Two Stages of R&D Spillovers: Technological and Economic Impacts

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ABSTRACT

This paper empirically evaluates the effects of regional and industrial R&D on the performances of individual firms in two separated stages: (1) the stage of technological outcome from R&D and (2) the stage of economic outcome from technological outcome. Technological spillovers are separated from negative congestion effects through the stage-specific estimation. The firm-level Korean Innovation Survey data merit in coping with the endogeneity problem inherent in the estimation of spillovers. The estimation results show that: (1) there exist significant R&D spillovers both in regional and industrial dimensions, (2) the hypothesized technological spillovers and economic congestion effects are both in effect, and (3) firms with smaller individual R&D investments show greater spillovers.

KEYWORDS: R&D spillovers, congestion effects, Korean Innovation Survey, innovation stages

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1. INTRODUCTION

1.1 Background and Objective

The significance of innovation activity and the resulting knowledge spillovers have been emphasized by numerous scholars since the 1970s.[1] With knowledge spillovers or positive externalities from innovation activity, the innovation activities of an economic agent carries positive impacts on other geographically or technologically close innovations and outcomes by economic agents.

Several nations have pursued a Regional Innovation System and innovation clustering policies to promote knowledge spillovers. Implied within the policies are the international consensus of the ex-

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1 Early studies include Griliches (1979) and Mansfield (1977).

2 Cameron (1998) surveys empirical analyses of R&D spillovers.

istence and influence of knowledge spillovers generated by R&D and other knowledge production activities.

Empirical identification and testing of spillovers from innovation activity have been inadequate due to limited data and endogeneity problems.[2] Difficulties in empirical analysis are attributed to the following factors. First, the outcome of innovation activity, i.e. innovation, cannot be directly observed or numerically measured. Various estimates rely upon input variables such as R&D investment, patents, and economic outcome variables such as profits, sales, and productivity. Second, when estimating the effects of innovation activity on economic outcome, it is difficult to distinguish the impact of innovation activity from various economic activities and environmental factors, due to the long chain of the process from R&D and other innovation activities to economic outcomes. Third, when estimating the impacts of geographically and technologically close economic agents, there exists an econometric issue called an endogeneity problem. The first and second issues are direct concerns in studies estimating the effects of innovation activity, while the third issue is specific to the empirical analysis of spillovers and is explained in detail in the econometric modeling in Section 3. This study distinguishes the impacts of R&D onto the outcome of a firm into 2 stages, to empirically test the existence of geographical and technological spillovers among Korean manufacturing firms.

Stage (1): Technological spillovers - the impact of regional and industrial R&D or innovation activity on the success of the innovation of an individual firm.

Stage (2): Economic congestion effects - the impact of regional and industrial innovation on the market outcomes of a firm, i.e. revenue and profit.

R&D spillovers are divided into the stages of technological outcome from R&D and the stage of economic outcome from technological outcome. In each stage, R&D spillovers are tested in two different dimensions of geography and technology, in which spillovers represent regional and industrial group effects, respectively.

The data and methods of this study have the following advantages. First, this study uses a more direct innovation activity outcome variables than existing studies since the 2005 Korean Innovation Survey: KIS2005 data can directly observe whether individual firms succeeded in innovation in a specific period of time. By directly estimating the technological effects of innovation activity, the impact of extraneous variables during the path to economic outcome is limited. Second, the possible negative spillover effects due to congestion in the product market can be explicitly considered through a stage-specific process. The regional and industrial innovation activity is expected to have positive technological spillovers in the first stage, while the innovation of a competitor may have negative effects on the market outcome of a firm in the second stage. Third, endogeneity from industrial or other group-level analysis or time series analysis can be effectively treated by using individual firm-level data.

According to the empirical analysis, statistically and economically significant spillovers are found in both regional and industrial dimensions. In the industrial dimension, spillovers through patented technology are especially significant. Additionally, the hypothetical assumption of stage-specific analysis in the theoretical model is justified through the positive impacts of technological spillovers on the innovation of an individual firm and the negative impacts of spillovers on the economic outcome of an individual firm. Lastly, firms with smaller individual R&D investments have greater spillovers.

1.2 Literature

The basis of the literature is the idea that since knowledge is inherently public, a firm in a geographical or technological space with a high research activity level can yield better results than a firm in a space with a lesser research activity level (given an equivalent input to research activity). The idea has been observed in the pioneering work conducted in the 1970s by Griliches (1979) and Mansfield (1977). The same idea has risen as one of the core ideas in economic growth theory as it was highlighted as a source of continued economic growth by Romer (1986), Lucas (1988), and Grossman & Helpman (1991).

Early empirical studies focused on the case studies of an individual technology or industry, or focused on the dispersion effects at the meso-economic level. The main technological case studies include Griliches (1957, 1958, 1964), Schultz (1954), Masnfield et. al (1977), and Bresnahan (1986). On the other hand, studies involving regional spillovers at the meso-economic level set the total factor productivity as the dependent variable of interest and estimated the impact flow among industries or among innovative technologies. Scherer (1982, 1984), Schankerman (1979), and Mohnen & Lepine (1988) are prime examples of such studies.

