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R&D SPILLOVERS IN MANUFACTURING INDUSTRIES

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The empirical findings of this paper suggest that manufacturing industries derive substantial benefits from research and development performed in other industries and other countries. In fact, R&D spillovers tend to be more potent force behind productivity gains in the OECD manufacturing sector than the industry's own R&D activities. Inter-industry R&D spillovers are found to play a particularly important role in improving industrial productivity. In certain industries, however, international R&D spillovers may have stronger effects especially for countries more open to international trade.

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I. INTRODUCTION

To gauge the extent of technical progress, economists have traditionally tried to measure the residual growth rate of output not explained by the growth in inputs in the context of total factor productivity (TFP).[1] Whereas technical progress was initially treated as an exogenous process in the neoclassical theory as shown in the Solow model, ample empirical literature has established a strong positive relationship between cumulative R&D and TFP growth. As a result,

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[1] The residual growth rate may in fact cover many other components besides technical change. Abramovitz (1956) called the residual growth rate of output as a just 'measure of ignorance.' Without alternative measures accepted as widely, however, TFP growth is frequently interpreted to estimate the extent of technical change.

commercially oriented innovation efforts are by now widely regarded as a major engine of technical progress (see Griliches, 1988, for a review). Many studies in fact have found that the rate of return on R&D is much higher than that on investment in physical capital.[2]

However, the benefits of cumulative R&D activities are not just limited to the firms which originally have carried out those activities. Industrial innovations based on R&D tend to spread to other firms in the same industry, or often emanate even across industries. There exists plenty of convincing empirical evidence of inter-firm and inter-industry diffusion of innovations.[3]

Furthermore, the diffusion of innovations is not necessarily confined to within the national border in a world with free flows of goods and services, capital, and information. According to Grossman and Helpman (1991), international trade provides transmission channels of R&D spillovers across borders by facilitating cross-border learning of production methods, product design, organizational methods and market conditions. International trade also enables a country to imitate foreign technologies and employ intermediate products and capital equipments that differ in quality and are vertically differentiated form the domestically produced ones. Coe and Helpman (1995) in fact offer strong empirical evidence that a country's productivity growth depends not only on its own cumulative R&D effort, but also on the R&D spillovers from its trade partners.

This paper studies the extent to which an industry's productivity level depends on its own R&D capital stocks as well as R&D spillovers. In line with many of theoretical and empirical studies, cumulative R&D expenditure is used as a proxy for R&D capital stocks. The construction of R&D capital stocks follows Lee and Kim (2006). In determining the effect of R&D spillovers on productivity, two types of variables are considered: R&D capital stocks of other domestic industries and foreign R&D capital stocks within a given industry. Foreign R&D capital stocks are constructed by using import weighted sums of trade partners' R&D capital stocks, and they represent the extent of international R&D spillovers within an industry. R&D capital stocks of other domestic industries, on the other hand, measure the extent of inter-industry R&D spillovers within a country.

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[2] For a review, see Griliches (1994) among others.

[3] For example, Mansfield et al. (1977) find that the gap between social and private rates of return from industrial innovations is large.

In measuring TFP growth, the Malmquist index is calculated instead of the traditionally used residual growth rates. Although the residual growth rates are of interest for intertemporal comparisons of productivity for a given country, they are less useful for comparing the relative productivity of different countries. In terms of the residual growth rate, for example, a country can show a much more rapid productivity growth than other countries simply because it starts from a lower level.[4] Since the sample used for analysis consists of 14 OECD countries, this study adopts the Malmquist index approach which is more useful for comparing the relative productivity growth of these countries. Several studies investigated comparative productivity growth in the framework of the Malmquist index. They include among others: Färe et al. (1994); Taskin and Zaim (1997); Arcelus and Arozena (1999); and Maudos et al. (2000).

Based on a sample of 14 OECD countries during the period 1982-1993, this paper finds that both inter-industry and international R&D spillovers have important effects on TFP, and these effects in fact tend to outweigh those of the industry's own R&D capital stocks. Inter-industry R&D spillovers are found to play a particularly important role in improving industrial productivity. In certain industries, however, international R&D spillovers may have stronger effects especially for countries more open to trade.

The next section contains a discussion of the Malmquist index and its decomposition. The main features of data used in this paper are reviewed in Section Ⅲ. The main empirical findings are reported in Section Ⅳ. Section Ⅴ concludes.

