DISCUSSION PAPERS IN ECONOMICS

Working Paper No. 03-02

R&D, Trade, and Productivity Growth in Korean Manufacturing

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January 2003

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The first draft: January 2002
The second draft: June 2002
This draft: January 2003

Abstract:

This paper investigates the effects of both R&D spillovers and trade patterns on productivity in Korean manufacturing, using industry-level data. Our results show that domestic and foreign R&D capital stocks have played an important role in productivity growth of Korean manufacturing over the period 1976-96, and that foreign R&D capital has had more effect than domestic R&D in improving the total factor productivity of Korean manufacturing. Moreover, productivity is greater in export industries and in the more opening industries, and the effects of foreign R&D capital are greater in the industries with large import shares or large intra-industry trade shares.

JEL: F10, O32, O47

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1. Introduction

Korea's rapid economic growth since the early 1960s has been due to the expansion of capital investment and international trade. Increases in physical and human capital investments, as inputs to production, can expand output directly, while the expansion of trade contributes to growth indirectly. Developing countries can gain the opportunity to absorb new technology developed in advanced countries through trade. Thus, trade can be considered as one of the main generators of productivity growth, especially for a country like Korea, where trade makes a relatively large contribution to economic growth.

Many studies have examined the relationship between trade and economic growth. Edwards (1998) showed that openness causes productivity, and Coe & Helpman (1995), Coe *et al*. (1997), and Keller (2002) demonstrated that international trade plays an important role as a channel for transmitting research and development (R&D) spillovers.

Remark: We would like to thank professors Frank S. T. Hsiao, Murat F. Iyigun, Robert F. McNown, and Keith E. Maskus for their comments and suggestion. We are also indebted to Dr. Sunmi Jang.for help in

Countries enjoy substantial benefits from the R&D undertaken by their trade partners. Engelbrecht (1997) and Lichtenberg & Potterie (1998) are extensions of Coe and Helpman (1995). Braconier *et al*. (2001 are a case study of Swedish firms, which focuses on FDI-related R&D spillovers. However, there have been few industry-level studies that have examined the effects of international R&D spillovers on developing countries.

This paper investigates the effects of both R&D spillovers and trade patterns on productivity in Korean manufacturing, using industry-level data. Previous studies of economic growth in Korea concentrated on the role of trade policy in productivity growth. Nadiri and Kim (1996) used R&D capital as an input of production, but did not study R&D spillovers. Lee (1996), Feenstra *et al*. (1999), and Kim (2000) analyzed the relationship between trade policy and total factor productivity (TFP).

This paper differs from previous studies in the following ways. First, we use industry-level data of Korean manufacturing to investigate domestic and international R&D spillovers. Coe *et al*. (1997) examined north-south R&D spillovers using aggregate data. Keller (2002) used industry-level data, but the data were confined to eight industrial OECD countries. Second, we examine the effects of trade patterns on productivity in Korean manufacturing, as differences in productivity among industries may be related to their different trade patterns. Third, we break down foreign R&D capital into three subgroups: the United States, Japan, and the other OECD countries, and we investigate which country's R&D capital has played the most important role, relatively speaking, in Korean productivity. Since Korea has different trade structures with these countries, the effects of their R&D capital on Korean productivity will differ.

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collecting data.

Finally, we use two productivity indexes in this study: the Törnqvist and Malmquist productivity indexes. While most studies have used the Törnqvist productivity index, Färe *et al*. (1994) argued that the Malmquist productivity index is more general than the Törnqvist index, as it allows for inefficient performance and does not presume an underlying functional form for production technology.[1]

Our results show that there have been both domestic and foreign R&D spillovers in Korean manufacturing. Domestic other-industry R&D and foreign R&D played an important role in the productivity growth of Korean manufacturing from 1976 to 1996. Foreign R&D had a stronger effect, relatively speaking, than domestic R&D on the productivity growth of Korean manufacturing. The effect of Japanese R&D on Korean productivity was larger than that of other foreign R&D stocks, which is consistent with the results of Coe *et al*. (1997). Generally, productivity is greater in those industries that export more, and trade more, in comparison to other industries. This implies that exports and openness play a positive role in productivity growth. However, foreign R&D effects on Korean productivity are greater in industries that import more, because imports are a vehicle for foreign R&D spillovers. Foreign R&D capital stocks have more effect in industries that have a larger intra-industry trade share, because foreign technology is more easily absorbed by industries that can export and import simultaneously.

The remainder of this paper is organized in the following manner. Section 2 presents the theoretical background for understanding R&D, trade patterns, and productivity, and specifies the empirical framework. Section 3 is a descriptive summary of the main variables and presents estimates of the productivity indexes. The empirical

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[1] The differences between two indexes are discussed briefly in the next section.

results are discussed in Section 4. Concluding remarks are offered in Section 5.

II. Theoretical Background and Empirical Specifications

In traditional growth theory, exogenous technology shock is necessary for sustainable economic growth. In new growth theory (Romer, 1986; Grossman and Helpman, 1991a, 1991b and 1991c), however, innovation is determined endogenously, and this enables sustainable long-run growth without exogenous technology shock. There are two types of endogenous growth models: the varieties growth model (or horizontally differentiated model), and the quality-ladder growth model (or vertically differentiated model).

Both the varieties model (Romer, 1990; Grossman and Helpman, 1991a) and the quality-ladder models (Grossman and Helpman, 1991c; Aghion and Howitt, 1992) emphasize the role of R&D investment in productivity or technology. However, there are also some channels of international technology spillovers[2]: trade, foreign direct investment and patent citation. This paper deals with domestic and international R&D spillovers as well as its own R&D activity in industry level of Korean manufacturing. Each industry uses not only intermediates invented by its own industry, but also intermediates invented by other industries. Scherer (1982) and Griliches and Lichtenberg (1984) examined inter-industry domestic R&D spillovers using an inter-industry technology flow matrix. Moreover, in an open economy, domestic industry uses intermediates imported from trade partners, along with those produced by domestic industries. As the development of foreign intermediate goods also depends on foreign R&D stock, we can consider foreign R&D spillovers in the context of an open economy.

Based on the theoretical background, we constructed an empirical framework. The basic empirical model will be as follows:

$$lnT_{it} = \beta_0 + \beta_1 \, lnR\&D_{it}^{DS} + \beta_2 \, lnR\&D_{it}^{DO} + \beta_3 \, lnR\&D_{it}^{F} + \varepsilon_{it}$$

$$\varepsilon_{it} = \mu_i + \eta_t + v_{it} \qquad (1)$$

where the subscripts i and t are the industry and year, respectively; lnT_{it} is the log of the total factor productivity (TFP) index; $lnR\&D^{DS}$ and $lnR\&D^{DO}$ are the logs of the domestic same- and other-industry R&D capital stocks, respectively; $lnR\&D^{F}$ is the log of the foreign R&D capital stock imported indirectly through trade; ε_{it} is an error term, which has three components; μ_i is an unobservable industry-specific factor that reflects the variation across industries; η_t is a time-specific factor varying over time; and v_{it} denotes the remaining disturbances.[3]

In this paper, two methods for estimation of TFP have been used: Törnqvist and Malmquist productivity indexes.[4] The main differences between these two are as follows. First, the Törnqvist productivity index[5] presumes that production activity is always efficient, while the Malmquist index does not. Second, calculation of Malmquist index does not require any information on cost or income shares, and prices of inputs or

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[2] See Keller (2001) for the survey on technology diffusion.
[3] Hereafter, ε_{it} has the same three terms.
[4] See Färe *et al*. (1994) and Caves *et al*. (1982) for more details.

outputs, while the Törnqvist index does. Only quantities of inputs and outputs are required in the measure of productivity index in the Malmquist index. Thus, the method of the Malmquist index is less data-demanded relative to the Törnqvist index. Third, the Törnqvist productivity index suggested by Caves *et al*. (1982) is multilateral indexes in which the Törnqvist productivity index can compare the level of TFP between industries and time periods, but the Malmquist productivity index can not.