Since the 1990s, improvements in econometric methods and available data have made analysis at the microeconomic individual firm level possible. Such studies include Geroski et. al. (1993) that use the British Science Policy Research Unit data and Adam & Jaffe (1996) that use the United States National Science Foundation R&D data.

While these studies reflected the characteristics of independent research from different countries, more recent studies utilized a more standardized and broader international statistical project, the European Community Innovation Survey (CIS), of which the KIS2005 was modeled after. Mariesse & Mohnen (2002, 2004), Cassiman & Veugelers (2002), and Jammotte & Pain (2005) used CIS in their studies and constitute a significant proportion of recent empirical analysis.

While most of the aforementioned studies look at regional spillovers, Jaffe (1986), Adams & Jaffe (1996), and Orlando (2004) look at the additional dimension of spillovers through geographical and technological proximity. In particular, Jaffe (1986) focuses on the main topic of this study, the distinction between technological dispersion and economic outcome. He points out that from a pure technological perspective, the R&D spillovers always bring positive externalities, but the observed economic variables comprise negative economic effects. This study does not explicitly separate the two effects due to data limitations, but implicitly verifies the existence of both effects via patent information.

The use of KIS2005 in this paper made it possible to explicitly estimate the two effects by setting up the "innovation success" variable as the main variable. The variable represents technological progress more directly than the proxy variables used by Jaffe (1986)[3], such as patents and profits.

[3] On the other hand, Jaffe (1986) has a relative advantage by establishing technological proximity metric through detailed patent data and defining the technological spillovers pool. Due to data limitations, this paper uses the industry group as a technological spillover pool. Considering that industrial grouping does not necessarily coincide with technological grouping, the validity of results may be limited.

2. THEORETICAL MODEL AND ANALYSIS METHOD

This section separates the innovation activity of a firm into the stage of "technological innovation from investment of innovation activity" and of "technological innovation to economic outcome," and assumptions about the special characteristics of each stage are established. In addition, variables affecting each stage are identified and an empirical approach using these variables is explained.

2.1 Identifying the Stages of Innovation Activity

The innovation activity of a firm and its results can be identified in the following 2 stages.

Stage 1: Innovation Input à Innovation (Technological Outcome)

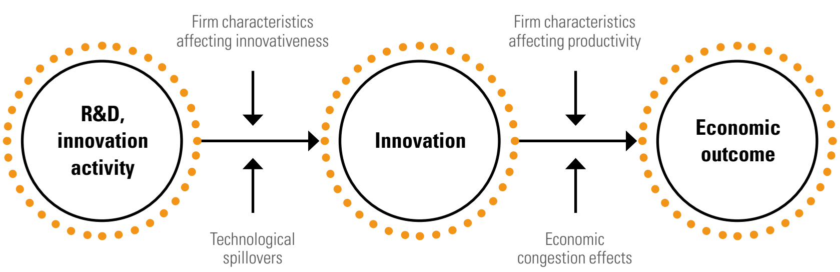
Stage 1 is where a firm invests resources to produce knowledge and achieves "innovation" as a result. Main inputs in Stage 1 include R&D investment, innovation activity, and R&D human resources. The main outputs include innovation and inventions. While patent applications involve a legal process, it is a result prior to economic outcome and can be included as an output in Stage 1.

Technological spillovers occur in this stage. The main paths involve personal and professional networking among researchers and engineers, technological transfers and trade among firms, and adoption and reverse engineering. Technological spillovers are expected to have positive externalities on the technological innovation levels of other firms.

Stage 2: Innovation (Technological Outcome) à Economic Outcome

Stage 2 is where innovation is transferred into economic outcome through revenue increase or cost reduction in the process of commercializing or manufacturing. Main inputs in Stage 2 include innovation outcome or new technology, and main outputs are measured in profits, sales, the market value of firms and other standard economic variables. In this stage, commercialized new technologies compete to gain market demand. The higher the level of innovation within a region or industry is expected to lower profits and sales for individual firms for a given market size through the congestion effects. Figure 1 summarizes and charts the stages of innovation activity.

FIGURE 1 STAGE-SPECIFIC MODEL OF INNOVATION ACTIVITY – INNOVATION – ECONOMIC OUTCOME



Variables affecting Stage 1 of the innovation activity include variables affecting the innovativeness of a firm and those that will make a difference in the innovation outcome given same level of innovation input. These include the firm size, age, industrial and regional characteristics, and other observables, along with the characteristics of human resources, organizational flexibility, the attitudes of the CEO toward innovation, and other unobservables.

Variables affecting Stage 2 are the ability of a firm to transform a given level of innovation into market sales and profits, such as industrial structure, market competition, market growth speed, productivity factors other than innovation, commercialization, and marketing. Observables such as firm size, age, industrial and regional characteristics, and other unobservables such as business administration techniques are all included.

2.2 Empirical Analysis Strategy

To establish the importance of the analysis of stage identification, the empirical analysis estimated the impact of innovation activity on the economic outcome of a firm as the benchmark. Then, verify the theories suggested in the stage identification by estimating the stage-specific model.