Ⅱ. THE MALMQUIST INDEX

To estimate TFP growth rates, this paper uses the Malmquist index approach proposed by Caves et al. (1982). The basic idea of this method is to construct the best-practice frontier using data on input-output combinations of a sample of countries (or industries or firms), and measure the distance between any particular observation and the frontier. Following Shephard (1970) and Caves et al. (1982), the output distance function at time t, D_o^t, is defined as follows:

$$D_o^t(x^t, y^t) = \inf\{\theta : (x^t, y^t/\theta) \in S^t\} \qquad (1)$$

[4] This possibility is discussed in the huge literature on convergence theory. See Baumol (1986), Abramovitz (1990) and Dowrick and Nguyen (1989) among others.

where S^t denotes the production technology which is defined as $S^t = \{(x^t, y^t)$: x^t can produce y^t at time $t\}$. x^t and y^t are vectors of inputs and outputs at time t respectively. Note that $D_o^t \le 1$ corresponds to $(x^t, y^t) \in S^t$, and that $D_o^t = 1$ indicates that (x^t, y^t) lies on the technology frontier or boundary. Caves et al. (1982) define the output-based Malmquist index between periods t and $t+1$ as

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \right]^{1/2} \tag{2}$$

A value of M_0 greater than unity indicates positive growth of TFP from period t to $t+1$, and a value less than unity represents deterioration in TFP. Under the technology of constant returns to scale, this output-based Malmquist index will provide the same measure of productivity change as the input-based index.

One should note that the growth accounting method such as the Törnqvist index implicitly assumes that all units of production are technically efficient. If this assumption does not hold, the estimated productivity change will fail to represent the true technological progress. In contrast, the Malmquist index allows technical inefficiency by relying on the technology frontier concept. Following Färe et al. (1994), the Malmquist index in Eq. (2) can be rewritten as

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \times \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)} \right]^{1/2} \tag{3}$$

Eq. (3) shows the decomposition of the Malmquist index into two basic components - efficiency change (EC) and technical change (TC).[5] The first ratio on the right hand side of Eq. (3) represents the change in technical efficiency or catch-up effect between the two periods t and $t+1$ (EC), and the term inside the bracket shows the change in technology (TC). If a sufficient number of observations are provided in each period, these change indexes based on pairs

[5] Efficiency change can be further divided into scale change and pure efficiency change when the variable returns to scale (VRS) technology is assumed (Färe et al., 1994).

of successive periods can then be calculated.

For estimation of technology frontiers, several methods have been developed since Farrell (1957). This study uses the data envelopment analysis (DEA) approach to estimate the frontiers and calculate Malmquist indexes. In the DEA approach, the best-practice frontiers are estimated by non-parametric linear programming methods. In solving optimization problems, the DEA focuses on all individual observations whereas other statistical approaches usually concern average values.

Ⅲ. DATA

The sample consists of 14 OECD countries for which data on fixed capital investment and R&D investment are available over the period of 1982-1993: Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, South Korea,[6] Spain, Sweden, the United Kingdom, and the United States. The period 1982-1993 is chosen due to data unavailability at the two-digit ISIC level in Korea before 1982, and also because of data inconsistency in Germany after 1993 stemming from its unification.

The appendix presented at the end details data sources and the construction of varaibles for estimation purposes. This section instead highlights some features of data that are noteworthy. As shown in Table 1, OECD countries exhibit robust productivity gains in manufacturing industries over the period of 1983-1993. Average Malmquist indexes tend to be greater than unity in most industries at the two-digit ISIC level for all sample countries except for Spain which experienced actual TFP regress in six out of eight industries. Among the sample countries, Korea, Norway and the Netherlands exhibit particularly strong TFP growth in most industries. In wood products and furniture industry, Finland and France show the largest TFP growth, whereas Italy, Canada, and Finland lead the pack in the paper and printing industry. During the period this study covers, the chemical products industry in particular stands out in terms of productivity growth.[7] This industry not only registered higher TFP growth than any other industries during the period, but also achieved on average productivity progress

[6] Hereafter 'Korea'. Technically speaking, Korea was not an OECD member country during the period this study covers. Korea joined the OECD in 1996.

[7] The industry includes chemicals, drugs and medicines, petroleum refineries and products, and rubber and plastic products industries.

in all sample countries.

[Table 1] Malmquist Index: Averages 1983-1993

	31	32	33*	34*	35	36	37	38
Canada	1.031	1.024	1.039	1.072	1.073	1.042	1.055	1.002
Denmark	1.026	1.030	0.998	0.988	1.048	1.055	0.974	1.011
Finland	1.049	0.994	1.080	1.070	1.057	1.023	1.047	1.017
France	1.041	1.050	1.079	1.008	1.061	1.050	1.036	1.035
Germany	1.018	1.051	1.011	1.023	1.049	1.040	0.981	0.996
Italy	1.055	1.043	1.065	1.076	1.054	1.028	1.032	1.047
Japan	0.999	0.986	0.994	1.024	1.042	1.038	1.025	1.043
Korea	1.040	1.064	1.072	1.044	1.088	1.083	1.109	1.080
Netherlands	1.074	1.042	0.995	1.044	1.078	1.072	1.012	1.034
Norway	1.104	1.074	1.066	1.068	1.102	1.055	1.071	1.033
Spain	0.994	0.973	0.989	0.983	1.021	1.003	0.981	0.954
Sweden	1.049	1.065	1.047	1.045	1.074	1.047	0.998	0.981
UK	1.034	1.038	0.985	0.991	1.061	1.025	1.043	1.015
US	1.032	1.039	1.035	1.038	1.057	1.045	1.023	1.035

Note: ISIC codes classified as follows: 31. Food, beverages and tobacco; 32. Textiles, apparel and leather; 33. Wood products and furniture; 34. Paper, paper products and printing; 35. Chemical products; 36. Non-metallic mineral products; 37. Basic metal industries; 38. Fabricated metal products.