The United States and Japan are Korea's most important trade partners, although Korea has different trade structures with each of these two countries. Korea imports machinery and equipment mainly from Japan, while the United States is Korea's largest market for its exports. Due to these different trade structures, the R&D stocks of the U.S. and Japan affect Korean productivity differently. To examine the different effects of foreign R&D stocks, we decompose the foreign R&D stocks ($lnR\&D_{it}^{F}$) in Equation (1) into three subgroups: foreign R&D stocks from the United States, Japan, and the remaining OECD countries. Thus, the empirical model becomes:

$$lnT_{it} = \beta_0 + \beta_1\, lnR\&D_{ti}^{DS} + \beta_2\, lnR\&D_{it}^{DO} + \beta_3\, lnR\&D_{it}^{F-USA} + \beta_4\, lnR\&D_{it}^{F-JPN} + \beta_5\, lnR\&D_{it}^{F-OTH} + \varepsilon_{it} \qquad (2)$$

where $lnR\&D_{it}^{F-USA}$, $lnR\&D_{it}^{F-JPN}$, and $lnR\&D_{it}^{F-OTH}$ are the logs of the foreign R&D stocks from the United States, Japan, and the rest of the OECD countries, respectively.

We also consider trade-related variables in order to explain the determinants of

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[5] See pp. 58-61 in Färe *et al*. (1996) for details.

productivity. Kim and Kim (1997) and Lawrence and Weinstein (1999) showed that export industries have higher productivity than net import industries. This may be because export industries are relatively more competitive in the world market than import industries. Exporters acquire knowledge of new production methods and product designs from their international contacts, and this learning may result in higher productivity relative to their more insulated domestic counterparts, especially in developing countries (Aw *et al*., 1998). Thus, we can expect a net exporter to have greater productivity than a net importer. Secondly, Grossman and Helpman (1991b) have argued that countries that are more open to the world market have a greater opportunity to absorb or imitate the advanced technology generated in advanced countries. According to this argument, opening the domestic market is positively associated with domestic productivity growth.[6] Thus, we estimate the following equation:

$$lnT_{it} = \beta_0 + \beta_1\, lnR\&D^{DS}_{it} + \beta_2\, lnR\&D^{DO}_{it} + \beta_3\, lnR\&D^{F}_{it} + \beta_4\, lnIMP_{it} + \beta_5\, lnOPEN_{it} + \varepsilon_{it} \qquad (3)$$

where $lnIMP_i$ is the log of the share of imports in the production of industry *i*, and a higher import share implies an import industry;[7] and $OPEN_i$ is the trade share in the production of industry *i*, and a higher trade share implies a more open industry.[8] The

[6] For empirical cross-country studies on openness and productivity growth, see Dollar (1992) and Edwards (1998).
[7] Another index for defining net exporter or net importer is the net export index. The correlation between the net export index and the variable *IMP,* used here, is very high. To examine the effect of interaction between import share and foreign R&D stocks, we used the import share variable as the net importer index.
[8] We can define market openness in several ways, including the presence of a price protection policy or

estimates β_4 and β_5 are expected to be negative and positive, respectively.

We expect interactions between the foreign R&D stock and import shares, as well as intra-industry trade. Coe and Helpman (1995) showed that technology spillovers are larger in industries with a higher import share, because imports of foreign technology are proportional to imports of intermediate goods. In other words, since an industry with relatively greater import share imports more foreign R&D indirectly through trade, the interaction term between import share and foreign R&D stock may be positively associated with domestic productivity.

Hakura & Jaumotte (1999) argue that technology spillovers in intra-industry trade (IIT) with industrial countries have more of an effect, relative to inter-industry trade, because industries are more likely to absorb foreign technologies when they import products that are similar to items they produce and export themselves.

Therefore, we will investigate the following model to examine this:

$$\ln T_{it} = \beta_0 + \beta_1 \, lnR\&D_{it}^{DS} + \beta_2 \, lnR\&D_{it}^{DO} + \beta_3 \, lnR\&D_{it}^{F} + \beta_4 \, lnIMP_{it}$$

$$+ \beta_5 \, lnOPEN_{it} + \beta_6 \, lnIMP{*} \, lnR\&D_{it}^{F} + \beta_7 IIT{*} \, lnR\&D_{it}^{F} + \varepsilon_{it} \qquad (4)$$

where *IIT* is a dummy variable which has 1 for an industry classified as involved in intra-industry trade and 0 otherwise. Accordingly, both β_6 and β_7 are positive.

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quota protection, as in Kim (2000), although these data are not available for each industry or for the entire period of analysis covered in this study.

III. Descriptive Summary of the Data

1. R&D and Trade

The data sources and variables are explained in Appendix B in detail. Here, we summarize some features of the data. Table 1 compares the real R&D investment per worker in terms of U.S. dollars based on the1990 purchasing power parity (PPP) for Korean, U.S., and Japanese corresponding manufacturing.

Table 1 shows that R&D investment per worker is smaller in Korea than in the U.S. and Japan. For the period 1976-80, the relative ratios of Korean R&D investment per worker to those of the U.S. and Japan were 0.05 and 0.14, respectively. The relative ratios, however, increased consistently, and had risen to 0.51 and 0.90, respectively, by the period 1991-96. This trend implies that even if R&D investments in Korean manufacturing are smaller than such investments in the U.S. and Japan, Korea's R&D investments grew rapidly when compared to those in the U.S. and Japan over the period 1976-96.

Table 1 - *Comparison of real R&D investment per worker: US $ of 1990 PPP*

Period	Average R&D investment per worker			Relative ratio	
	KOR(K)	USA(U)	JPN(J)	(K)/(U)	(K)/(J)
76-80	133	2,536	943	0.05	0.14
81-85	437	3,499	1,430	0.12	0.31
86-90	1,068	4,106	2,088	0.26	0.51
91-96	2,132	4,193	2,366	0.51	0.90
76-96	**999**	**3,613**	**1,738**	**0.28**	**0.57**

Source: See Appendix B.
Note: The figures show the annual average of the real R&D investment per worker in each period.

Table 2 shows shares and annual average growth rates of each sector in total R&D stock within Korea and 14 OECD countries in 1976 and 1996, respectively. First, in the case of OECD countries, the dominant sector of R&D stock is fabricated metal products (08) followed by chemical products (05) in both years. The shares of fabricated metal products (08) in total R&D stock are 71.9% in 1976 and 71.2% in 1996. The shares of chemical products (05) in total R&D stock are 19.4% in 1976 and 21.1% in 1996. The share of these two sectors is 90% of total R&D stock of 14 OECD countries. In case of Korea, the share of fabricated metal products (08) is highest but its share is only 38.4% in 1976 and the second largest share is textiles, apparel and leather sector (02), which is 22.3%. However, the trend of shares is almost the same as that of OECD countries in 1996.

In the comparison between light (LGT) and heavy (HVY) sectors, each share of light and heavy sectors is stable in OECD countries, 6% and 94% over two years, respectively. However, the shares of light and heavy sectors are 45% and 55%, respectively, in 1976 and 9% and 91%, respectively in 1996. These results can be explained by the comparison of annual average growth rate of R&D stock. In OECD countries, these two sectors show almost the same growth rates (3.4 and 3.6%, respectively), but in Korea, annual growth rate of heavy is 22.5%, while annual growth rate of light industry is 11.7%. For the last two decades Korean manufacturing has invested in R&D sector to catch up OECD countries. Growth rate of R&D stock in Korea is 20.0% per year while that of OECD is 3.6% over 1976-1996.

The domestic R&D capital stock of Korea and 14 OECD countries is the cumulative real R&D investment, allowing for depreciation. The foreign R&D capital stock of Korea is a weighted average of the domestic R&D capital stocks of the OECD countries. The construction of the foreign R&D capital stocks follows both Coe and Helpman (1995, hereafter referred to as CH) and Lichtenberg and Potterie (1998, hereafter referred to as LP). In the CH method, the foreign R&D capital stock is defined as the import-share-weighted average of the domestic R&D capital stocks of trade partners. However, Lichtenberg and Potterie (1998) propose an alternative measure of foreign R&D stock that is much less sensitive to the level of data aggregation imposed in CH method. The details of calculating foreign R&D capital stocks are explained in Appendix B.

