the ratio of R&D outsourcing to total R&D investment increased by twelve percentage points from 13.8% in 1998 to 25.8%

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in 2003 (Howells, Gagliardi and Malik, 2008). For Korean firms, Lim and Lee (2009) report that of 24.1 trillion KRW of total R&D expenditures in 2007, 3.5 trillion KRW (14.3%) was spent on the external sourcing of R&D. The development of Korean firms from 'fast follower' approaches to creative and innovative 'technological leader' strategies has been accompanied by an increased emphasis on technological cooperation and R&D outsourcing.

Few studies focused on the impact of R&D outsourcing on technological innovation and productivity despite the increased importance of R&D outsourcing. In this paper, we test whether R&D outsourcing makes a positive contribution to production and total factor productivity (TFP) within the Korean manufacturing sector. Our approach is different from previous studies in that we assume and test non-linearity between R&D outsourcing and productivity and the estimation is based on a systematical estimation of R&D outsourcing using an Input-Output (I-O) Table. In addition, we distinguish a high-technology industry from low-technology industry in consideration of an industry specific character.

From the Korean Input-Output Table, we first estimate the volume of R&D outsourcing within the Korean manufacturing sector, and conduct an empirical estimation to test relationships among factors. In this study, a panel of 13 Korean manufacturing industries is analyzed from 2001 to 2009. A production function and TFP equation are formulated to estimate the contribution of R&D outsourcing on increased productivity. The main findings of this paper point to a non-linear U-shaped relationship between productivity and the share of R&D outsourcing capital in total R&D capital; in addition, the U-shaped relationship is particularly pronounced in high-technology industries.

The article is organized as follows. Section II summarizes previous literature regarding R&D outsourcing. Empirical estimations and the results of those estimations for 13 Korean manufacturing industries are summarized in Section III. Section VI concludes the paper.

2. LITERATURE REVIEW

Previous research into R&D outsourcing focuses on an explanation of why R&D outsourcing has increased so quickly and what factors motivate companies to outsource R&D. Transaction-cost theory (Williamson, 1987, Pisano, 1990) and core-competence theory (Veugelers, 1997, Cassiman and Veugelers, 2006) are used to explain the development of R&D outsourcing. Williamson (1987) utilizes transaction-cost theory to suggest that the deciding factors for a company in the decision to make or buy its technology ultimately rests on transaction costs. His approach evaluates uncertainty and transaction-specific assets to determine the magnitude of transaction costs. In this situation, uncertainty refers to changes in an environment that cannot be estimated but which could alter and have a significant impact on the terms and conditions of a transaction, and where this uncertainty can increase transaction costs through a variety of paths. For example, a higher likelihood of accidents would introduce imperfections into a contract, with an accompanying rise in the costs of contract enforcement and maintenance. Along with high levels of uncertainty come difficulties in the assessment of personal contributions, and this may result in negligence. These diverse uncertainties raise transaction costs and compel companies to select internal R&D rather than contracted R&D. In addition, the higher transaction-specific aspects become more pronounced also entails the attraction for contract companies to engage in opportunistic behavior. For example, a pharmaceuticals company that contracts with a start-up technology firm for several years of drug development has to invest heavily in early R&D and human resources development. If this leads to transaction-specific assets, the pharmaceutical company will be unable to subsequently change partners because of the scale of the initial development and provide the contracted R&D company leverage to pursue opportunistic behavior. According to transaction-cost theory, high levels of uncertainty and transaction-specificity cause companies to prefer in-house R&D over market-mediated transactions.