1) Estimation Model

(1) Benchmark Model: Impact of Innovation Activity on Economic Outcome

This model ignores the stage identification and estimates the impact of regional or industrial R&D on the economic outcome of an individual firm as the current literature does. In the benchmark model, the explanatory variable representing regional or industrial innovation activity uses the average R&D intensity of the regions or industry of a firm, and the dependent variable represents the outcome of a firm that uses the profits of a firm. The estimated spillovers from the benchmark model analysis are expected to be less than the spillovers estimated from the Stage 1 model discussed as follows. This is because the congestion effect from Stage 2 will be mixed in the estimation.

(2) Model 1: First Stage of Innovation Activity

This model is the first stage of the stage-specific model. The goal of econometric analysis is to verify the statistically positive impact of regional or industrial innovation activity on the technology innovation progress of an individual firm, then compare the results with the benchmark model results.

The regional or industrial average R&D intensity of a firm is used as the explanatory variable representing the regional and industrial innovation activity level. The success of technological innovation and patent applications within the observed period are used as the dependent variable representing the innovation outcome of a firm.

(3) Model 2: Second Stage of Innovation Activity

This model is the second stage of the stage-specific model. The goal of econometric analysis is to verify the statistically negative impact of the regional or industrial innovation activity level on the economic outcome of an individual firm, then compare the result with the benchmark model again.

The innovation rate or proportion of firms succeeding in technological innovation[4] among all the firms is used as the explanatory variable that represents regional and industrial innovation activity outcome. Individual firm profits are used as the dependent variable representing individual economic outcome.

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[4] Technological innovation is defined to include production innovation and process innovation following the OECD/Eurostat (2005).

2) Endogeneity of Group Effect Analysis

The biggest impediment in empirical analysis using a group level variable such as Model 1 and Model 2 is the endogeneity issues arising from estimating group effects in general. Specifically, the estimates may be biased due to unobservable or uncontrollable variables.

(1) Endogeneity Issue of Model 1

There are two main sources of the endogeneity issue in Model 1.

First, the estimated group effect is biased if there exists unobservable but common socioeconomic variables within the group affecting the innovation success of a firm. In Model 1, the impact of regional or industrial characteristics such as government policy and infrastructure may collectively be estimated as spillovers if other regional or industrial characteristics beside the R&D level is not perfectly controlled.

Second, the estimated group effect is biased if the unobservable heterogeneity of an individual firm is correlated to a group variable. For example, the estimated spillovers are upward biased if unobservable firm characteristics such as research personnel characteristics, organizational flexibility, or the attitude of a CEO toward innovation are associated with the choice of region or industry by a firm.

(2) Endogeneity Issue of Model 2

Similar to Model 1, there can exist two main sources of endogeneity in Model 2. However, the choices or environmental factors of an individual firm should not have a significant effect at this stage since the impact of the group innovation rate is estimated given the innovation level. Hence, the endogeneity issue in Model 2 should be significantly smaller.

(3) Solving Endogeneity Issue: The R&D Intensity of an Individual Firm

To address the endogeneity issue in Stage 1, the R&D intensity of an individual firm can be thought of as the control variable. All the endogeneity among common socioeconomic variables or unobservable factors are statistically correlated with the R&D intensity of a firm.[5] Hence, this variable functions as a sufficient statistic for variables raising endogeneity. A further endogeneity issue is not assumed after controlling for the R&D intensity of a firm and as a result, the coefficient of R&D intensity is not interpreted as marginal effects. Following the same logic, the existence of endogeneity issue in Model 2 is solved using the innovation outcome of an individual firm as the control variable.

3. DATA

The KIS2005 is used for data on individual firm level characteristics, innovation activity and success, regional and industrial group R&D intensity, and group technological innovation.

The KIS2005 is a survey on technological innovation activity for firms included in the Korean Standard Industry Classification (KSIC) section 15-37, with 10 or more employees. The main idea

[5] In many studies focusing on the R&D impact of a firm on innovation outcome, this variable is a main problem as the endogenous variable. This study estimates the regional or industrial R&D intensity effects. The R&D intensity of a firm is used only to control for the endogeneity and the estimates are not interpreted as marginal effects.

and methods follows the OECO Oslo manual (OECD/Eurostat, 2005) and the selection of the methods follows the European CIS. The sample includes 2,743 firms proportionally drawn to represent the whole population.

Considering the topic, only firms in 8 of the relatively high innovation rate industries are included in the empirical analysis.[6] Regarding regions, Jeju and Gangwon provinces are excluded. Additionally, after eliminating the non-response samples, a total of 997 samples are used in the actual analysis.

To create regional group variable, Korea is divided into 4 cosmopolitan areas: METRO comprising Seoul, Incheon, and Gyeonggi-do, CENTRAL comprising Daejoen, Chungcheongbuk-do, and Chungcheongnam-do, SOUTHEAST comprising Busan, Daegu, Ulsan, Gyeongsangbuk-do, and Gyeongsangnam-do, and SOUTHWEST comprising Gwangju, Jeollabuk-do, and Jeollanam-do. As mentioned, Jeju and Gangwon provinces are excluded due to the lack of an adequate sample and the difficulty in assigning them into 4 cosmopolitan areas. Henceforth, regional R&D intensity, regional innovation rate, and other regional variables represent average values within the region. On the other hand, the 8 industries with vibrant innovation activity are used as industrial group variables directly; FOOD (KSIC code 15), REFINERY (23), CHEMICAL (24), PLASTIC (25), MACHINERY (29), COMPUTER (30), ELECTRONIC (31), and TELECOM (32). Similarly, industrial R&D intensity, industrial innovation rate, and other industrial group variables represent average values in the industry.