Table 2 - *Comparison of the Domestic and Foreign R&D Stocks*

Industry	Korea's R&D stock			14 OECD's R&D stock			Share in total imported foreign R&D stock into Korea		Import share of foreign R&D stock	
	Share in total R&D stock of Korea		Growth rate (1976-96)	Share in total R&D stock of 14 OECD		Growth Rate (1976-96)	CH (1996)	LP (1996)	CH (1996)	LP (1996)
	1976	1996		1976	1996 (A)		(B)	(C)	(B)/(A)	(C)/(A)
01	4.4	3.1	18.2	1.7	1.9	4.1	1.7	0.5	24.9	0.2
02	22.3	2.7	9.4	0.8	0.5	2.0	0.3	0.3	14.0	0.5
03	7.8	0.1	-2.2	0.3	0.3	3.9	0.2	0.0	23.7	0.1
04	0.3	0.6	24.3	1.0	1.0	3.7	1.2	0.3	31.7	0.2
05	15.3	14.3	19.7	19.4	21.1	4.0	16.6	17.7	21.7	0.7
06	8.5	1.6	11.6	1.3	1.2	3.2	1.4	0.7	31.4	0.5
07	1.6	3.0	23.2	2.8	2.2	2.3	2.5	2.0	32.0	0.7
08	38.4	74.1	23.3	71.9	71.2	3.5	75.3	78.1	29.2	0.9
09	1.6	0.4	13.6	0.8	0.6	2.5	0.7	0.4	30.6	0.5
Lgt	44.7	8.5	11.7	5.8	5.6	3.4	5.5	2.2	27.0	0.3
Hvy	55.3	91.5	22.5	94.2	94.4	3.6	94.5	97.8	27.6	0.8
All	615	33,367	20.0	812,961	1,669,761	3.6	459,964	13,516	27.5	0.8

Source: See Appendix B.
Notes: – Lgt is light industry (01-04, 06, 09); Hvy is heavy industry (05, 07, 08); and All is total manufacturing. Industry categories, 01-09, are detailed in Appendix A. – The 14 OECD's R&D stock (B) is the sum of the domestic R&D stocks of 14 OECD countries. – The units of the real R&D capital stock are millions of US dollars converted at the 1990 PPP exchange rate in row ALL. Growth rates are annual average growth rates over 1976-1996 in percentage.

We used both measures to construct foreign R&D capital stocks and compared both estimates of the 1996 foreign R&D capital stocks in Table 2. First, as in the first column, the third column shows share of each sector in imported total foreign R&D stock for both measures for 1996, but the trend is similar for 1976. The share of each sector in foreign R&D stock shows the similar pattern with that for domestic R&D stock for 9 industries and light and heavy sectors. This result suggests that the magnitude of imported foreign R&D stocks in heavy industry is much greater than that of light industry and that R&D spillovers are more predominant in heavy industry than in light industry.

Secondly, we considered how much of 14 OECD's R&D capital stock was indirectly imported into Korea. Columns (B/A) and (C/A)[9] in Table 2 show that in the CH method, 27.5% of the total foreign R&D stock was imported in all manufacturing in 1996, but in the LP method, only 0.8% of 14 OECD's total R&D stock was imported in the same year. The results are similar for light and heavy industries. In the CH method, 27.0 and 27.6% of the total foreign R&D stock was imported into Korean light and heavy industries, respectively. By contrast, only 0.3 and 0.8% of the total foreign R&D stock was imported into the same industries in the LP method.

Table 3 presents the trends in trade volume and the intra-industry trade (IIT) index for Korean manufacturing with the 14 OECD countries. The average annual growth rates of exports and imports for all manufacturing are 11.24 and 13.50%, respectively and the growth rate for heavy industry (15.95 and 14.09%, respectively) was larger than that for light industry (5.22 and 10.85%, respectively) over the period 1976-96. In particular, the

[9] We can calculate the level of each R&D stock using each total volume reported in the row, All. Then (B/A) and (C/A) can be replicated.

export growth rate of heavy industry was almost triple that of light industry. With regard to Korean manufacturing, there has been a rapid expansion in trade with the 14 OECD countries in heavy industry relative to such trade in light industry.

Table 3 - *Trends of Trade Volume and IIT Index (in percent per year)*

Industry	Growth rates		Export share	Import share	IIT index		
	Export	Import			1976	1996	1976-96
01	8.06	11.75	4.16	4.47	16.74	31.61	25.03
02	4.59	7.51	38.40	7.39	19.99	36.77	24.95
03	-3.71	23.29	11.72	3.53	22.53	37.56	38.36
04	10.18	12.79	2.32	10.60	33.73	48.61	44.00
05	15.25	12.89	5.37	14.54	21.47	36.93	29.67
06	8.31	17.78	5.45	5.74	59.98	47.45	45.23
07	11.76	11.09	9.37	13.77	26.96	37.96	39.56
08	16.56	14.89	23.76	31.65	33.63	38.38	36.08
09	8.77	13.93	49.56	10.00	49.53	69.31	53.02
Lgt	5.22	10.85	17.77	6.19	22.84	39.01	29.99
Hvy	15.95	14.09	14.83	22.20	27.27	37.87	34.47
All	11.24	13.50	16.37	15.05	24.72	38.18	32.38

Source: See Appendix B.
Note: IIT index is Grubel and Lloyd (1975) index defined as $[1 - |X_{it} - M_{it}|/(X_{it} + M_{it})]x100$, where X_{it} and M_{it} are exports and imports of industry *i* at time *t*, respectively. The trade partners are 14 OECD countries. Export and import shares and IIT index for Lgt, Hvy and All are the weighted average from 9 industries.

The export and import shares in production for all manufacturing are 16.37 and 15.05%, respectively, and in comparison between light and heavy industries, export share of heavy (14.83%) is smaller than that (17.77%) of light industry, but import share of heavy is larger than that of light industry. It may come the fact that Korean manufacturing imports machinery and equipments mostly from Japan and the USA.

According to Table 3, the IIT index for Korean manufacturing with the 14 OECD countries is 24.72% in 1976; subsequently, it increased rapidly and is 38.18% in 1996. Over the period 1976-1996, average IIT index of heavy industry is 34.47% and that of light industry is 29.99%. This trend may reflect the fact that trade patterns in Korean manufacturing, especially in heavy industry, have become similar to the trade patterns of the OECD countries. Finally, IIT index of every industry except industry 06 has been increased in 1996 relative to that of 1976.

2. Total Factor Productivity

We estimated the Törnqvist and Malmquist productivity indexes for 28 Korean manufacturing sectors over the period 1970-96, using one output and three inputs as follows: labor, physical capital stock, and intermediates. The Törnqvist productivity index is based on the method of Caves *et al*. (1982), while the Malmquist productivity index follows the method of Färe *et al*. (1994). The computer program DEAP 2.1 (Coelli, 1996), which adopts the nonparametric linear programming technique of Färe *et al*. (1994), was used to estimate the Malmquist productivity index.[10]

Table 4 shows the average annual growth rates of output, inputs, and productivity indexes in Korean manufacturing for each period. The average annual growth rate of real output in total manufacturing is 12.32%, and those of labor, capital, and intermediates are 4.82, 14.56, and 11.34%, respectively, for the period 1970-96. Of the inputs, the growth rate of capital is the largest, and that of labor is the smallest. The average growth rate of the Törnqvist productivity index (TFP_TQ) is 1.37%, and that of the Malmquist productivity index (TFP_MQ) is 1.87%, for all manufacturing for the entire period.[11]

The growth rates of TFP, as well as output and inputs, have gradually declined

[10] The Malmquist productivity index can be decomposed into efficiency and technical progress indexes, but in this paper we focus on the Malmquist productivity index only.
[11] Although the productivity indexes determined by the two methods differ, the trends in the two indexes are similar. The correlation between the two TFP indexes is 0.847 and is significant at the 1% level for 28

over time. These results are consistent with the arguments of Young (1995) and Krugman (1994) that the rapid growth in East Asian economies has been derived, in the main, from factor accumulation, while technological progress has had little effect, with the result that there will be an eventual limit to growth.