Another explanation for the growth of R&D outsourcing, the resource-based view, emphasizes core competencies. Winter (1987) and Prahalad and Hamel (1990) claim that the core competencies of a company must be entrusted to a company in which a long-term investment has been made in the areas of learning and development, using resources to secure a present and future comparative advantage. Transaction-cost theory focuses on isolated transactions and assesses their characteristics and associated costs; however, the resource-based view considers how diverse technical cooperative initiatives (strategic alliances, joint ventures, licensing, outsourcing, and cooperative research organization) help develop core competencies as well as how to choose the appropriate cooperation approach according to specific criteria. Companies want to maximize the value of existing core competencies or choose forms of cooperation that complement core competencies. With the goal of maximizing core competencies emerges the necessity for companies to connect to or develop existing knowledge resources. In this context, R&D outsourcing plays a key role in the assessment of the competitiveness of a company's core competencies. Cohen and Levinthal (1990) argue that absorptive capacity is the ability of a firm to evaluate the value of external knowledge and technology that enable its successful use. This absorptive capacity may be a by-product of a company's internal R&D, but could also be something that a firm naturally accumulates in the course of doing business. Transaction-cost theory assumes a decision of 'make' or 'buy'; however, the concept of absorptive capacity stresses the possibility of a correlation between internal 'make' and external 'buy'. Arora and Gambardella (1990) argue that internal technical ability determines the efficient use of external knowledge by a firm, and that this internal ability helps the firm evaluate and screen possible external knowledge. Rothwell (1992) indicates that technical innovation helps firms use external knowledge more effectively and efficiently.

Howells, et al., (2004 and 2008) and Mehta and Peters (2007) empirically analyze the motives of a company for R&D outsourcing and suggest that companies externally source R&D to compensate for limited internal R&D and technological ability, to reduce product development time, to reduce costs, and to share the risk and uncertainty with a partner or partners. Also, an interest in obtaining complementary assets and technologies which a firm could not source internally could be another reason for that firm's R&D outsourcing (Pisano, 1990, Chesbrough, 2003).

Davidson and McFetridge (1984) find that the likelihood of R&D outsourcing is inversely related to the size of the firm's R&D department and the radicalness of its technology. Wilson

(1977) and Kogut and Zander (1993) showed that R&D outsourcing is more likely for technologies that are less complex and that can be codified.[1] Trefler (2005) argued that outsourcing is the appropriate choice for sufficiently routine projects that can be fully scoped and described. Outsourcing is also affected by generic factors (Laursen and Salter, 2006). Outsourcing is more likely in industries with plenty of technological opportunities. Large companies are more likely to outsource because they look for high resource-soluble and complex technological innovations; however, knowledge-based small companies depend more on new and creative ideas and are hesitant to cooperate with outsiders due to the risk of idea leakage.

Of studies that empirically test the economic results of R&D outsourcing, some find that there is a positive correlation between R&D outsourcing and productivity improvements (Bönte, 2003, Griffith et al., 2004; Beneito, 2006, Lokshin et al., 2008). Cassiman and Veugelers (2006) showed that firms that actively combine internal and external R&D are more successful at technological innovation. Piga and Vivarelli (2004) examined the R&D decision-making process and found that R&D outsourcing decision-making is closely related to internal R&D decision-making, and firms with larger R&D expenditures the concentrate on product innovation have a higher propensity to source R&D externally. Regarding a firm's absorption capacity, internal R&D and external R&D complement each other and the positive impact of R&D outsourcing is possible when a firm has sufficient capacity to absorb the results (Lokshin et al., 2008). This implies that internal R&D can enhance a firm's absorption capacity that subsequently improves the practical use of external knowledge. Similarly, an empirical study of the Dutch manufacturing sector by Audretsch et al. (1996) found that R&D outsourcing reciprocally substitutes for internal R&D in mid- to low-technology industries; however, in high-technology industries, they complement each other.

3. ESTIMATION MODEL AND RESULTS

3.1.Estimation model

The impact of R&D outsourcing on productivity is estimated for 13 Korean manufacturing industries over the 2001-2009 period using the following two estimation equations (Equation (1) and Equation (3))[2] . As do Bönte (2003) and Husan et al. (2011), we also assume a non-linear relationship between productivity and R&D outsourcing[3].

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[1] The degree of complexity is measured by the amount of R&D needed for production.

[2] See Appendix 1 for a more complete discussion of estimation models.

[3] We report estimation results in which the linear relationship between productivity and R&D outsourcing is assumed.