TABLE 1 SUMMARY STATISTICS: FIRM CHARACTERISTICS BY REGION AND INDUSTRY

	Sample size	**Age**	**Firm size**
all	997	18.65 (13.05)	236.98 (558.09)
METRO	498	19.33 (14.16)	227.43 (472.15)
CENTRAL	171	17.11 (11.61)	333.04 (955.00)
SOUTHEAST	290	18.72 (12.07)	202.41 (359.20)
SOUTHWEST	38	16.11 (10.44)	193.74 (369.73)
FOOD	112	21.24 (15.63)	379.76 (778.31)
REFINERY	25	15.64 (12.37)	317.44 (774.49)
CHEMICAL	178	24.85 (16.74)	324.22 (850.35)
PLASTIC	115	19.14 (12.71)	197.08 (461.38)
MACHINERY	224	17.19 (9.82)	165.99 (365.46)
COMPUTER	29	14.86 (10.69)	243.41 (353.56)
ELECTRONIC	137	18.10 (11.70)	156.85 (290.80)
TELECOM	177	13.76 (9.03)	224.28 (380.83)

** The third and forth columns report average (standard deviation).*

Table 1 reports the sample size and the mean and standard deviation of firm age (2005-founding year) and size (number of employees), for the entire sample, regions, and industries.

[6] The included 8 industries (KSIC code) are food products (15), coal and refined petroleum products (23), chemicals and chemical products (24), rubber and plastic products (25), machinery and equipment (29), computer and office machinery and equipment (30), electronic components and equipment (31), and radio, television, communication equipment, and apparatus (32).

TABLE 2 SUMMARY STATISTICS: INNOVATION ACTIVITY BY REGION AND INDUSTRY

	R&D intensity (million won)	**Innovation rate**	**Patent application rate**
all	4.78 (15.86)	0.60 (0.49)	0.41 (0.49)
METRO	6.55 (20.46)	0.64 (0.48)	0.44 (0.50)
CENTRAL	3.25 (8.44)	0.55 (0.50)	0.41 (0.49)
SOUTHEAST	3.01 (9.54)	0.55 (0.50)	0.37 (0.48)
SOUTHWEST	2.02 (5.10)	0.61 (0.50)	0.32 (0.47)
FOOD	2.45 (12.41)	0.58 (0.50)	0.28 (0.45)
REFINERY	3.77 (10.62)	0.56 (0.51)	0.28 (0.46)
CHEMICAL	4.79 (12.36)	0.65 (0.48)	0.42 (0.49)
PLASTIC	3.75 (14.12)	0.53 (0.50)	0.32 (0.47)
MACHINERY	4.13 (7.49)	0.63 (0.48)	0.49 (0.50)
COMPUTER	11.24 (22.61)	0.62 (0.49)	0.41 (0.50)
ELECTRONIC	3.03 (5.53)	0.55 (0.50)	0.34 (0.48)
TELECOM	8.18 (28.74)	0.59 (0.49)	0.50 (0.50)

** All values are average (standard deviation).*

Regionally, METRO and SOUTHEAST have relatively more firms and older firms. In terms of size, CENTRAL firms are especially large. In terms of industry, FOOD and CHEMCIAL industries have older firms, and FOOD, REFINERY, and CHEMICAL industries are especially large.

Table 2 summarizes the input and outcome of innovation activity. The R&D intensity shown in the second row is by dividing the total R&D investment in 2004 by the number of employees. The average R&D intensity of firms within the sample is 4.78 million won, and the average R&D intensity of METRO exceeds it significantly at 6.55 million won. In terms of industry, the R&D intensity of COMPUTER and TELECOM industries are high.

The technological innovation rate in the third row is defined by the Oslo manual and shows the ratio of firms with at least one successful product innovation or process innovation among firms from 2002-2004. Lastly, the rate of patent application in the fourth row shows the ratio of firms with at least one patent among firms from 2002-2004. Regionally, METRO with a high R&D intensity also has the highest rates of technological innovation and patent application. Compared to SOUTHWEST, CENTRAL has relatively high R&D intensity, but lower rates of technological innovation. In terms of industry, while R&D intensity shows large variations, it is contrasted by even distribution in the technological innovation rate across all industries.

The relationship among the input variable, technological outcome variables, and economic outcome variable is further illustrated in Figure 2 and Figure 3. There exists a clear positive correlation between the innovation input and technological output variables through the regional distribution shown in Figure 2 and through industrial distribution in Figure 3, but not a directly proportional relationship. In addition, there exist discrepancies between the output variables technological innovation rate and the patent application rate. Such results show the limitations of R&D investment or patent application as proxy variables for innovation. In contrast, profits show completely different distribution levels than innovation inputs and outputs. Especially, CENTRAL and REFINERY created very high economic outcomes relative to innovation rate.[7]

[7] Similar graphical representation is tried for the sales variable and the results coincide with each other.