* The corresponding sample period is 1984-1990 due to the classification problem in R&D data for Korea.

Between 1982 and 1993, R&D capital stock increased significantly in all sample countries as reported in Table 2. In Korea in particular, the stock increased more than 30 percent a year for the whole manufacturing sector, but the growth was more modest in other countries, mostly ranging from about 10 to 15 percent per year on average. The United Kingdom and United States tend to show the slowest expansion of their R&D capital stocks of about 6 to 8 percent per year for the whole manufacturing sector. As can be seen from Figure 1, the annual changes in R&D capital stocks in manufacturing exhibit not only variations across countries but also fluctuations over time.

The annual changes in R&D capital stocks also show variations between individual industries (Table 2). The wood products and furniture industry exhibits

[Table 2] Domestic R&D Capital Stocks: Average Annual Growth Rates 1983-1993

	3	31	32	33*	34*	35	36	37	38
Canada	0.106	0.057	0.127	0.169	0.106	0.072	0.079	0.062	0.125
Denmark	0.116	0.102	0.036	0.087	0.076	0.132	0.048	0.214	0.118
Finland	0.134	0.157	0.114	0.140	0.120	0.141	0.146	0.076	0.139
France	0.095	0.127	0.064	0.081	0.119	0.093	0.077	0.078	0.096
Germany	0.096	0.076	0.082	0.135	0.084	0.079	0.096	0.042	0.105
Italy	0.120	0.152	0.293	0.492	0.010	0.094	0.141	0.100	0.132
Japan	0.134	0.124	0.112	0.100	0.177	0.124	0.132	0.107	0.141
Korea	0.339	0.257	0.202	0.185	0.240	0.248	0.270	0.275	0.402
Netherlands	0.082	0.077	0.080	0.172	0.105	0.080	0.080	0.079	0.085
Norway	0.106	0.119	0.052	0.057	0.099	0.142	0.112	0.104	0.098
Spain	0.145	0.147	0.173	0.657	0.129	0.118	0.085	0.041	0.166
Sweden	0.108	0.068	0.086	0.031	0.110	0.141	0.048	0.021	0.109
UK	0.063	0.049	-0.018	0.031	0.071	0.115	0.027	0.010	0.047
US	0.079	0.086	0.095	0.046	0.073	0.092	0.055	0.007	0.078
Total	0.123	0.114	0.107	0.170	0.109	0.120	0.100	0.087	0.131

Note: ISIC codes classified as follows: 3. Total manufacturing; 31. Food, beverages and tobacco; 32. Textiles, apparel and leather; 33. Wood products and furniture; 34. Paper, paper products and printing; 35. Chemical products; 36. Non-metallic mineral products; 37. Basic metal industries; 38. Fabricated metal products.

* The corresponding sample period is 1984-1990 due to the classification problem in R&D data for Korea.

the most rapid expansion of R&D capital stocks at an annual growth rate of about 17 percent on average over the 1983-1993 period, whereas the basic metal industries show the slowest expansion at an average rate just below 9 percent per year. To the extent that R&D spillovers from other domestic industries are measured by the sum of R&D capital stocks in other industries, the pace at which R&D spillovers expand tends to differ less dramatically from industry to industry than the pace of the industry's own R&D capital expansion. As shown in Table 3, the sum of R&D capital stocks in other industries shows a narrower range of the growth rate distribution among industries - between 11 and 14 percent - than the industry's own R&D capital stocks. The pace of R&D spillovers from other industries was particularly great in the paper and printing industry and the wood products and furniture industry, and was the slowest in the fabricated metal products industry.

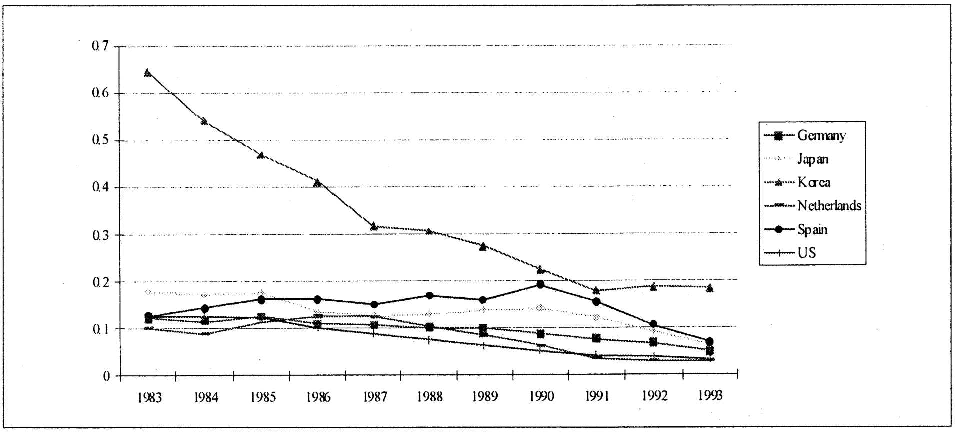
[Table 3] R&D Capital Stocks in Other Domestic Industries: Average Annual Growth Rates 1983-1993