Table 4 - *Average Growth Rates of Output, Inputs, and TFP in Korean Manufacturing (in percent per year)*

Industry	Period	Output	Worker	Capital	Intermediate	TFP_TQ	TFP_MQ
01	1970-96	7.62	2.37	11.69	5.59	1.76	3.19
02		7.84	1.88	11.02	8.60	-0.27	0.10
03		5.00	1.92	9.06	4.62	0.13	0.57
04		11.78	4.54	13.60	11.94	0.74	0.70
05		11.95	5.51	14.92	11.73	0.32	1.59
06		11.02	3.81	13.59	9.95	1.30	1.99
07		17.51	5.31	15.57	17.14	1.16	1.15
08		19.76	8.60	18.73	18.95	2.58	2.51
09		9.23	1.08	14.76	10.11	-0.17	-0.72
Lgt	1970-96	8.34	2.43	11.99	7.25	0.82	1.55
	1970-80	13.63	7.04	15.11	11.24	2.47	3.89
	1980-90	8.09	1.35	9.90	7.90	0.26	0.03
	1990-96	-0.04	-3.48	10.27	-0.47	-1.00	0.19
Hvy	1970-96	15.63	7.39	16.58	14.95	1.50	1.92
	1970-80	19.04	11.89	20.76	19.81	1.75	3.15
	1980-90	14.98	6.30	16.02	12.77	1.21	1.06
	1990-96	11.03	1.69	10.55	10.49	1.57	1.31
All	1970-96	12.32	4.82	14.56	11.34	1.37	1.87
	1970-80	15.70	8.90	17.85	14.62	2.34	3.72
	1980-90	11.77	3.84	13.74	10.62	0.75	0.58
	1990-96	7.62	-0.37	10.46	7.09	0.77	0.95

Note: TFP_TQ and TFP_MQ denote the Törnqvist and the Malmquist productivity index, respectively.

In comparing light and heavy industries, we observed that the average growth rate of TFP is higher in heavy industry than in light industry except the period 1970-80 for the both measures. This trend can be observed in comparison across industry from 01 to 09. The growth rate of real output for heavy industry (15.63%) is twice that (8.34%) of light

industries over the period 1970-96.

industry, in particular, light industry experienced a negative growth rate in output and productivity (Törnqvist productivity index) over the period 1990-96. These trends may have resulted from the Korean government's heavy/chemical industry promotion policy, which has been in effect since the early 1970s.

IV. Empirical Results

1. Domestic and Foreign R&D stock

A two-way fixed-effect method (considering industry-specific and time-specific effects) has been used to treat the panel data in regression models testing the determinants of TFP.[12] Since Korean R&D data are only available for 9 manufacturing sectors over the period 1976-96 in its entirety, all the variables for the 28 sectors are aggregated into 9 sectors in the regressions.

Table 5 shows the regression results using the foreign R&D stocks calculated by the LP method.[13] The estimated coefficients of $lnR\&D^{DS}$ are all positive and statistically significant at a 1% level. This implies that R&D investment in an industry increases the TFP of that industry. The elasticity of the TFP indexes with respect to own-industry R&D ranges from 0.034 to 0.100.[14]

The coefficients of domestic other-industry R&D ($lnR\&D^{DO}$) are positive and statistically significant, and are larger than those of the domestic same-industry R&D stock. These results show that there are domestic R&D spillovers in Korean

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[12] The Hausman test rejects the hypothesis for two-way random-effect models.
[13] The regression results using foreign R&D stocks from the CH method are reported in Appendix C.
[14] The elasticity of TFP with respect to own-industry R&D in Keller (2002) is 0.074 for 13 industries in eight OECD countries over the period 1970-91.

manufacturing, and that the domestic spillover effects are greater than the effects of own-R&D stock on productivity.

All of the coefficients of $lnR\&D^{F}$ are positive and statistically significant at the 1% level. Moreover, the coefficients are larger than those for $lnR\&D^{DS}$ and $lnR\&D^{DO}$. Thus, foreign R&D capital stocks have a greater effect on productivity than domestic R&D capital stocks in Korean manufacturing. These results are contrary to Coe *et al*. (1995) and Keller (2002). In both studies, domestic R&D capital stocks had a greater effect on productivity than foreign R&D capital stocks. The differences in the results may come from the different datasets used. Coe *et al*. (1995) and Keller (2002) dealt with R&D spillovers within OECD countries, while this paper examines R&D spillovers in Korea, a developing country. This implies that the domestic R&D stocks of advanced countries, making the predominant R&D investment in the world, are more effective than foreign R&D stocks. By contrast, in developing countries like Korea, R&D investment is relatively small compared with OECD countries (Refer to Table 2); thus, foreign R&D stocks can be more effective than domestic R&D stocks.

We tested the hypothesis that the coefficients of the domestic and foreign same-sector R&D stocks are equal. The F-value for testing the hypothesis $lnR\&D^{DS} = lnR\&D^{F}$ in Table 5 shows that we can reject the hypothesis. Thus, the coefficients of $lnR\&D^{F}$ are significantly larger than those of $lnR\&D^{DS}$, except in equation (M.4). Here, we must note that the empirical models do not consider the effect of foreign other-sector R&D stock because of data limitations. In Keller (2002), the effect of foreign other-sector R&D stock (0.150) is much larger than the effect of foreign same-sector R&D stock (0.047).

Table 5 - *Regression Results Using the Foreign R&D Stocks Based on the LP method: Dependent variable = lnTFP*

Model	Using Törnqvist productivity index					Using Malmquist productivity index				
	(T.1)	(T.2)	(T.2)'	(T.3)	(T.4)	(M.1)	(M.2)	(M.2)'	(M.3)	(M.4)
$lnRD^{DS}$	.084 ***	.100 ***	.065 ***	.052 ***	.034 ***	.077 ***	.091 ***	.065 ***	.056 ***	.037 ***
	(7.69)	(8.30)	(5.77)	(5.17)	(3.37)	(5.80)	(6.22)	(4.37)	(4.16)	(2.92)
$lnRD^{DO}$	.111 ***	.122 ***	.129 ***	.127 ***	.137 ***	.079 **	.093 ***	.085 ***	.076 **	.109 ***
	(4.20)	(4.62)	(5.53)	(5.54)	(6.33)	(2.45)	(2.91)	(2.77)	(2.49)	(3.98)
$lnRD^{F}$	.124 ***			.182 ***	.174 ***	.125 ***			.170 ***	.076 **
	(5.68)			(9.28)	(6.31)	(4.74)			(6.56)	(2.19)
$lnRD^{F\_USA}$		.052 ***	.074 ***				.020	.040 **		
		(3.47)	(5.75)				(1.10)	(2.33)		
$lnRD^{F\_JPN}$		.053 ***	.066 ***				.094 ***	.101 ***		
		(3.72)	(5.37)				(5.48)	(6.25)		
$lnRD^{F\_OTH}$		.050 ***	.043 ***				.049 **	.041 **		
		(3.17)	(3.20)				(2.57)	(2.35)		
lnIMP			-.177 ***	-.198 ***	-.308 ***			-.163 ***	-.182 ***	-.094
			(7.58)	(8.08)	(4.50)			(5.30)	(5.60)	(1.09)
lnOPEN			.125 ***	.152 ***	.116 ***			.191 ***	.233 ***	.192 ***
			(3.06)	(3.64)	(2.97)			(3.56)	(4.21)	(3.90)
$lnIMP*lnRD^{F}$					.016 **					-.003
					(2.27)					(0.29)
$IIT*lnRD^{F}$					.056 ***					.104 ***
					(4.68)					(6.84)
R^2	.651	.687	.779	.762	.802	.930	.937	.948	.943	.957
F (28, •) value for no fixed effect	3.83***	4.75***	7.98***	7.38***	9.65***	47.30***	42.19***	20.25***	19.68***	26.76***
F(1, •) value for $R\&D^{DS} = R\&D^{F}$	3.44*	7.22***	36.38***	36.01***	21.49***	3.43*	8.74***	20.71***	16.03***	1.05
F(1, •) value for $RD^{F\_USA} = RD^{F\_JPN}$	-	0.00	0.16	-	-	-	6.71 **	5.36 **	-	-

Notes: – In (T.6), (T.6)', (M.6), and (M.6)', the F test is $lnR\&D^{DS} = lnR\&D^{F\_USA} + lnR\&D^{F\_JPN} + lnR\&D^{F\_OTH}$. – The estimates of constant term, time and industry dummies are not reported here, for the sake of simplicity. – Obs = 178. R&D data are missing for 11 of the 189 observations. – ***, **, and * are significant at the 1, 5, and 10% level, respectively. – The figures in parentheses are absolute t-values. – In (M.4), the F test for $R\&D^{DS} = R\&D^{F}$ cannot be rejected. Following the suggestion of referee, we test $R\&D^{DS} = R\&D^{F} + lnIMP*lnRD^{F} + IIT*lnRD^{F}$. In this case the F(1, 142) value is 10.58, which can be rejected at the 1% significance level, and the total elasticity of $lnRD^{F}$ is 0.187, which is close to that in (M.3).