FIGURE 2 INNOVATION INPUT, INNOVATION OUTPUT, AND ECONOMIC OUTCOME: BY REGION

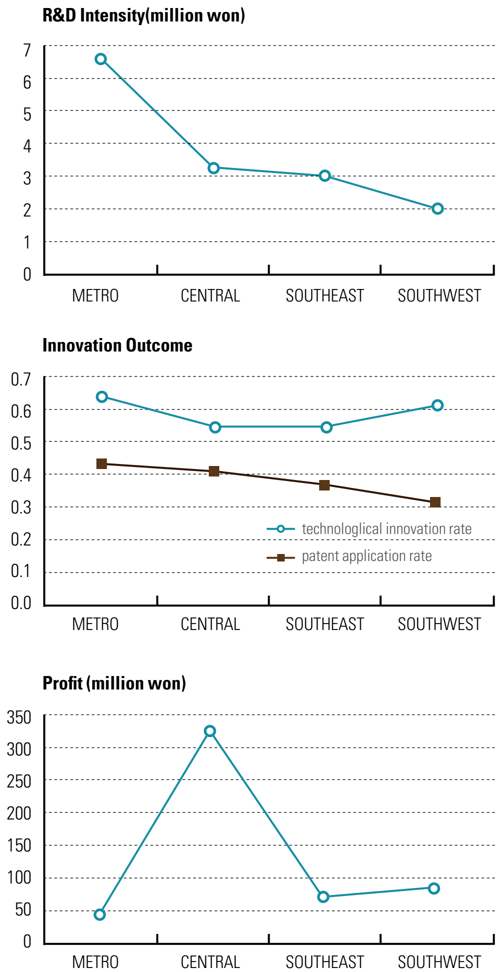
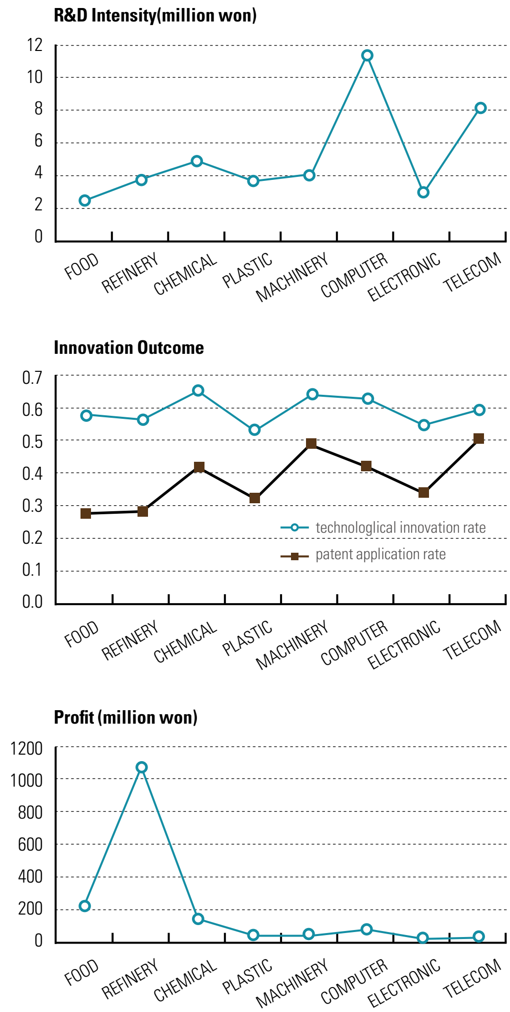


FIGURE 3 INNOVATION INPUT, INNOVATION OUTPUT, AND ECONOMIC OUTCOME: BY INDUSTRY



4. ECONOMETRIC MODEL

This chapter establishes estimation equations for empirical analysis of the benchmark model, Model 1 and Model 2. The economic outcome variable used is profit. Innovation outcome variables are technological innovation (success / success rate) and patent (application / application rate) are all used and compared against each other. In all equations, firm age and firm size are included as control variables. In addition, models estimating regional and industrial impacts have the same structure and only the regional impact estimates are explicitly explained here. For industrial impact estimates, all regional variables are substituted with industrial variables.

First, the benchmark model is as follows.

$$\Pi_{ir} = \alpha_0 + \alpha_1 RDIi_r + \alpha_2 RDI_r + \alpha_3 (RDI_{ir} \times RDI_r) + \alpha_3 AGE_{ir} + \alpha_5 SIZE_{ir} + \varepsilon_{ir} \quad \text{(1)}$$

The subscript *i* represents individual firms, subscript *r* regions, *Π* profits, *RDI* R&D intensity, *AGE* firm's age, and *SIZE* firm's size. In the actual estimation, the average R&D intensity of a region is used as *RDIr* representing regional R&D intensity. $\alpha_0, \ldots, \alpha_5$ are parameters to be estimated, and ε is the error with mean of 0.

This model estimates the impact of the R&D intensity of individual firm and regional R&D intensity on the economic outcome and profits of a firm. Considering different regional spillovers on the R&D levels of an individual firm, an interacting variable (RDI_{ir} x RDI_r) of firms *RDI* and regional RDI is included. The regional effects of $\alpha_2 + \alpha_3 RDI_{ir}$ estimated from the model are dependent on the R&D level of an individual firm. The estimates previously mentioned have both spillover and economic congestion effects.