	31	32	33*	34*	35	36	37	38
Canada	0.108	0.106	0.114	0.120	0.115	0.106	0.109	0.075
Denmark	0.117	0.117	0.121	0.126	0.110	0.118	0.116	0.114
Finland	0.133	0.135	0.155	0.161	0.133	0.134	0.138	0.129
France	0.094	0.095	0.099	0.101	0.095	0.095	0.095	0.093
Germany	0.097	0.097	0.107	0.109	0.102	0.096	0.098	0.078
Italy	0.119	0.120	0.134	0.135	0.131	0.120	0.120	0.096
Japan	0.134	0.134	0.145	0.149	0.137	0.134	0.136	0.122
Korea	0.344	0.349	0.363	0.400	0.369	0.341	0.342	0.255
Netherlands	0.082	0.082	0.101	0.101	0.083	0.082	0.082	0.080
Norway	0.106	0.107	0.123	0.124	0.098	0.106	0.106	0.119
Spain	0.145	0.145	0.162	0.158	0.156	0.147	0.149	0.114
Sweden	0.109	0.108	0.119	0.123	0.103	0.109	0.112	0.107
UK	0.063	0.064	0.070	0.072	0.046	0.063	0.064	0.095
US	0.079	0.079	0.090	0.095	0.076	0.079	0.080	0.083
Total	0.124	0.124	0.136	0.141	0.125	0.124	0.125	0.111

Note: ISIC codes classified as follows: 31. Food, beverages and tobacco; 32. Textiles, apparel and leather; 33. Wood products and furniture; 34. Paper, paper products and printing; 35. Chemical products; 36. Non-metallic mineral products; 37. Basic metal industries; 38. Fabricated metal products.

* The corresponding sample period is 1984-1990 due to the classification problem in R&D data for Korea.

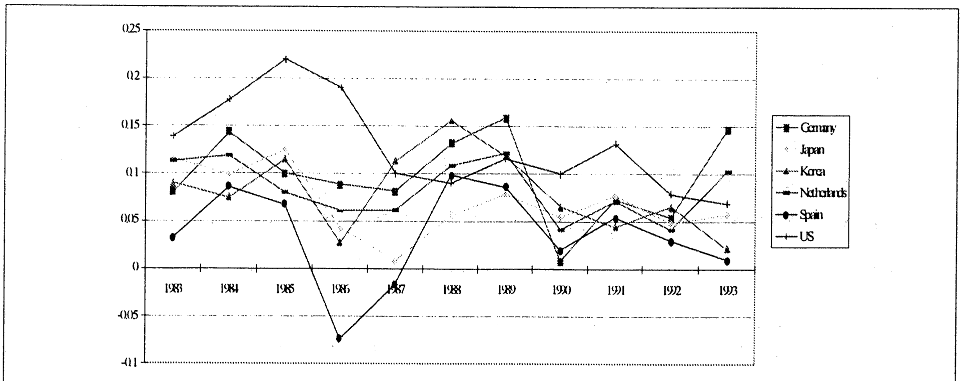
[Figure 1] Annual Growth Rates of Domestic R&D Capital Stocks: Total Manufacturing (ISIC 3)



The growth of foreign R&D capital stocks tends to be more modest than that of domestic R&D capital stocks for the sample countries (Table 4). In the manufacturing sector as a whole, foreign R&D capital stocks expanded on average at only about 8 percent per year over the 1983-1993 period, while domestic R&D capital stocks grew at more than 12 percent per year during the same period. The average annual growth rates of foreign R&D capital stocks were in fact less than 10 percent in all industries. However, the annual changes in foreign R&D capital stocks fluctuated more widely from year to year than those in domestic R&D capital stocks, as can be seen by comparing Figure 2 with Figure 1. Among the sample countries, the United States faced the largest expansion of foreign R&D capital stocks in all industries, and Spain experienced their slowest expansion in all industries except for the basic metal industries where Japan shows the smallest increase. The chemical products industry experienced the fastest expansion of foreign R&D capital stocks, closely followed by the textiles, food and beverage, and fabricated metal products industries.

Table 5 reports average import shares in GDP over the period of 1982-1993. Among the sample countries, the Netherlands had by far the largest import shares (on average 42.2 percent), followed by Korea (29.6 percent). In contrasst, the United States and Japan had the smallest import shares with their average shares being 8.6 percent and 7.9 percent of GDP respectively. Figure 3 also shows that the Netherlands continued to surpass other sample countries in import shares during the whole period while the United States and Japan had the lowest level every year. For all sample countries, however, import shares fluctuated considerably over time.