The first estimation equation is based on the Cobb-Douglas production function framework:

$$(1)\quad \ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) = \mu_0 + lnA_{i,t} + \beta\ln\left(\frac{K_{i,t}}{L_{i,t}}\right) + \gamma\ln\left(\frac{R_{i,t}}{L_{i,t}}\right) + (k-1)lnL_{i,t}$$

$$+\theta s_{i,t}^{out} + \rho(S_{i,t}^{out})^2 + u_{i,t}$$

where $Y_{i,t}$ is value-added of the i th industry at period t, $L_{i,t}$ is labor, $K_{i,t}$ is physical capital stock, $R_{i,t}$ is R&D capital stock and $A_{i,t}$ is a multiplicative technology parameter. k=(α+β+γ) is defined as the degree of homogeneity. It is assumed that R&D capital stock consists of two types of capital: internal R&D capital ($R_{i,t}^{int}$) and R&D outsourcing capital ($R_{i,t}^{out}$). R&D capital stock can be calculated as:

$$(2)\quad R_{i,t} = R_{i,t}^{int} + R_{i,t}^{out} = R_{i,t}(1 + s_{i,t}^{out})$$

where $s_{i,t}^{out}$ is the share of R&D outsourcing capital stock in total R&D stock:

$$s_{i,t}^{out} = R_{i,t}^{out}/R_{i,t}$$

Secondly, we estimate the impact of R&D outsourcing on productivity using the index of total factor productivity (TFP):

$$(3)\quad \ln TFP_{i,t} = \mu_0 + \theta s_{i,t}^{out} + \rho(s_{i,t}^{out})^2 + u_{i,t}$$

where the index of total factor productivity (TFP) is defined as: $TFP_{i,t} = \frac{Y_{i,t}}{L_{i,t}^{\alpha}K_{i,t}^{\beta}R_{i,t}^{\gamma}}$ [4]

Here, it is assumed that an industry's TFP is a function of its share of R&D outsourcing.

Depending on the sign of θ and ρ in Equation (1) and Equation (3), there exist several possibilities. Case *1-a* and *1-b* in Figure 1 are two extreme ones; case *1-a* assumes ρ>0 *and θ* >0, and productivity continues to rise as the share of outsourcing increases. Case *1-b* is the opposite in which productivity declines as the share of outsourcing rises.

Figure 2 assumes ρ<0 *and θ* >0. In this case, it has a convex-shaped curve, that shows that R&D outsourcing has a negative impact on productivity if the share of R&D outsourcing exceeds a certain threshold level. A firm's R&D outsourcing may lead to an increased inflow of external knowledge that reciprocally raises productivity (positive assimilation effects) in early stages of outsourced R&D (Phase I). However, an increase in the share of outsourced R&D is synonymous with a decrease in the share of internal R&D that may result in a reduction in the ability of a firm to exploit knowledge spillovers (negative exploitation effects) and Phase II. Husan et al. (2010) explain the existence of Phase II in Figure 2 using the distance effect. They argue that a firm exhausts its op-

[4] The index of total factor productivity used in this study is defined as the ratio of real value-added to Thörnqvist index of inputs. Total input growth is the weighted sum of individual input growth rates.

tions for nearby R&D outsourcing partners and starts to outsource to geographically distant firms as the dependence of a firm on R&D outsourcing increases. Monitoring and information sharing with a firm over a long distance incurs additional expenses; subsequently, firms that depend more on distant outsourcing partners incur extra costs and see a reduced contribution of R&D outsourcing on productivity.

Figure 3 depicts the case of $\rho>0$ <0, and in this case, it has a convex, U-shaped curve. In Phase I of Figure 3, firms incur two kinds of costs (Husan et al., 2010). First, in order for a firm to build an outsourcing module in the early stage of R&D outsourcing, it creates fixed modularization costs, called modularity effects. In addition, a firm needs to get through the learning costs to select and monitor R&D partners as well as acquire subsequent know-how. Initial costs in the early stage of R&D outsourcing offset the benefits of outsourcing, resulting in a negative correlation between R&D outsourcing and productivity (Phase I of Figure 3).

FIGURE 1. CASE 1-a : $\rho > 0$ *and* $\theta > 0$; CASE 1-b : $\rho < 0$ *and* $\theta < 0$