Model 1 specifically estimating regional spillovers is as follows. Technological innovation variable and patent variable are alternatively used and compared.

$$\Pr(TI_{ir} = 1 | X) = \Phi[\beta_0 + \beta_1 RDI_{ir} + \beta_2 RDI_r + \beta_3 (RDI_{ir} \times RDI_r) + \beta_4 AGE_{ir} + \beta_5 SIZE_{ir}] \quad \text{(2)}$$

$$\Pr(PA_{ir} = 1 | X) = \Phi[\lambda_0 + \lambda_1 RDI_{ir} + \lambda_2 RDI_r + \lambda_3 (RDI_{ir} \times RDI_r) + \lambda_4 AGE_{ir} + \lambda_5 SIZE_{ir}] \quad \text{(2)'}$$

Pr(…) represents the probability of an event as noted in the parenthesis occurring, *X* a vector of all explanatory variables in the estimation equation, and Φ a standard normal cumulative distribution function. *TI* is an indicator variable, noting 1 when a firm succeeds in one or more technological innovation and 0 if not. *PA* is a similar indicator variable for patent applications. Parameters to be estimated are $\beta_0, \ldots, \beta_5$ and $\lambda_0, \ldots, \lambda_5$. In this paper, *TI* is seen as a more direct variable showing the technological innovation outcome and equation (2) is used as the main estimation equation. Equation (2)' is an estimation equation to verify the validity of *PA* as a proxy variable. Technological spillovers are estimated through (β_2, β_3) and (λ_2, λ_3) and are expected to have positive values given an appropriate RDI_{ir} level.

Last, Model 2 estimating the congestion effect within competition among firms at a given innovation level is as follows.

$$\Pi_{ir} = \Upsilon_0 + \Upsilon_1 TI_{ir} + \Upsilon_2 TI_r + \Upsilon_3 AGE_{ir} + \Upsilon_4 SIZE_{ir} + \xi_{ir} \quad \text{(3)}$$

Group variable TI_r is the average regional technological innovation rate. Parameters to be estimated are $\Upsilon_0, \ldots, \Upsilon_4$, and ε is the error with mean 0. Υ_2 indicates the economic congestion effect and is theoretically expected to have a negative value.

In the 4 equations, substituting regional variables, RDI_r and *TI*, for industrial variables, RDIs and TIs (s representing industry), becomes the estimation method for industrial effects. Equations (1) and (3) are ordinary least squares (OLS) and equations (2) and (2)' are probit models. All 8 estimation results are reported in the following chapter. Table 3 summarizes the estimation equations involved in each dimension and stage of the empirical analysis.

TABLE 3 SUMMARY OF ESTIMATION EQUATIONS

		Dimension	
		Region	Industry
No stage Consideration	Benchmark Model: Mix of technological spillovers and economic congestion effects	(1)	(1)
Stage-specific approach	Stage 1 (Model 1): Technological spillovers	(2) and (2)'	(2) and (2)'
	Stage 2 (Model 2): Economic congestion effects	(3)	(3)

5. EMPIRICAL RESULTS

5.1 Benchmark Results

Table 4 summarizes the estimation results for the benchmark model showing the impact of regional and industrial R&D intensity on the profits of a firm. The results are OLS estimates for each region and industry. In the sample used, the group R&D level has a significant negative effect on individual firm profits.

TABLE 4 BENCHMARK RESULTS: EFFECTS OF GROUP R&D INTENSITY ON FIRM PROFITS

Dependent variable: Π (million won)	Regional effect	Industrial effect
RDI (million won)	125.90 (0.20)	106.40 (0.27)
Group RDI* (million won)	-2637.91 (-2.17)	-1497.17 (-1.46)
RDI × group RDI* (million won)	-10.48 (-0.10)	-7.82 (-0.14)
AGE	-253.314 (-1.55)	-312.97 (-1.90)
SIZE	64.77 (17.17)	65.14 (17.25)
Constant	12222.26 (1.82)	7833.81 (1.21)
R^2	0.2385	0.2363

** RDIr in the regional effect estimation and RDIs in the industrial effect estimation*
*** All values are estimate (t-value).*

Estimate results in the second row shows the regional R&D intensity influences firm profits at marginal effect of -2637.91 + (-10.48) x 0.55 = -2643.67, when evaluated at median of 550,000 won for individual firm R&D intensity. An increase of 1 won per capita in regional average R&D intensity results in a decrease of 2644 won in individual firm profits. In addition, since these marginal effects are decreasing with the RDI of an individual firm, they can be interpreted as the profit reduction effect being larger for higher levels of R&D by a firm. However, the effects are not that statistically significant.

Similar inference applied to estimation results in the third row, the marginal effects of industry R&D on the profits of a firm (evaluated at the median R&D intensity of a firm) is -1501.47. An increase of 1 won in the industry average per capita R&D will result in a decrease of 1501 won in individual firm profits. Similarly, the higher the R&D level of a firm, then the greater the profit reduction effect. However, economically or statistically, these effects have a smaller significance than regional effects.

Interpreting these empirical results on the surface would lead to the conclusion that Korean R&D investments have no positive spillovers, or rather negative effects on neighboring firms in the regional and industrial dimensions. However, considering the aforementioned stage-identification, the results can be hypothesized as resulting from the negative congestion effects exceeding the positive technological spillovers. Such identification of effects will be clearer in the following stage-specific model estimation results.