[Figure 2] Annual Growth Rates of Foreign R&D Capital Stocks: Total Manufacturing (ISIC 3)



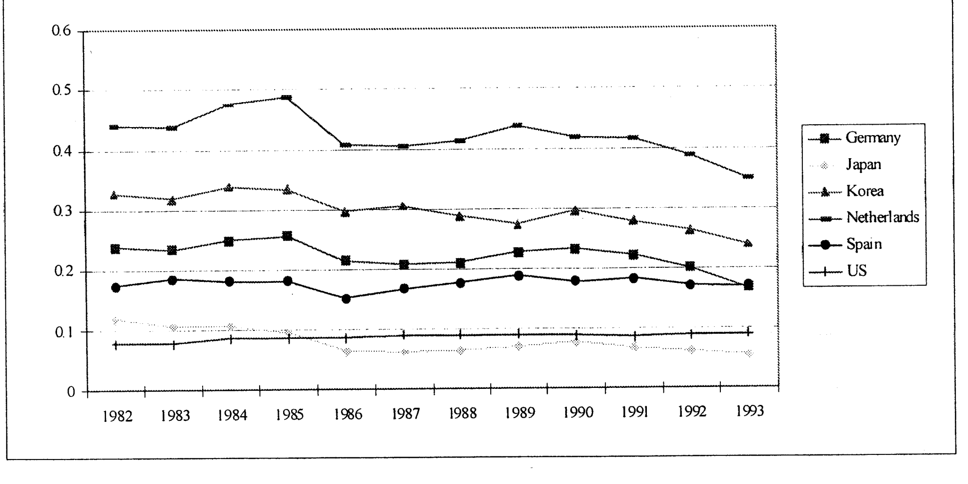
[Table 4] Foreign R&D Capital Stocks: Average Annual Growth Rates 1983-1993

	3	31	32	33*	34*	35	36	37	38
Canada	0.078	0.086	0.095	0.037	0.065	0.091	0.060	0.020	0.077
Denmark	0.082	0.074	0.074	0.106	0.084	0.087	0.079	0.048	0.082
Finland	0.091	0.090	0.086	0.081	0.084	0.097	0.088	0.058	0.091
France	0.087	0.089	0.089	0.082	0.075	0.092	0.083	0.050	0.088
Germany	0.096	0.103	0.104	0.067	0.084	0.106	0.100	0.081	0.094
Italy	0.071	0.077	0.073	0.069	0.045	0.077	0.067	0.040	0.070
Japan	0.069	0.075	0.087	0.027	0.048	0.083	0.047	0.004	0.068
Korea	0.081	0.091	0.098	0.058	0.081	0.091	0.085	0.062	0.079
Netherlands	0.084	0.085	0.082	0.072	0.065	0.089	0.080	0.049	0.084
Norway	0.085	0.083	0.077	0.070	0.081	0.092	0.077	0.049	0.084
Spain	0.036	0.043	0.051	0.013	0.002	0.051	0.034	0.012	0.033
Sweden	0.089	0.088	0.082	0.085	0.082	0.095	0.085	0.055	0.089
UK	0.096	0.103	0.109	0.071	0.076	0.101	0.092	0.063	0.096
US	0.128	0.118	0.114	0.120	0.150	0.119	0.136	0.108	0.133
Total	0.084	0.086	0.087	0.068	0.073	0.091	0.079	0.050	0.083

Note: ISIC codes classified as follows: 3. Total manufacturing; 31. Food, beverages and tobacco; 32. Textiles, apparel and leather; 33. Wood products and furniture; 34. Paper, paper products and printing; 35. Chemical products; 36. Non-metallic mineral products; 37. Basic metal industries; 38. Fabricated metal products.

* The corresponding sample period is 1984-1990 due to the classification problem in R&D data for Korea.

[Figure 3] Import Shares in GDP



[Table 5] Import Shares in GDP: Averages 1982-1993

Canada	0.234
Denmark	0.257
Finland	0.219
France	0.188
Germany	0.221
Italy	0.176
Japan	0.079
Korea	0.296
Netherlands	0.422
Norway	0.231
Spain	0.176
Sweden	0.221
UK	0.222
US	0.086

Source: IMF, Direction of Trade Statistics Database

Ⅳ. EMPIRICAL RESULTS

To determine the effect of R&D spillovers on productivity, the empirical work in this paper is based on linear specifications in which variations in TFP are explained by variations in both domestic and foreign R&D capital stocks. The simplest equation has the following specification for the whole manufacturing sector:

$$M_{i,t+1} = \alpha_i + \alpha_R \frac{R_{i,t+1} - R_{i,t}}{R_{i,t}} + \alpha_F \frac{F_{i,t+1} - F_{i,t}}{F_{i,t}} \tag{4}$$

where i is a country index, $M_{i,t+1}$ is the Malmquist index between years t and $t+1$, R represents the domestic R&D capital stock, and F represents the foreign R&D capital stock defined as the import-share-weighted average of the domestic R&D capital stocks of other countries in the sample. In this specification the constant α_i is allowed to differ across countries to account for country specific effects that are not captured by the variables used in the equation. The regressions based on the same specification were also carried out using technical change and efficiency change each as a dependent variable.