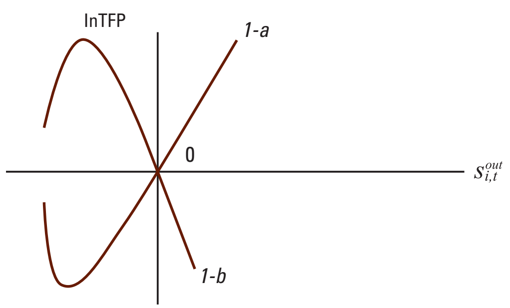


FIGURE 2. $\rho < 0$ *and* $\theta > 0$

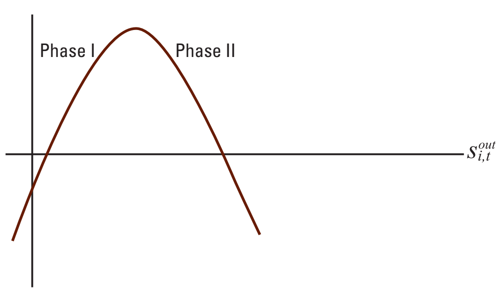
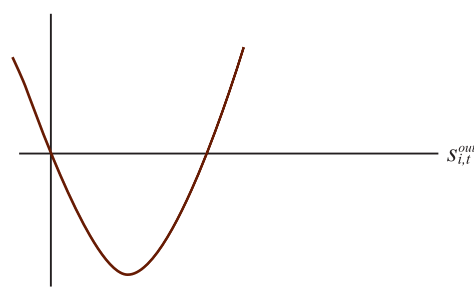


FIGURE 3. $\rho > 0$ *and* $\theta < 0$



3.2. Data

This study uses panel data for 13 manufacturing sectors in Korea from 2001-2009. To allow for differences between industries, we split the sample into two groups (high-technology industries and low-technology industries) using classifications proposed by the OECD[5]. Appendix 2 shows

[5] See Appendix 2 for technology classifications.

that six industries in the panel are regarded as high-technology industries. Data regarding the real value-added, labor income distribution rate, and capital income distribution rate used in this study were obtained from the Korea National Accounts of the Bank of Korea. The labor income distribution rate is based on the share of employee income and capital income distribution is calculated by subtracting the labor income distribution rate from Value 1. Labor force is obtained from Statistics Korea and represents the number of employees regardless of the number of working hours. R&D data is based on the Survey of Research and Development in Korea, published by the Ministry of Education, Science and Technology and OECD STAN data is used to calculate total fixed capital formation. Since the OECD STAN data covers only 1995-2006, total fixed capital formation data for 2007-2009 is computed using Bank of Korea data[6].

Capital stock is calculated using the perpetual inventory method and by assuming the depreciation rate of R&D capital and fixed capital stock at 15.0% and 9.4%, respectively. In estimating the initial value of physical capital stock and R&D capital stock, the following equations are used,

(4) $$K_{i,t-1} = \frac{KI_{i,t}}{\tau_K + g_K}, \quad R_{i,t-1} = \frac{RI_{i,t}}{\tau_K + g_R}$$

Where KI_t and RI_t represent investment in physical capital and R&D capital at time t, respectively. g_K and g_K are the average rates of increase for physical capital and R&D capital, respectively. τ_K and τ_K stand for the depreciation rate of physical capital and R&D capital.

Adopting the perpetual inventory method, we estimate physical capital and R&D capital stock as:

(5) $$K_{i,t} = KI_{i,t} + K_{i,t-1}(1-\tau_K)$$
$$R_{i,t} = RI_{i,t} + R_{i,t-1}(1-\tau_R)$$

To estimate R&D outsourcing investment, we follow the method used in Campa and Goldberg (1997) and Strauss-Kahn (2003), and using the Korean Input-Output Table provided by the Bank of Korea, the amount of R&D outsourcing is estimated from equation (6). Equation (6) shows R&D outsourcing (RDO_i), where dq_{ji} represents the total value of inputs from the domestic R&D service industry (j) employed to produce the output of industry i [7].

(6) $$RDO_i = \sum_{j=k+1}^{n} dq_{ji}$$

R&D outsourcing stock is calculated using the perpetual inventory method presented in equation (5)[8].

[6] See Appendix 3 for basic statistics.

[7] There is a possibility of overestimating when estimating R&D outsourcing using the I-O Table. But because the survey data conducted by Statistics Korea does not provide individual firm information, it is hard to construct consistent panel data. Therefore, we use the Korean Input-Output Table in our panel data despite this weakness. R&D service industries include ISIC 73 (research and development) and ISIC 74 (professional, science and technology services).

[8] See Appendix 4 for the share of external R&D and the growth of TFP.