5.2 Stage-Specific Model Results

Table 5 is the results from the first stage of the stage-specific model - Model 1, estimating in the regional and industrial dimensions for equations (2) and (2)'.

TABLE 5 MODEL 1: EFFECTS OF GROUP R&D INTENSITY ON FIRM INNOVATION SUCCESS

Dependent variable	Regional effects		Industrial effects	
	TI	PA	TI	PA
RDI (million won)	0.4188 / 0.1303 (6.54)	0.1812 / 0.0711 (6.26)	0.3353 / 0.1036 (9.06)	0.0609 / 0.0238 (4.53)
Group RDI* (million won)	0.0617 / 0.0192 (2.18)	0.0672 / 0.0264 (2.52)	0.0194 / 0.0060 (0.86)	0.0539 / 0.0211 (2.46)
RDI × group RDI* (million won)	-0.0440 / -0.0137 (-4.15)	-0.0218 / -0.0085 (-4.68)	-0.0263 / -0.0081 (-5.50)	-0.0020 / -0.0008 (-0.87)
AGE	0.0067 / 0.0021 (1.87)	0.0042 / 0.0016 (1.26)	0.0070 / 0.0021 (1.91)	0.0060 / 0.0024 (1.81)
SIZE	0.0004 / 0.0001 (3.52)	0.0004 / 0.0001 (4.48)	0.0004 / 0.0001 (3.75)	0.0004 / 0.0001 (4.46)
Constant	-0.6648 (-4.39)	-0.9666 (-6.50)	-0.4890 (-3.45)	-0.8915 (-6.52)
Log likelihood	-536.86	-594.48	-535.31	-603.53

** RDIr in the regional effect estimation, and RDIs in the industrial effect estimation*
*** All values are estimated coefficient/marginal effect (z-value), except constant, which reports coefficient (z-value).*

The impact of regional and industrial average R&D intensity on variables TI and PA (that represent the innovation outcome of an individual firm) are estimated as probit models separately. Positive and very significant technological spillovers exist.

First, looking at the second and third rows estimating the regional technological spillovers, the marginal effects of regional R&D on the probability of innovation by a firm, evaluated at median of firm R&D intensity, is 0.0192 + (-0.0137) x 0.55 = 0.0117. When the regional R&D intensity increases by 1 million won, then the technological innovation success rate of individual firms in the region increases by 1.17%. Such spillovers are larger with the lower R&D level of an individual firm, and the spillovers disappear when the R&D intensity reaches 1.4 million won. The smaller the size of the firm, then the smaller the R&D ability, the greater the positive externality from the R&D investments by other firm and it agrees with the general conclusions of relevant studies.

The marginal effect of regional R&D intensity through the patent application rate of a firm is higher at 2.17%, and the two estimates are both statistically significant. In conclusion, there exists a substantial level of regional spillovers among Korean manufacturing industries, especially in patent applications.

Similarly, industrial effects can be calculated through the results from the third and forth rows. First, when evaluated at the median of individual R&D intensity, the marginal effects of average industrial R&D intensity on individual technological innovation is 0.15%. Compared to regional spillovers, it is smaller and statistically insignificant. However, the marginal effect on patent application is 2.07%, similar to regional spillovers and statistically significant. In light of these results, the technological/industrial spillovers among firms within an industry can be said to affect patented innovations in particular.

The explored estimate results from Model 1 are the core results that address the main question of this study: the existence of technological spillovers of R&D investments. The estimates are synthesized with the estimate results from the second stage model and compared to the results from the benchmark model.

TABLE 6 MODEL 2: EFFECTS OF GROUP INNOVATION RATE ON FIRM PROFITS

Dependent variable: ∏ (million won)	Regional effects		Industrial effects	
TI	2563.97 (0.61)	-	1814.37 (0.43)	-
Group TI*	-117955.80 (-2.54)	-	-29364.39 (-0.58)	-
PA	-	-1125.15 (-0.27)	-	529.67 (0.12)
group PA**	-	-55736.75 (-0.95)	-	-62864.04 (-2.48)
AGE	-265.86 (-1.64)	-275.63 (-1.69)	-277.25 (-1.70)	-323.77 (-1.98)
SIZE	64.41 (16.98)	65.18 (17.08)	64.85 (17.06)	64.65 (16.96)
Constant	69175.98 (2.49)	23565.89 (0.97)	16794.36 (0.56)	26704.96 (2.41)
R^2	0.2394	0.2351	0.2347	0.2392

** TIr in the regional effect estimation, and TIs in the industrial effect estimation.*
*** PAr in the regional effect estimation, and PAs in the industrial effect estimation. *** All values are estimate (t-value).*

Table 6 estimates the effects of the regional and industrial technological innovation rate on the profits of an individual firm given a technological innovation level and result in the congestion effects for Model 2. The second row shows a 1% increase in the regional technological innovation rate results for the industrial firm profit decrease of 1.18 billion won. The 3rd row shows a 1% increase in the regional patent application rate decreases individual firm profits by 557 million won. However, the effects through patents are not statistically significant, so effects through the technological innovation rate are used in a comparison with the benchmark model.