Next, we decompose foreign R&D capital stocks into three groups--the U.S., Japan, and the other OECD countries--and use these segmented foreign R&D stocks instead of $lnR\&D^{F}$ in regression equations (T.2), (T.2)', (M.2), and (M.2)' in Table 5. In the regression results, the three decomposed variables are all positive and statistically significant, except for the coefficient of $lnR\&D^{F\_USA}$ in equation (M.2).

The coefficient of $lnR\&D^{F\_JPN}$ is the largest of the three coefficients of the foreign R&D stock variables, except in equation (T.2)'. The last row of Table 5 gives the F-statistics for the hypothesis that the estimated foreign R&D stocks of the U.S. and Japan are equal. According to this test, the coefficients for the U.S. and Japan do not differ significantly when using the Törnqvist productivity index, but they do differ significantly, and the coefficient of $lnR\&D^{F\_JPN}$ is larger than that of $lnR\&D^{F\_USA}$, when the Malmquist productivity index is used. This result is consistent with Coe *et al*. (1997).[15]

Why do R&D investments in Japan have more effect on Korean productivity than such investments by the U.S.? One explanation lies in the difference in the trade structures between Korea and these two countries. Korean imports from Japan exceed those from the United States in heavy industry, which has large R&D investments generally. According to our calculation, heavy industry imports from Japan are twice those from the U.S., suggesting that Japanese R&D stock has a relatively greater effect on Korean productivity than that of the U.S.

Another explanation may be seen in the pattern of patent citations. Korean

[15] Coe *et al*. (1997) show that R&D in Japan has a greater influence on the productivity of Asian countries,

patents are much more likely to cite Japanese patents than U.S. patents (Hu and Jaffe, 2001); this implies that Korea adopts more Japanese technology than U.S. technology. Hence, we expect Japanese R&D stock to play a relatively larger role in Korean manufacturing than U.S. R&D stock. However, this evidence is only found in the regressions using the Malmquist productivity index.

2. Trade-Related Variables

As we expected, the coefficients of the variable *lnIMP* are negative and statistically significant in all the equations, except for equation (M.4). This is consistent with the results of Kim and Kim (1997) and Coe *et al*. (1997), in which productivity is lower in industries or countries with larger import shares. The coefficients of the variable *OPEN* are significantly positive in all the regression models, implying that productivity is greater in industries with larger trade shares in production.

In regressions (T.4) and (M.4), we investigate the interactive effects of trade pattern and foreign R&D capital on productivity. Foreign R&D stock affects domestic productivity via imports. Thus, we expect the effect of foreign R&D on domestic productivity to be larger in an industry with a larger import share. The coefficient of $lnIMP*lnRD^F$ is positive and significant at the 5% level in equation (T.4). This implies that the effect of foreign R&D on productivity is positive in the import industry, even if productivity is lower than in an export industry. This result is similar to those of Coe *et al*. (1997).

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because Japan is their most important trade partner, even if the foreign R&D spillovers from the U.S. are generally the largest among developing countries.

The coefficients of $IIT*lnR\&D^F$ are positive and significant at the 1% level, showing that foreign R&D has a greater effect on productivity in an industry with more intra-industry trade. This confirms the argument of Hakura and Jaumotte (1999), who held that an industry with a large intra-industry trade share faces more competition and absorbs foreign technology more easily than do industries with more inter-industry trade.

3. Sensitivity Analysis [16]

Table C1 in Appendix C shows the regression results using the foreign R&D capital stocks based on the CH method. We briefly summarize the similarities and dissimilarities between these two results in Tables 5 and C1. In general, the estimates in Table C1 are similar to those in Table 5. The main difference is that the elasticity of TFP with respect to the domestic R&D capital stock in Table C1 is smaller than that in Table 5, while the elasticity with respect to the foreign R&D capital stock in Table C1 has been increased (although it is somewhat reduced in the model using the Malmquist productivity index). This might occur because, as shown in Table 2, the foreign R&D capital stock calculated by the CH method is larger than that using the LP method. In the Törnqvist productivity index models, most of the estimates are statistically significant,

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[16] Following the suggestion from the referees, we also test the robustness of the results in several ways. One has been tested using 5 percent depreciation rate in calculating R&D capital stocks. The second is to consider the simultaneous bias or endogeneity problem between productivity and R&D stock. Keller (2002) also suggests using instrument variable method. However, there exists limitation to obtaining these instrument variables for both long time period and every industry in Korean manufacturing. Therefore, one way to deal with simultaneous bias is to estimate the regression models for every 5-year observation over 1976-1996, namely, 1976, 1981, 1986, 1991, and 1996. In the case, the sample size is only 41 observations (4 missing observation) so that we prefer using annual data (178 observations). However, the results for these two alternatives are not significantly different from the results in Table 5. Only domestic, other industry R&D stock is not statistically significant in some cases, but not in all models. Second, the test of $R\&D^{DS} = R\&D^F$ cannot be rejected, but the coefficients of $R\&D^F$ is still larger than those of $R\&D^{DS}$. These results can be obtained from the authors by request.

while the degree of significance is lower in the Malmquist productivity index models. The significance of the trade-related variables is essentially the same as in Table 5.

Comparing the results of the CH and the LP methods, we can say that the LP method is better for constructing foreign R&D stock because, as shown in Tables 5 and C1, the LP method improves R^2, which means that the LP method fits the model well. Moreover, all the coefficients of $lnR\&D^{DO}$ are statistically insignificant in the Malmquist productivity index model in Table C1, while they are statistically significant in the Malmquist productivity index model in Table 5, which uses the foreign R&D capital stock calculated by the LP method.

V. Concluding Remarks

Trade has played an important role in Korea's rapid economic growth since the early 1960s. Trade with developed countries provides an opportunity to absorb the advanced technology developed by these trade partners, thereby increasing productivity. In new growth theory, technology transmission via trade is linked to productivity. Coe & Helpman (1995), Coe *et al*. (1997), and Keller (2002) empirically analyzed international R&D spillovers through trade within developed countries as well as between North and South. These studies, however, did not examine industry in developing countries.

We investigated the effects of R&D spillovers on productivity using data from Korean industry. Our estimates suggest that domestic and foreign R&D have played an important role in the productivity of Korean manufacturing over the period 1976-96. In

Korea, foreign R&D stock has had a greater effect on productivity than domestic R&D, and foreign R&D stock from Japan has been more important than that of the U.S or other OECD countries. This may have been due to the different trade structures that pertain between Korea and these trade partners. We also observed that domestic other-industry R&D contributed more to productivity than domestic own-industry R&D in Korean manufacturing. This suggests that there have been both domestic and foreign R&D spillovers in Korean manufacturing.

In examining the relationship between trade patterns and productivity, our results show that productivity is greater in export industries and in the more open industries. The results also show that the effects of foreign R&D capital are greater in industries with large import shares or large intra-industry trade shares. Even if productivity is lower in an import industry, the effects of foreign R&D capital on productivity are greater in the import industry, since imports are a vehicle for foreign R&D spillovers. The effects of foreign R&D capital on productivity are also greater in industries with large intra-industry trade shares, since foreign technology is more easily absorbed in industries that import products similar to those that they themselves produce and export.

This paper focused on the effects of domestic and international R&D capital and trade on the productivity of Korean manufacturing. However, we also believe that domestic variables, like domestic market structure or direct foreign investment, are additional determinants of domestic productivity, and this opens up another avenue for further research.