3.3. Estimation Results

Table 1 summarizes the estimation results of Equation (1) using the OLS estimation, random effects model and fixed effects model. We also assume that the share of R&D outsourcing capital stock in total R&D capital stock is both linear and non-linear. Model (1) in Table 1 represents the OLS results using a dummy variable for year. The coefficient of R&D outsourcing share, $s_{i,t}^{out}$ is statistically significant at 1% and is positive. Other variables are also statistically significant at 1%. Models (2) and (3) are estimation results reached using fixed effects and random effects models, respectively. It fails to prove that the share of R&D outsourcing has a significant impact on productivity both in Models (2) and (3). Other variables (except physical capital) are also shown to be statistically insignificant.

Models (4) through (6) assume non-linear R&D outsourcing capital stock. In all results, the coefficients of non-linear R&D outsourcing capital stock $(s_{i,t}^{out})^2$, have a positive sign within the 5.08-6.29 range, and all are statistically significant at the 1% level; however,, $s_{i,t}^{out}$ has a negative sign with coefficient values between -10.7 and -8.0. Other independent variables are shown to be statistically significant. These results support the U-shaped curve in Figure 3, implying that R&D outsourcing triggers positive contributions to productivity only after the existing R&D outsourcing exceeds a certain threshold level.

Table 2 shows the estimation results for Equation (3). We test the effect of R&D outsourcing on total factor productivity using OLS estimation, a random effects model, and a fixed effect model; in addition, Table 1 tests for the possibility that $s_{i,t}^{out}$ is linear or non-linear. Assuming $s_{i,t}^{out}$ is linear in Models (1) through (3), the results show that $s_{i,t}^{out}$ is negative and statistically significant at the 1% level. Models (4) through (6) in Table 2 assume $s_{i,t}^{out}$ is non-linear. All of the non-linear terms of R&D outsourcing stock, $(s_{i,t}^{out})^2$, have positive values between 2.4 and 3.4, while the coefficients for $s_{i,t}^{out}$ all have a negative sign (-6.4 to -4.0). Table 2 reveals that R&D outsourcing shows a U-shaped

TABLE 1. Production Function Estimation Results

	OLS (1)	Fixed (2)	Random (3)	OLS (4)	Fixed (5)	Random (6)
ln(L)	-0.1956*** (0.0230)	-0.0941 (1.2229)	-0.2149*** (0.0583)	-0.2707*** (0.0850)	-0.1858* (0.1042)	-0.2629*** (0.0593)
ln(K/L)	0.6752*** (0.0346)	0.5372*** (0.1299)	0.6104*** (0.0822)	0.6195*** (0.1067)	0.6737*** (0.1117)	0.6183*** (0.0802)
ln(R/L)	0.1010*** (0.0259)	0.0382 (0.0678)	0.0273 (0.0477)	-0.0781 (0.0923)	-0.0619 (0.0593)	-0.0044 (0.0457)
s^{out}	0.6079*** (0.2440)	-0.3075 (0.5037)	-0.1908 (0.4115)	-10.4932*** (1.7702)	-10.7427*** (1.6753)	-8.0294*** (1.5075)
$(s^{out})^2$				6.2944*** (1.0172)	6.5028*** (1.0116)	5.0821*** (0.9529)
constant	2.7065*** (0.4768)	2.9863* (1.7924)	4.0513*** (0.9932)	8.6643*** (1.4401)	7.6749*** (1.6797)	7.5772*** (1.1690)
R^2	0.937	0.899	0.928	0.988	0.797	0.876
N	117	117	117	117	117	117

*Notes: 1) L: number of workers; K: physical capital stock; R: R&D capital stock; S^{out} share of R&D outsourcing capital in total R&D capital; standard error shown in parentheses; * denotes significant at 10% level; ** denotes significant at 5% level; *** denotes significant at 1% level; N: number of observations. 2) OLS estimations include unreported, year-specific dummy variables to control for time effects.*

curve with respect to total factor productivity and is similar to Table 1 that tests the impact of R&D outsourcing on productivity based on Equation (1). This again supports Figure 3, where R&D outsourcing contributes positively to total factor productivity only when it exceeds a certain threshold level.