On the contrary, effects through technological innovation are not significant while effects through patents are significant in the industrial dimension. A 1% increase in the individual patent application rate decreases individual firm profits by 628 million won. Since effects through patents are particularly significant in both stages of the industrial dimension, the patent application rate is used in a comparison with the benchmark model.

5.3 Benchmark and Stage-Specific Model Result Comparisons

The estimates from sections 5.1 and 5.2 are used in this section to compare the benchmark model result with Model 1 and Model 2, and check the validity of the stage-identification and analysis method in Chapter 2. Specifically, by combining the estimation results from each stage of the stage-specific models, they can be quantitatively compared with the economic marginal effects of the R&D investments from the benchmark model.

First, from the first stage estimation results of regional effects, R&D investment affects the technological innovation rate of an individual firm by 1.17%. An increase of 1 million won in the average R&D intensity of a region increases the technological innovation rate of a region by 1.17%. Next, from the second stage estimation results, a 1% increase in the regional technological innovation rate decreases the individual firm profits by 1.18 billion won for the region. If the regional technological innovation rate increases by 1.17%, then the individual firm profits decrease by 1.38 billion won, 0.0117 x (-117955.8). Combining the 2 stages, an increase of 1 won in the average R&D intensity of a region is expected to reduce individual firm profits by 1380 won. In comparison, according to the benchmark model estimation results in Section 5.1, the marginal effects of regional average R&D intensity on individual firm profits were -2644 won, a larger effect than the stage-specific model results. This is because in the stage-specific model, the path in which R&D investments can influence profits is restricted as innovation success whereas the benchmark model encompasses many other possible paths. For example, an increase in regional R&D investment increases the regional innovation rate through regional spillover effects and increases the input price in the R&D input factor market that includes R&D personnel that results in lower profits.

Next, applying similar calculations to regional effects, the stage-specific model estimates of profit reduction effects through patent application rate is 0.0207 x (-62864.04) = -1301.29. An increase of 1 won in industrial average R&D intensity decreases individual firm profits by 1301 won. Again, this is lower than the benchmark model estimates of the 1510 won reduction effect. Similar to regional effects, the reason benchmark model effects are larger is due to additional effects on the factor market beyond the effects on the patent application rate. However, the difference between the benchmark model and stage-specific model estimates is small compared to the regional effects. Thus, the competition effects of the R&D factor market are larger within a specific region rather than a specific industry.

Last, Table 7 summarizes the comparison between benchmark and stage-specific model estimation results.

TABLE 7 COMPARISON OF BENCHMARK AND STAGE-SPECIFIC MODEL RESULTS

	Stage-specific model	Benchmark model
Regional effects	$\frac{\partial TI_i}{\partial RDI_r} = 0.0117$ $\frac{\partial \Pi_i}{\partial TI_r} = -117956$ ↓ $\frac{\partial \Pi_i}{\partial RDI_r} = -1380$	$\frac{\partial \Pi_i}{\partial RDI_r} = -2644$
Industrial effects	$\frac{\partial TI_i}{\partial RDI_s} = 0.0207$ $\frac{\partial \Pi_i}{\partial TI_s} = -62864$ ↓ $\frac{\partial \Pi_i}{\partial RDI_s} = -1301$	$\frac{\partial \Pi_i}{\partial RDI_s} = -1501$

** The marginal effects of RDI are evaluated at the median level of RDI, 0.55 million won.*

6. CONCLUSION AND LIMITATIONS

The summary of empirical analysis results are as follows. First, among the Korean firms with relatively active R&D investments and high levels of innovation, there exist both R&D spillovers through regional and industrial proximity. Such spillovers are verified when technological effects are analyzed excluding the economic effects. Second, the lower the R&D level of an individual firm, then the higher the impact from spillovers. The benefits of spillovers disappear once the R&D of an individual firm reaches a specific level. Third, when comparing the regional proximity effects with industrial proximity effects, the spillover effects of a region are explicitly reflected in technological innovation. Meanwhile, the industrial spillovers only appear to have significant effects on the patent application rate and the importance of industrial dispersion effects in patented technological innovation. Fourth, the empirical analysis results confirmed the validity of the stage-specific analysis method. As expected, analyzing only the economic results cannot verify R&D spillovers regionally or industrially. Instead, an increase in the group average R&D investments decreases individual economic outcomes. Such results occur from an estimation with regional and industrial competition effects or congestion effects. However, using stage-specific analysis, technological spillovers are estimated separately and the existence of positive spillover effects are verified both regionally and industrially. These results show the necessity of separating the technological stages of innovation success to estimate the true R&D spillovers.

This study still has limitations as an evaluation of R&D spillovers based on individual firm outcomes. Summing up individual firm outcomes alone is not sufficient when evaluating positive economic effects of R&D investments or innovation policies. It is because the outcomes of an individual firm do not include the post-effects of innovation on society as a whole, such as dispersion effects or price reduction effects through competition pressure. Evaluations based on the economic outcomes of an individual firm underestimate the effects of R&D investment. The evaluation requires estimating social benefits beyond individual benefits and the technological dispersion effect estimation applied in this paper is only the first step. Any ultimate evaluation of socioeconomic effects must follow the estimates of socioeconomic values brought by the increase in innovation rates that must also include cost reduction effect, market exploration effects, and the proceeding increase in consumer welfare.

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