Appendix A - *Industry Classification of Manufacturing Sectors*

9 Ind	28 Ind	ISIC Rev. 2	STAN industry category	SITC classification
01		**(31)**	Food, Beverages & Tobacco	
	01	311/2	Food	01-09 (0482), 211, 2232, 2239, 2632, 2681, 291, 4(4314), 5921.
	02	313	Beverages	0482, 11.
	03	314	Tobacco	12.
02		**(32)**	Textiles, Apparel & Leather	
	04	321	Textiles	2223, 261, 263(2632), 2667, 2672, 2682, 2686, 2687, 65(6576), 8451, 846(8465).
	05	322	Wearing Apparel	6576, 842, 843, 844, 845(8451), 8465, 847, 848.
	06	323	Leather & Products	61(6123), 831.
	07	324	Footwear	6123, 851.
03		**(33)**	Wood Products & Furniture	
	08	331	Wood Products	2460, 248, 63, 6597.
	09	332	Furnitures & Fixtures	82.
04		**(34)**	Paper, Paper Products & Printing	
	10	341	Paper & Products	251(2511), 641, 642(6423).
	11	342	Printing & Publishing	2511, 6423, 892.
05		**(35)**	Chemical Products	
	12	351	Industrial Chemicals	2331, 266, 2671, 2814, 51, 52, 53, 56, 58, 591, 5981, 6514, 6517.
	13	352	Other Chemicals	4314, 533, 541(5419), 55, 57, 592, 598, 882.
	14	353	Petroleum Refineries	334, 3351, 3354.
	15	354	Petroleum & Coal Products	323, 3352, 3353.
	16	355	Rubber Products	62.
	17	356	Plastic Products, nec	893.
06		**(36)**	Non-Metallic Mineral Products	
	18	361	Pottery, China etc	6639, 666, 8122.
	19	362	Glass & Products	664, 665.
	20	369	Non-Metallic Products, nec	661, 662, 663(6639).
07		**(37)**	Basic Metal Industries	
	21	371	Iron & Steel	67(677).
	22	372	Non-Ferrous Metals	2881, 68, 6999.
08		**(38)**	Fabricated Metal Products	
	23	381	Metal Products	677, 69(6954, 6973, 6999), 711, 7187, 7492, 8121, 8951.
	24	382	Non-Electrical Machinery	6954, 6973, 712, 713, 718(7187), 72, 73, 74(7492, 7493), 75, 7784, 8946, 951.
	25	383	Electrical Machinery	716, 76, 77, 8748, 8983.
	26	384	Transport Equipment	713, 714, 7493, 78, 79, 8941.
	27	385	Professional Goods	5419, 87(8748), 88(882), 8974, 8996.
09		**(39)**	Other Manufacturing	
	28	390	Other Manufacturing	667, 6993, 89(8941, 8946, 8951, 8974, 8983, 8996), 961.

Note: Figures in parentheses are excluded from the sub-classification of each industry.

Appendix B. Data Sources and Construction of Variables

This paper used a number of different data sources: (1) data on output, inputs and their prices for estimating productivity indexes, (2) R&D data for Korea and OECD countries by industry, and (3) bilateral trade data by industry and trade partner for the 14 OECD countries. The 14 OECD countries are as follows: Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, the United Kingdom, and the United States.

B.1 Korean Manufacturing Data

The data on output, number of workers, value-added, and wage compensation for Korean manufacturing for the period 1970-96 came from the OECD STAN database. The STAN database is classified into 28 manufacturing industries based on the 3-digit ISIC Rev. 2. Since the OECD STAN data are reported in current values, we needed to use a price index for each variable to calculate a constant value. The output deflator for each industry was obtained from the Bank of Korea (BOK), and deflators for intermediate goods were created by averaging the price deflators of 55 inputs using their weights. The weight of each input is defined as the relative share of purchases by each industry to the input, based on the Input-Output Tables of the BOK. Using these price indexes, each current value was converted into a 1990 constant value. The data on physical capital stock reported in terms of 1990 constant values were from Pyo (1998). The productivity index estimates were based on data for 28 Korean manufacturing sectors for the period 1970-96.

B.2 R&D and Trade Data

The Korean R&D data are from various issues of Science and Technology Statistics published by the Korea Ministry of Science and Technology, while the R&D data for the 14 OECD countries are from the OECD ANBERD database, which maintains a flow of R&D expenditure by economic activity for the 15 largest OECD R&D performing countries for the period 1973-1998. Since the STAN database does not report production for Ireland, 14 countries were used to construct the foreign R&D capital stock.

R&D investment was disaggregated into 9 industries common to each country. The nominal value of these R&D outlays in the national currency were converted into a constant 1990 value using the GDP deflator from the OECD Economic Outlook (2002). Then, these constant R&D expenditures were converted into U.S. dollars using the 1990 purchasing power parity exchange rates. Data for Korean R&D investment were only available for 9 industries after 1976. Therefore, we reclassified the variables for all 28 sectors (ISIC 3-digit) into the 9 sectors (2-digit ISIC) that corresponded to the Korean R&D data for 1976-96 (see Appendix A for details).

We calculated the domestic R&D capital stock of each industry from the R&D expenditures using the method of Coe and Helpman (1995) for Korea and the 14 OECD countries. We assume that the depreciation rate is 10% for every industry.

In constructing foreign R&D capital stock, the CH and the LP methods were used. In the CH method, foreign R&D stock of industry *i* at time *t*, S_{it}^{f-CH}, is defined as follows:

$$S_{it}^{f-CH} = \sum_{j \neq i} S_{ijt}^{f-CH} = \sum_{j \neq i} \frac{m_{ijt}}{m_{it}} S_{ijt}^{d} \qquad \text{for each industry } i \qquad \text{(B1)}$$

where S_{ijt}^{d} is industry *i*'s domestic R&D stock of trade partner *j*, m_{ijt} is the imports flow of industry *i* from one of trade partner *j*, and m_{it} is the total imports of industry *i* at time *t* from its total trade partners, namely, $m_{it} = \sum_{j \neq i} m_{ijt}$.

On the other hand, in the LP method, foreign R&D stock of industry *i* at time *t*, S_{it}^{f-LP}, is calculated as follows:

$$S_{it}^{f-LP} = \sum_{j \neq i} S_{ijt}^{f\text{-}LP} = \sum_{j \neq i} \frac{m_{ijt}}{y_{ijt}} S_{ijt}^{d} \qquad \text{for each industry } i \qquad \text{(B2)}$$

where y_{ijt} is industy *i*'s output level of trade partner *j* at time *t* LP (1998) argues that this formulation reflects the intensity as well as the direction of international R&D spillovers.

The trade data used to calculate the bilateral trade shares of the industries are from the World Trade Flows Database CD-ROM (Feenstra et al., 1997; Feenstra, 2000). The industry code of trade data is the SITC Rev. 2, but the R&D data are based on ISIC Rev. 2. Therefore, the 4-digit SITC is matched to the 3-digit ISIC using the OECD classification. These industries were re-classified into 9 industries to match the Korean R&D data set, and we constructed foreign R&D stocks for the 9 industries.[17]

[17] See Appendix A for the industry classification. Korean R&D data are available by industry from 1976.

Appendix C. Alternative Empirical Result

Table C1: *Regression results using the foreign R&D stocks based on the CH method: Dependent Variable = lnTFP*

Model	Törnqvist productivity index					Malmquist productivity index				
	(T.1)	(T.2)	(T.2)'	(T.3)	(T.4)	(M.1)	(M.2)	(M.2)'	(M.3)	(M.4)
$lnRD^{DS}$	.056 *** (5.08)	.073 *** (6.34)	.044 *** (3.22)	.034 *** (2.86)	.031 *** (2.92)	.053 *** (3.88)	.057 *** (3.98)	.038 ** (2.23)	.043 *** (2.82)	.039 *** (2.99)
$lnRD^{DO}$	.061 ** (2.21)	.067 ** (2.44)	.065 ** (2.43)	.059 ** (2.18)	.063 ** (2.41)	.042 (1.21)	.047 (1.37)	.031 (0.91)	.023 (0.67)	.060 * (1.88)
$lnRD^{F}$	.185 *** (4.76)			.193 *** (5.32)	.227 *** (4.18)	.110 ** (2.27)			.117 *** (2.51)	.036 (0.53)
$lnRD^{F\_USA}$		.080 *** (4.29)	.085 *** (4.79)				.022 (0.95)	.025 (1.12)		
$lnRD^{F\_JPN}$		.060 *** (3.53)	.045 *** (2.74)				.065 *** (3.06)	.048 ** (2.29)		
$lnRD^{F\_OTH}$		.021 (1.27)	-.007 (0.42)				-.005 (0.26)	-.029 (1.30)		
LnIMP			-.121 *** (4.16)	-.127 *** (4.76)	-.772 *** (3.50)			-.118 *** (3.21)	-.113 *** (3.31)	-.423 (1.56)
LnOPEN			.108 ** (2.19)	.133 *** (2.76)	.063 (1.43)			.194 *** (3.09)	.213 *** (3.46)	.137 ** (2.52)
$lnIMP*lnRD^{F}$					.046 *** (3.07)					.024 (1.32)
$IIT*\ lnRD^{F}$					.182 *** (6.14)					.282 *** (7.74)
R^2	.631	.644	.685	.682	.756	.922	.925	.931	.929	.950
F(28, •) value for no fixed effect	3.44 ***	3.31 ***	3.64 ***	4.07 ***	6.71 ***	42.22 ***	30.98 ***	14.23 ***	13.82 ***	21.14 ***
F(1, •) value for $R\&D^{DS} = R\&D^{F}$	9.14 ***	7.45 ***	6.52 ***	15.43 ***	12.01 ***	1.12	0.37	0.02	2.02	0.00
F(1, •) value for $RD^{F\_USA} = RD^{F\_JPN}$	-	0.70	2.88 *	-	-	-	2.00 ξ	0.59	-	-