TABLE 2. Total Factor Productivity Estimation Results

Variables	OLS (1)	Fixed (2)	Random (3)	OLS (4)	Fixed (5)	Random (6)
S^{out}	-0.6051*** (0.0888)	-1.2600*** (0.1477)	-1.0888*** (0.1292)	-4.0153*** (0.7248)	-6.4443*** (0.9990)	-4.5878*** (0.9054)
$(S^{out})^2$				2.5387*** (0.5362)	3.4383*** (0.6567)	2.3760*** (0.6118)
constant	5.2426*** (0.0650)	5.6730*** (0.1062)	5.5501*** (0.0979)	6.3491*** (0.2411)	7.5636*** (0.3733)	6.7965*** (0.3317)
R^2	0.395	0.338	0.338	0.500	0.400	0.397
N	117	117	117	117	117	117

*Notes: 1) S^{out}: share of R&D outsourcing capital in total R&D capital; standard error shown in parentheses. * denotes significant at 10% level; ** denotes significant at 5% level; *** denotes significant at 1% level; N: number of observations. 2) OLS estimations include unreported, year-specific dummy variables to control for time effects.*

We relax the assumption of identical slope coefficients by allowing for different slope coefficients that depend on the level of technology. To test for the differences between groups of industries, we introduce group dummy variables into Equation (3)[9]. The estimation results, in which industries are sorted into high-tech and low-tech according to OECD guidelines, are provided in Table 3. Of thirteen industries in our data, six are categorized as high-tech industries and we use a dummy variable for these high-tech industries[10]. Models (1) through (3) in Table 3 assume a linear relationship between R&D outsourcing and total factor productivity, while Models (4) through (6) assume non-linearity between the two. In Model (1), (based on OLS estimation) both R&D outsourcing, $S_{i,t}^{out}$, and the variable that combines $S_{i,t}^{out}$ with a high-tech industry dummy, $S_{i,t}^{out} D_{high}$, have statistically significant coefficients. For the high-tech industries, we estimate that the coefficient for R&D outsourcing is -0.2905 (-0.5099 + 0.2194), while it is -0.5099 for the low-tech industries. When assuming the non-linearity of R&D outsourcing, the coefficient for the combination variable, $S_{i,t}^{out} D_{high}$, using both fixed effects model (Model (5)) and random effects model (Model (6)), is statistically significant. This shows that there exists a significant difference between high-tech and low-tech industries. In addition, the value of the coefficients for variables $S_{i,t}^{out} + S_{i,t}^{out} D_{high} < 0$ and $(S_{i,t}^{out})^2 + (S_{i,t}^{out} D_{high})^2 > 0$ means that the U-shaped relationship in Tables 1 and 2 still holds.

[9] See Appendix 5 for a more complete explanation of the group dummy estimation equation.

[10] Chemicals and chemical products; basic metals/fabricated metal products (except machinery and equipment); machinery and equipment; other machinery and equipment; office, accounting and computing machinery/electrical machinery and apparatus, and radio, TV & communication equipment and apparatus; motor vehicles, trailers/other transport equipment.

TABLE 3. Total Factor Productivity Estimation Results Using High-Technology Industries Dummy

Variables	OLS (1)	Fixed (2)	Random (3)	OLS (4)	Fixed (5)	Random (6)
S^{out}	-0.5099*** (0.0697)	-0.2584 (0.2714)	-1.0315*** (0.1241)	-3.1194*** (0.6294)	-1.3405 (2.4311)	-3.9438*** (0.8538)
$(S^{out})^2$				2.0239*** (0.4331)	0.7044 (1.5750)	2.4054*** (0.6061)
$S^{out}D_{high}$	0.2194*** (0.0257)	-1.3421*** (0.3142)	0.0894 (0.0672)	0.4295** (0.2050)	-5.7300** (2.6233)	0.9943*** (0.3021)
$(S^{out})^2D_{high}$				-10.4932*** (1.7702)	-10.7427*** (1.6753)	-8.0294*** (1.5075)
constant	5.1169 (0.0526)	5.3642*** (0.1220)	5.4816*** (0.0918)	5.9159*** (0.2360)	6.4790*** (0.5302)	6.2653*** (0.3151)
R^2	0.640	0.257	0.447	0.720	0.355	0.501
N	117	117	117	117	117	117