Since the foreign R&D capital stock F is the import-share-weighted average, it does not reflect the level of imports. Therefore, if productivity gains from the foreign R&D capital stock are related to trade volumes, the above specification may not capture adequately the role of international trade. For this reason, the paper also estimates a modified version of equation (4) that accounts for the interaction between foreign R&D capital stocks and the level of imports:

$$M_{i,t+1} = \alpha_i + \alpha_R \frac{R_{i,t+1} - R_{i,t}}{R_{i,t}} + \alpha_F \lambda_{i,t+1} \frac{F_{i,t+1} - F_{i,t}}{F_{i,t}} \tag{5}$$

where λ_i stands for the fraction of total imports in GDP. In this equation the elasticity of TFP with respect to the foreign R&D capital stock, $\alpha_F \lambda_i$, varies across countries in proportion to their import shares whenever α_F is the same for all countries.

[Table 6] Estimates of Coefficients in Eq. (4)

M		TC		EC	
α_R	α_F	α_R	α_F	α_R	α_F
0.064 (0.914)	0.081 (0.921)	0.082 (2.386)	0.115 (2.659)	-0.017 (-0.291)	-0.038 (-0.523)

Notes: 1) M, TC, and EC represent Malmquist index, technical change, and efficiency change respectively.
2) t-values are in parentheses.

[Table 7] Estimates of Coefficients in Eq. (5)

M		TC		EC	
α_R	α_F	α_R	α_F	α_R	α_F
0.053 (0.750)	0.461 (1.251)	0.072 (2.068)	0.570 (3.172)	-0.017 (-0.285)	-0.129 (-0.418)

Notes: 1) M, TC, and EC represent Malmquist index, technical change, and efficiency change respectively.
2) t-values are in parentheses.

The regression results based on Eqs. (4) and (5) are presented in Tables 6 and 7 respectively. They indicate that the estimated elasticities of TFP are of the expected sign and their magnitudes are plausible. Previous studies find that the estimated elasticities of TFP with respect to both domestic and foreign R&D capital stocks tend to be in the range of 0.06 to 0.1.[8] Tables 6 and 7 also report the estimated elasticities of technical change and efficiency change with respect to domestic and foreign R&D capital stocks. The estimated elasticities of technical change in particular are found to be both economically and statistically more significant than those of TFP, suggesting that R&D influences productivity mainly by promoting innovation. In fact, the estimated elasticities of efficiency change with respect to both domestic and foreign R&D capital stocks are found to be negative although they are not significantly different from zero.

It appears that international R&D spillovers play a key role in promoting innovation in the OECD manufacturing sector. The elasticity of technical change is estimated to be greater with respect to foreign R&D capital stocks than the domestic R&D stocks. When the trade volume is accounted for, the estimated elasticity with respect to foreign R&D is found to outweigh the one with respect to domestic R&D if a country's total imports are at least 12.3 percent of its GDP. If this finding is taken at face value, average import shares reported in Table 5 suggest that international R&D spillovers tend to have stronger effects on innovation than domestic R&D in all sample countries except for Japan and the United States.

Inside the national borders, the benefits of cumulative R&D also tend to spread to other domestic firms. The existing empirical evidence suggests a significant role of inter-firm or inter-industry diffusion of innovations for productivity growth. To investigate the impact of inter-industry R&D spillovers in addition to international R&D spillovers, this paper estimates the following equation for individual industries:

$$M^j_{i,t+1} = \alpha^j_i + \alpha^j_R \frac{R^j_{i,t+1} - R^j_{i,t}}{R^j_{i,t}} + \alpha^j_o \frac{O^j_{i,t+1} - O^j_{i,t}}{O^j_{i,t}} + \alpha^j_F \frac{F^j_{i,t+1} - F^j_{i,t}}{F^j_{i,t}} \qquad (6)$$

where $M^j_{i,t+1}$ is the Malmquist index for industry j between years t and $t+1$, R^j represents the domestic R&D capital stock of industry j, O^j represents the sum of domestic R&D capital stocks in industries other than industry j, and F^j represents the foreign R&D capital stock of industry j

[8] Griliches (1988) summarizes the estimated elasticities of TFP found in single-country studies. See Coe and Helpman (1995) for the estimates in the context of OECD countries.

defined as above. This paper also estimates a modified specification - Eq. (7) - that allows the elasticity with respect to the foreign R&D capital stock to vary, depending on trade volumes, across countries and over time. Each of technical change and efficiency change was also used as a dependent variable in regressions based on both equations.

$$M^j_{i,t+1} = \alpha^j_i + \alpha^j_R \frac{R^j_{i,t+1} - R^j_{i,t}}{R^j_{i,t}} + \alpha^j_o \frac{O^j_{i,t+1} - O^j_{i,t}}{O^j_{i,t}} + \alpha^j_F \lambda_{i,t+1} \frac{F^j_{i,t+1} - F^j_{i,t}}{F^j_{i,t}} \quad (7)$$

[Table 8] Estimates of Coefficients in Eq. (6)