Notes: - See notes in Table 5. - ξ is rejected at the 20.0% significance level.

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Abstract: R&D, Trade, and Productivity Growth in Korean Manufacturing: This paper investigates the effects of both R&D spillovers and trade patterns on productivity in

Korean manufacturing, using industry-level data. Our results show that domestic and foreign R&D capital stocks have played an important role in productivity growth of Korean manufacturing over the period 1976-96, and that foreign R&D capital has had more effect than domestic R&D in improving the total factor productivity of Korean manufacturing. Moreover, productivity is greater in export industries and in the more open industries, and the effects of foreign R&D capital are greater in the industries with large import shares or large intra-industry trade shares. JEL no. F10, O32, O47

(* Appendix D is only for referees, not for publication.)

Appendix D: Estimation Methodology of Total Factor Productivity Index

D.1 The Törnqvist Productivity Index

In this paper, we use two methods for the estimation of TFP: the Törnqvist and the Malmquist productivity indexes. The main differences between these two are as follows. First, the Törnqvist productivity index suggested by Caves, Christensen, and Diewert (1982) is multilateral indexes in which the Törnqvist productivity index can compare the level of TFP between industries and time periods, but the Malmquist productivity index can not. On the other hand, the Törnqvist productivity index[18] presumes that production activity is always efficient, while the Malmquist index does not. Thus, the Malmquist index decomposes TFP into efficiency and technical progress. Second, calculation of the Malmquist index does not require any information on cost or income shares, and prices of inputs or outputs, while the Törnqvist index does. Only quantities of inputs and outputs are required in the Malmquist method. Thus, the method of the Malmquist index is less data-demanded relative to the Törnqvist index.

On the basis of Törnqvist-Theil index, Caves et al. (1982) used multilateral translog index in which the Törnqvist productivity index can compare the level of TFP between cross-sectional industries and time periods. For the estimation of the Törnqvist productivity index, we need information on output and input indexes. The translog multilateral output index between industry groups k and l derived from the translog

[18] See pp. 58-61 in Färe et al. (1996) for details.

transformation function in Caves et al. (1982) is as follows:

$$\ln\delta_{kl} = \tfrac{1}{2}\sum_i (R_i^k + \overline{R}_i)(\ln Y_i^k - \overline{\ln Y_i}) - \tfrac{1}{2}\sum_i (R_i^l + \overline{R}_i)(\ln Y_i^l - \overline{\ln Y_i}) \qquad \text{(D1)}$$

where $\ln\delta_{kl}$ is output index, R_i^k and R_i^l are the output ratio of industry *i* to total output in each industry group. Y_i^k and Y_i^l are output of industry *i* in each group and $\overline{R}_i$ and $\overline{\ln Y_i}$ are arithmetic means of sum of R_i and $\ln Y_i$ from both groups *k* and *l*, respectively.

The translog multilateral input index ρ_{kl} is derived as follows:

$$\ln\rho_{kl} = \tfrac{1}{2}\sum_n (W_n^k + \overline{W}_n)(\ln I_n^k - \overline{\ln I_n}) - \tfrac{1}{2}\sum_n (W_n^l + \overline{W}_n)(\ln I_n^l - \overline{\ln I_n}) \qquad \text{(D2)}$$

where W_n^k is share of input n in total cost of group *k* and I_n^k is the amount of input n used in group k. The variables under the bar are arithmetic means of sum of groups *k* and *l*. Since we use three inputs: labor (*L*), capital (*K*) and intermediates (*M*), single multilateral input index is required from multi-inputs.

$$\begin{aligned}\ln\phi_{kl} = {} & \tfrac{1}{2}\sum_i (W_{Li}^k + \overline{W_{Li}})(\ln L_i^k - \overline{\ln L_i}) - \tfrac{1}{2}\sum_i (W_{Li}^l + \overline{W_{Li}})(\ln L_i^l - \overline{\ln L_i}) \\ & + \tfrac{1}{2}\sum_i (W_{Ki}^k + \overline{W_{Ki}})(\ln K_i^k - \overline{\ln K_i}) - \tfrac{1}{2}\sum_i (W_{Ki}^l + \overline{W_{Ki}})(\ln K_i^l - \overline{\ln K_i}) \qquad \text{(D3)} \\ & + \tfrac{1}{2}\sum_i (W_{Mi}^k + \overline{W_{Mi}})(\ln M_i^k - \overline{\ln M_i}) - \tfrac{1}{2}\sum_i (W_{Mi}^l + \overline{W_{Mi}})(\ln M_i^l - \overline{\ln M_i})\end{aligned}$$

where $W_{Ii} = p_i I_i / \sum X_i$, where $I = L, K$, and M. p is price of each input and $\sum X_i$ is total output of all industries.

Using the output index and single multilateral input index, the multilateral productivity index is defined as

$$\ln F_{kl} = \ln \delta_{kl} - \ln \phi_{kl} \qquad \text{(D4)}$$

This productivity index is very attractive for time series section comparison and cross section comparison as well as for panel data comparisons because this index has a property of transitivity between different time periods and different cross sections. We can also calculate growth rate of productivity by taking log-differences between two different productivity indexes.

D.2 The Malmquist Productivity Index

The method of the Malmquist productivity index is based on distance functions. Following Färe et al. (1994), the output-based Malmquist productivity index is defined as the geometric mean of two output-distance functions to avoid choosing an arbitrary benchmark:

$$\begin{aligned} \mathrm{M}(\mathbf{z}^{t+1}, \mathbf{z}^{t}) &= [\,\mathrm{M}^{t} \cdot \mathrm{M}^{t+1}\,]^{1/2} \\ &= \left[\left(\frac{\mathrm{D}^{t}(\mathbf{z}^{t+1})}{\mathrm{D}^{t}(\mathbf{z}^{t})} \right) \left(\frac{\mathrm{D}^{t+1}(\mathbf{z}^{t+1})}{\mathrm{D}^{t+1}(\mathbf{z}^{t})} \right) \right]^{1/2} \end{aligned} \qquad \text{(D5)}$$

Definition (D5) can be rewritten equivalently as the following way:

$$M(\mathbf{z}^{t+1}, \mathbf{z}^{t}) = \frac{D^{t+1}(\mathbf{z}^{t+1})}{D^{t}(\mathbf{z}^{t})}\left[\left(\frac{D^{t}(\mathbf{z}^{t+1})}{D^{t+1}(\mathbf{z}^{t+1})}\right)\left(\frac{D^{t}(\mathbf{z}^{t})}{D^{t+1}(\mathbf{z}^{t})}\right)\right]^{1/2} \qquad \text{(D5)}'$$

where the ratio outside the brackets measures the change in relative efficiency between t and t+1, and the geometric mean inside the bracket measures the shift in frontier. That is, the Malmquist productivity index can be decomposed into efficiency change and change in technical progress.[19]

For the empirical work, Färe et al. (1994) used non-parametric linear-programming techniques. As we can see in equation (13)′, we need solve four different linear-programming problems: $D^t(\mathbf{z}^t)$, $D^t(\mathbf{z}^{t+1})$, $D^{t+1}(\mathbf{z}^t)$, and $D^{t+1}(\mathbf{z}^{t+1})$. Calculating the Malmquist index relative to the constant-returns-to-scale technology, $D^t_j(\mathbf{z}^t)$ for each industy, $j \in k = 1, \dots, K$, one of the four different linear-programming problems, can be stated as:[20]

$$[D^t_j(\mathbf{z}^t_j)]^{-1} = \max_{\theta, w} \ \theta_j \qquad \text{(D6)}$$

$$\text{subject to} \qquad \theta_j y^t_{m,j} \le \sum_{k=1}^{K} w^t_k y^t_{m,k} \quad m = 1, \dots, M \qquad \text{(D6-1)}$$

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[19] See Färe et al. (1994) for the graphical explanation.