*Notes: S^{out}: share of R&D outsourcing capital in total R&D capital; D_{high}: dummy variable of high-technology industries; standard error shown in parentheses. * denotes significant at 10% level; ** denotes significant at 5% level; *** denotes significant at 1% level; N: number of observations. 2) OLS estimations include unreported, year-specific dummy variables to control for time effects.*

4. CONCLUSION

A number of expected benefits of R&D outsourcing on a firm level (access to outside knowledge and accelerated product development) have been documented (Chesbrough, 2006); however, systematic empirical studies on the profitability of R&D outsourcing remain scarce. In this paper, we test the relationship between R&D outsourcing and productivity for 13 Korean manufacturing sectors from 2001-2009. The results suggest that the efficient allocation of R&D activities between internal and external R&D is relevant.

Using the R&D outsourcing estimation method by Campa and Goldberg (1997) and Strauss-Kahn (2003), we obtain the following results. First, there exists a non-linear relationship between R&D outsourcing and productivity. In particular, the estimation indicates a U-shaped relationship between the two. This implies that R&D outsourcing can make a positive impact on total factor productivity only if the share of R&D outsourcing stock in the total R&D budget exceeds a certain threshold level. Further research is needed to explain why this is so, but we can surmise that the modular costs and selection and monitoring costs of R&D outsourcing surpass its benefit in the early stages of R&D outsourcing. The benefits begin to exceed the costs as R&D outsourcing is repeated and the volume increased to result in a positive overall effect of R&D outsourcing on productivity.

Secondly, we divided the 13 manufacturing industries into high-tech and low-tech industries to control for industry-specific characteristics. Of 13 manufacturing sectors, six (chemicals and chemical products; basic metals/fabricated metal products [except machinery and equipment]; machinery and equipment; other machinery and equipment; office, accounting and computing machinery/electrical machinery and apparatus, and radio, TV & communication equipment and apparatus; and motor vehicles, trailers/other transport equipment) are categorized as high-technology.

Using a high-tech industry dummy, we find that the high-tech industries are clearly differentiated; however, the U-shaped relationship still holds for the high-tech industries.

In this paper, we use industry-level data. Our results do not extend to the firm level and cannot identify this there is heterogeneity among firms. Also, the estimation of R&D outsourcing using the Korean Input-Output Table can result in the problem of overestimation. Therefore, it would be interesting to perform firm-level empirical testing using firm-level data to focus on the effects of firm-specific characteristics (such as firm size) on the relationship between R&D outsourcing and productivity.

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APPENDIX

Appendix 1

The Cobb-Douglas production function framework proposed by Bönte (2003) is used to compare the productivity effects of investment in outsourced R&D and internal R&D,

(1) $$Y_{i,t} = A_{i,t} L_{i,t}^{\alpha} K_{i,t}^{\beta} R_{i,t}^{\gamma}$$

where $Y_{i,t}$ is value-added of the i_{th} industry at period t, $L_{i,t}$ is labor, $K_{i,t}$ is physical capital stock, $R_{i,t}$ is R&D capital stock and $A_{i,t}$ is a multiplicative technology parameter. It is assumed that R&D capital stock consists of internal ($R_{i,t}^{int}$) capital and R&D outsourcing ($R_{i,t}^{out}$) capital. R&D capital stock can be calculated as:

(2)[11] $$R_{i,t} = R_{i,t}^{int} + R_{i,t}^{out} = R_{i,t}(1 + s_{i,t}^{out})$$

where $S_{i,t}^{out}$ is the share of R&D outsourcing capital stock in total R&D stock: $s_{i,t}^{out} = R_{i,t}^{out}/R_{i,t}$

Substituting Equation (2) in Equation (1), taking the log and approximating In (1+ $S_{i,t}^{out}$) by $S_{i,t}^{out}$, Equation (1) can be written as:

(3) $$\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) \cong lnA_{i,t} + \beta \ln\left(\frac{K_{i,t}}{L_{i,t}}\right) + \gamma \ln\left(\frac{R_{i,t}}{L_{i,t}}\right) + (k-1)lnL_{i,t} + \gamma s_{i,t}^{out}$$

where $\mathbf{k} = (\alpha + \beta + \gamma) = 1$.