Industries	M			TC			EC		
	α^j_R	α^j_o	α^j_F	α^j_R	α^j_o	α^j_F	α^j_R	α^j_o	α^j_F
Food, beverages and tobacco	-0.092	-0.096	0.134	-0.011	0.093	0.068	-0.080	-0.184	0.064
	(-0.837)	(-0.763)	(1.059)	(-0.252)	(1.868)	(1.364)	(-0.768)	(-1.534)	(0.528)
Textile, apparel and leather	0.004	0.249	0.054	0.016	0.079	-0.057	-0.012	0.164	0.106
	(0.102)	(2.948)	(0.427)	(0.679)	(1.648)	(-0.791)	(-0.300)	(2.053)	(0.890)
Wood products and furniture	-0.008	-0.293	-0.193	-0.009	0.330	-0.212	0.000	-0.613	0.010
	(-0.282)	(-1.697)	(-1.367)	(-0.461)	(3.028)	(-2.377)	(0.008)	(-3.875)	(0.081)
Paper, paper products and printing	-0.033	0.485	-0.037	-0.020	0.273	-0.009	-0.008	0.191	-0.030
	(-0.469)	(3.994)	(-0.438)	(-0.493)	(3.916)	(-0.182)	(-0.115)	(1.564)	(-0.357)
Chemical products	-0.163	0.139	-0.001	-0.151	0.329	0.050	-0.011	-0.166	-0.053
	(-0.582)	(0.978)	(-0.006)	(-0.784)	(3.365)	(0.396)	(-0.042)	(-1.208)	(-0.296)
Non-metallic mineral products	0.003	0.247	0.311	0.005	0.252	0.323	-0.001	-0.015	-0.017
	(0.026)	(1.776)	(2.879)	(0.095)	(3.453)	(5.694)	(-0.010)	(-0.100)	(-0.142)
Basic metal industries	0.047	0.253	-0.167	0.143	-0.237	-0.123	-0.082	0.478	-0.035
	(0.195)	(0.819)	(-0.546)	(1.044)	(-1.347)	(-0.709)	(-0.447)	(2.035)	(-0.149)
Fabricated metal products	0.009	0.092	0.081	0.045	-0.032	0.158	-0.031	0.107	-0.084
	(0.068)	(0.354)	(0.769)	(0.477)	(-0.183)	(2.224)	(-0.224)	(0.411)	(-0.802)

Notes: 1) M, TC, and EC represent Malmquist index, technical change, and efficiency change respectively.
2) t-values are in parentheses.

The empirical results reported in Tables 8 and 9 indicate that the industry's own R&D activities appear to be of secondary importance in enhancing productivity compared with R&D spillovers from other sources. The estimated coefficients of α^j_R, in fact, consistently fail to differ significantly from zero. In almost all industries at the two-digit ISIC level, however, the growth of R&D capital stocks of other industries is positively and significantly related to at least one component of the Malmquist index, suggesting an important role played by inter-industry R&D spillovers in improving industrial productivity. Technical change is found to depend significantly on R&D capital stocks of other industries in such industries as food and beverage, wood products and furniture, paper and printing, chemical products, and non-metallic mineral products, whereas efficiency change tends to depend importantly on inter-industry R&D spillovers in the textiles and basic metal industries. Particularly in the textiles, paper and printing, and non-metallic mineral products industries, the overall TFP gains are also found to depend significantly on the growth of R&D capital stocks of other industries.

[Table 9] Estimates of Coefficients in Eq. (7)

Industries	M			TC			EC		
	α_R^j	α_o^j	α_F^j	α_R^j	α_o^j	α_F^j	α_R^j	α_o^j	α_F^j
Food, beverages and tobacco	-0.090	-0.108	0.582	-0.011	0.083	0.360	-0.078	-0.185	0.204
	(-0.820)	(-0.845)	(1.101)	(-0.244)	(1.658)	(1.732)	(-0.753)	(-1.523)	(0.405)
Textile, apparel and leather	0.004	0.243	0.244	0.017	0.081	-0.192	-0.012	0.157	0.418
	(0.102)	(2.769)	(0.450)	(0.682)	(1.618)	(-0.621)	(-0.302)	(1.887)	(0.812)
Wood products and furniture	-0.006	-0.318	-1.012	-0.006	0.324	-0.875	0.000	-0.633	-0.182
	(-0.200)	(-1.828)	(-1.645)	(-0.323)	(2.921)	(-2.229)	(0.007)	(-3.952)	(-0.321)
Paper, paper products and printing	-0.033	0.485	-0.136	-0.018	0.281	0.061	-0.010	0.182	-0.208
	(-0.462)	(3.949)	(-0.369)	(-0.445)	(3.998)	(0.288)	(-0.136)	(1.475)	(-0.562)
Chemical products	-0.176	0.138	0.334	-0.165	0.328	0.426	-0.010	-0.166	-0.105
	(-0.623)	(0.971)	(0.411)	(-0.853)	(3.360)	(0.763)	(-0.035)	(-1.208)	(-0.133)
Non-metallic mineral products	0.023	0.224	1.211	0.027	0.235	1.201	-0.004	-0.020	-0.014
	(0.238)	(1.552)	(2.587)	(0.534)	(3.028)	(4.773)	(-0.036)	(-0.128)	(-0.027)
Basic metal industries	0.048	0.240	-0.372	0.144	-0.248	-0.244	-0.082	0.473	-0.040
	(0.200)	(0.771)	(-0.269)	(1.047)	(-1.399)	(-0.310)	(-0.446)	(2.001)	(-0.038)
Fabricated metal products	0.005	0.085	0.435	0.039	-0.045	0.805	-0.029	0.113	-0.398
	(0.039)	(0.328)	(0.989)	(0.416)	(-0.260)	(2.733)	(-0.210)	(0.437)	(-0.912)