[20] Ray and Desli (1997) emphasize the importance of variable returns to scale (VRS) in using a reference technology. However, the method of VRS in some cases has an infeasible solution (See Ray & Desli; 1997, p. 1037). One of comments of Färe et al. (1997) responding to Ray and Desli (1997) is that the constant returns to scale captures long-run and the VRS is appropriate for the short-run. Since our study analyzes the long-run productivity trend over 1970-96, we use the method of Färe et al. (1994).

$$\sum_{k=1}^{K} w_k^t x_{n,j}^t \le x_{n,j}^t \qquad n = 1, \ldots, N \qquad \text{(D6-2)}$$

$$w_k^t \ge 0 \qquad k = 1, \ldots, K \qquad \text{(D6-3)}$$

where n = 1,…, N are inputs, m = 1, …, M, outputs and w_k^t, an intensity variable indicating at what intensity a particular activity (here, each industry is an activity) may be employed in production. These intensity variables will be used as weights in taking convex combinations of the observed outputs and inputs in both (D6-1) and (D6-2), respectively. From equation (D6), the reciprocal of output distance function is to find maximum, θ which gives the maximal proportional expansion of output given constraints, (D6-1) - (D6-3).

Among other distance functions, the computation of $D^{t+1}(\mathbf{z}^{t+1})$ is exactly like (D6), where t+1 is substituted for t. Two other distance functions require information from two periods. $D^t(\mathbf{z}^{t+1})$ can be computed by replacing $y_{m,j}^t$ and $x_{n,j}^t$ in equation (D6-1) and (D6-2) with $y_{m,j}^{t+1}$ and $x_{n,j}^{t+1}$, respectively, and $D^{t+1}(\mathbf{z}^t)$ is the same as $D^t(\mathbf{z}^{t+1})$, where the t and t+1 superscripts are exchanged.[21]

Appendix E: An Alternative Regression Result

Appendix E is an alternative regression result using every 5-year observation to avoid simultaneous bias or endogeneity problem between domestic R&D investment and productivity. Basically, there is no significant difference between Table 5 and Table E1.

[21] See Coelli (1996), p. 27 for more details.

Table E1: Regression results using the foreign R&D stocks based on the LP method

Model	Törnqvist productivity index					Malmquist productivity index				
	(T.1)	(T.2)	(T.2)'	(T.3)	(T.4)	(M.1)	(M.2)	(M.2)'	(M.3)	(M.4)
Dep. Var / Indep. var	lnTFP					lnTFP				
$\ln RD^{DS}$	.125 *** (5.46)	.122 *** (4.74)	.108 *** (4.17)	.110 *** (4.59)	.084 *** (2.92)	.123 *** (4.81)	.117 *** (4.44)	.125 *** (5.27)	.135 *** (5.53)	.116 *** (4.77)
$\ln RD^{DO}$	.109 ** (2.30)	.096 * (2.04)	.083 * (1.80)	.094 ** (2.09)	.108 ** (2.58)	.120** (1.21)	.118 ** (2.44)	.075 * (1.78)	.074 (1.62)	.095 ** (2.26)
$\ln RD^{F}$	.159 *** (3.86)			.182 *** (4.50)	.222 *** (3.49)	.137 *** (2.97)			.130 *** (3.18)	.071 (1.10)
$\ln RD^{F\_USA}$		.080 *** (3.26)	.087 *** (3.76)				.045 * (1.78)	.045 ** (2.13)		
$\ln RD^{F\_JPN}$		.055 ** (2.21)	.059 ** (2.44)				.093 *** (3.58)	.081 *** (3.65)		
$\ln RD^{F\_OTH}$		.004 (0.13)	.006 (0.23)				.008 (0.26)	.002 (0.08)		
lnIMP			-.125 ** (2.40)	-.142 ** (2.61)	-.389 ** (2.15)			-.107 ** (2.24)	-.118 ** (2.14)	-.042 (0.23)
lnOPEN			.178 * (1.78)	.214 ** (2.12)	.188 * (2.04)			.329 *** (3.60)	.374 *** (3.66)	.360 *** (3.86)
$\ln IMP^{*}\ln RD^{F}$					.028 (1.60)					-.004 (0.22)
$IIT^{*} \ln RD^{F}$					.046 * (1.80)					.068 ** (2.65)
R^2	.817	.844	.878	.860	.895	.960	.971	.982	.975	.981
F(28, •) value for no fixed effect	4.59***	4.13***	4.99***	6.02***	7.77***	32.38***	37.56***	22.74***	19.20***	22.97***
F(1, •) value for $R\&D^{DS} = R\&D^{F}$	0.51	0.17	0.87	1.93	3.56 *	0.07	0.40	0.00	0.01	0.37
F(1, •) value for $RD^{F\_USA} = RD^{F\_JPN}$	-	0.41	0.59	-	-	-	1.41	1.17	-	-

Notes: (1) See notes in Table 5.

Table E2: Regression results using the foreign R&D stocks based on the CH method

Model	Törnqvist productivity index					Malmquist productivity index				
	(T.1)	(T.2)	(T.2)'	(T.3)	(T.4)	(M.1)	(M.2)	(M.2)'	(M.3)	(M.4)
Dep. Var / Indep. Var	lnTFP					lnTFP				
$\ln RD^{DS}$	.104 *** (4.15)	.120 *** (4.77)	.118 *** (4.01)	.110 *** (4.05)	.095 *** (4.35)	.112 *** (3.80)	.112 *** (3.91)	.132 *** (4.74)	.138 *** (5.05)	.121 *** (5.28)
$\ln RD^{DO}$	.037 (0.76)	.046 (1.02)	.032 (0.68)	.014 (0.27)	.009 (0.21)	.066 (1.15)	.074 (1.42)	.037 (0.81)	.020 (0.41)	.043 (0.95)
$\ln RD^{F}$	.227 *** (3.36)			.224 *** (3.40)	.395 *** (3.61)	.133 ξ (1.68)			.130 * (1.97)	.149 (1.30)
$\ln RD^{F\_USA}$		.108 *** (3.52)	.103 *** (3.28)				.054 ξ (1.53)	.041 (1.36)		
$\ln RD^{F\_JPN}$		.086 ** (2.71)	.075 ** (2.25)				.096 ** (2.66)	.078 ** (2.47)		
$\ln RD^{F\_OTH}$		-.002 (0.05)	-.012 (0.34)				-.017 (0.47)	-.023 (0.73)		
lnIMP			-.062 (1.03)	-.070 (1.20)	-1.281** (2.65)			-.062 (1.08)	-.067 (1.15)	-.560 (1.11)
lnOPEN			.149 (1.31)	.210 * (1.86)	.152 ξ (1.67)			.326 *** (3.02)	.373 *** (3.29)	.340 *** (3.57)
$\ln IMP*\ln RD^{F}$					.084 ** (2.56)					.035 (1.02)
$IIT*\ln RD^{F}$					.154 *** (2.91)					.189 *** (3.42)
R^2	.799	.839	.851	.825	.900	.951	.963	.976	.969	.981
F(28, •) value for no fixed effect	4.26***	3.71***	2.65***	4.44***	8.42***	27.27***	28.29***	17.04***	15.60***	22.62***
F(1, •) value for $R\&D^{DS} = R\&D^{F}$	2.39 ξ	1.22	0.49	2.15 ξ	6.96 **	0.05	0.08	0.32	0.01	0.05
F(1, •) value for $RD^{F\_USA} = RD^{F\_JPN}$	-	0.33	0.50	-	-	-	0.93	1.00	-	-

Notes: (1) See notes in Table 5.