Alternatively, the relationship between the share of R&D outsourcing and productivity can be expressed as follows,

(4) $$TFP_{i,t} = e^{\theta S_{i,t}^{out}}$$

where the index of total factor productivity (TFP) is defined as $TFP_{i,t} = \frac{Y_{i,t}}{L_{i,t}^{\alpha} K_{i,t}^{\beta} R_{i,t}^{\gamma}}$

Here, it is assumed that an industry's TFP is a function of its share of R&D outsourcing.

Bönte (2003) and Husan et al., (2011) criticize Equation (4), which assumes a linear relationship. In their estimation, they assume non-linearity, but with an ad-hoc relationship as follows:

(5) $$TFP_{i,t} = e^{\theta s_{i,t}^{out} + \rho (s_{i,t}^{out})^2}$$

[11] This specification implies that there is no difference between internal and external R&D capital in respect to their productivity enhancing effects. We assume a perfect substitution between internal and R&D outsourcing capital.

Appendix 2

Industry Classifications

	Industry	Two-digit classification	Level of technology
1	Food products and beverages/tobacco products	15,16	Low technology
2	Textiles/wearing apparel/tanning and dressing of leather	17,18,19	Low technology
3	Wood and products of wood and cork/pulp, paper and paper products	20,21	Low technology
4	Coke, refined petroleum products, nuclear fuel	23	Low technology
5	Chemicals and chemical products	24	High technology
6	Rubber and plastic products	25	Low technology
7	Other non-metallic products	26	Low technology
8	Basic metals/fabricated metal products (except machinery and equipment)	27,28	High technology
9	Machinery and equipment	29	High technology
10	Other machinery and equipment	31	High technology
11	Office, accounting and computing machinery/ electrical machinery and apparatus, radio, TV & communication equipment and apparatus	30,32	High technology
12	Motor vehicles, trailers/other transport equipment	34,35	High technology
13	Furniture/recycling	36,37	Low technology

Appendix 3

Basic Statistics

Variables	Observation	Mean	Standard Deviation	Min	Max
ln(Y)	117	16.28	0.80	14,67	17.98
ln(L)	117	12.12	0.97	9.24	13.19
ln(K)	117	16.69	1.03	14.41	18.92
ln(R)	117	15.20	1.28	12.48	18.43
s^{out}	117	0.07	0.01	0.04	0.10
ln(Y/L)	117	4.15	0.74	3.09	6.45
ln(K/L)	117	4.51	0.84	3.00	6.71
ln(R/L)	117	1.80	1.52	-1.37	5.03

Appendix 4

Industry	g_{TFP}	$g_{S^{out}}$	S^{out}
Food products and beverages/tobacco products	0.5	13.8	7.4
Textiles/wearing apparel/tanning and dressing of leather	-0.3	12.5	8.4
Wood and products of wood and cork/ pulp, paper and paper products	0.4	13.5	8.8
Coke, refined petroleum products, nuclear fuel	1.4	16.2	6.7
Chemicals and chemical products	2.7	13.0	6.8
Rubber and plastic products	1.6	13.0	6.7
Other non-metallic products	1.1	18.4	8.2
Basic metals/fabricated metal products (except machinery and equipment)	3.5	14.0	7.6
Machinery and equipment	3.3	15.5	7.2
Other machinery and equipment	7.5	17.9	4.6
Office, accounting and computing machinery/ electrical machinery and apparatus, radio, TV& communication equipment and apparatus	3.8	11.5	8.1
Motor vehicles, trailers/other transport equipment	4.1	17.7	4.8
Furniture/recycling	-0.3	11.3	7.0

Notes: g_{TFP} : average annual growth rate of TFP; $g_{S^{out}}$: average growth rate of the share of R&D outsourcing capital; S^{out}: average annual share of R&D outsourcing capital in total R&D capital stock.

Appendix 5

Total Factor Productivity estimation equation with high-technology industries dummy,

$$\ln TFP_{i,t} = \mu_0 + (\theta + \textstyle\sum_j D_j\theta_{Dj})\, s_{i,t}^{out} + (\rho + \textstyle\sum_j D_j\rho_{Dj})\, (s_{i,t}^{out})^2 + u_{i,t}$$

where j represents groups of industries and D is a group dummy. Estimation slope coefficients of group j can be calculated by $\theta_j = \theta + \theta_{Dj}$ *and* $\rho_j = \rho + \rho_{Dj}$.