Notes: 1) M, TC, and EC represent Malmquist index, technical change, and efficiency change respectively.
2) t-values are in parentheses.

The regression results presented in Tables 8 and 9 show that international R&D spillovers within an industry also play a key role in enhancing productivity of certain industries. In the fabricated metal products industry where R&D spillovers from other industries appear to be quite limited, the industry's innovation is found to depend importantly on R&D activities of other foreign firms in the industry. International R&D spillovers also appear to contribute to productivity growth in the non-metallic mineral products industry mainly by promoting innovation. The industry's overall productivity gains as well as technical change are found to depend significantly on the industry's foreign R&D capital stocks. In this industry there exists evidence of inter-industry R&D spillovers as well, but international R&D spillovers appear to assume more significance both economically and statistically. The estimated elasticity of TFP is greater with respect to foreign R&D capital stocks than with respect to the sum of R&D capital stocks in other domestic industries. However, when trade volume is accounted for, it holds true only for the countries whose import shares exceed at least 18.5 percent of GDP. As shown in Table 5, they include all sample countries except for Italy and Spain as well as Japan and the United States.

V. CONCLUSIONS

The empirical findings of this paper suggest that manufacturing industries derive substantial benefits from research and development performed in other industries and other countries. In fact, R&D spillovers are found to be more potent force behind productivity gains in the OECD manufacturing sector than the industry's own R&D activities. The regression results for individual industries show that the effect of the industry's own R&D capital stocks on industry TFP consistently fails to differ significantly from zero. In contrast, R&D spillovers from other industries are found to contribute significantly to TFP growth, mostly by promoting innovation, in all industries with the fabricated metal products industry being an only exception. In such industries as textiles, paper and printing, and non-metallic mineral products, a 1 percent increase in R&D capital stocks in other industries is found to raise industry TFP on average by 0.24 percent to 0.49 percent.

The regression results show that international R&D spillovers also play an important role in promoting innovation in the OECD manufacturing sector especially for countries more open to trade. Particularly in the fabricated metal products industry, international R&D spillovers appear to be major force behind the industry's technical progress. International R&D spillovers, along with inter-industry R&D spillovers, are also found to contribute significantly to productivity growth in the non-metallic mineral products industry mainly by promoting innovation. A 1 percent increase in foreign R&D capital stocks is found to raise the industry's TFP by 0.31 percent whereas the comparable rise in R&D capital stocks in other domestic industries entails a 0.25 percent increase in TFP. That is, international R&D spillovers tend to have greater effects on the industry's productivity growth than inter-industry R&D spillovers. However, this holds true only for the countries whose import shares exceed at least 18.5 percent of GDP when trade volume is accounted for.

Appendix

Malmquist indexes and their components are calculated for the whole manufacturing sector as well as individual industries at the two-digit ISIC level, based on data from the OECD STAN. Constant returns to scale (CRS) are assumed as underlying technology. Variable returns to scale (VRS) may be an alternative technology, but the Malmquist index is equivalent to the traditional notion of TFP under a CRS benchmark (Färe et al., 1997; and Ray and Desli, 1997). The measure of aggregate output is value-added in manufacturing, and labor and fixed capital stock are aggregate input proxies. Labor is defined as the number of workers, and fixed capital stock is calculated from gross fixed capital formation using the perpetual inventory method with the depreciation rate of 15 percent as in Verspagen (1997).

R&D capital stock is calculated from R&D expenditures using the depreciation rate of 15 percent as in capital stock. The calculations are based on data from ANBERD and the Science and Technology Annual (STA).[9] In line with Coe and Helpman (1995), the foreign R&D capital stock is defined as a weighted average of the domestic R&D capital stocks of other countries in the sample, using bilateral import shares with the sample countries as weights.[10]

All the variables are converted to U.S. dollars using the purchasing power parity (PPP) exchange rate from the STAN database. For calculation of Malmquist indexes, DEAP version 2.1 (Coelli, 1996) was used.

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[9] The STA, published by the Ministry of Science and Technology of Korea, was used for R&D expenditures figures of Korea.

[10] The bilateral import shares used for the estimation of foreign R&D capital stocks were calculated for each year based on data of total imports from the IMF's Direction of Trade Statistics Database.

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