DISCUSSION PAPERS IN ECONOMICS

Phases of Economic Development, Technology Differentiation in R&D Spillovers, and Human Capital

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Phases of Economic Development,

Technology Differentiation in R&D Spillovers, and Human Capital

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Abstract

This paper investigates the types of technology in international R&D spillovers and a relationship between technology levels and stage of economic development, which have not been identified in previous empirical studies. It also examines the role of human capital in R&D spillovers. The results of this paper show that medium-high technology is the main source of technology diffusion in developing countries, and high technology is more important in advanced countries. Furthermore, the second important technology in R&D spillovers is different across different stages of economic development: medium-low technology in the low-income group and high technology in the middle-income group. Third, the role of high technology in R&D spillovers becomes larger as per capita income rises. These findings suggest that stage of economic development matters in the type of technology diffusion. Finally, education is also a major factor in R&D spillovers and it plays more important role in relatively higher technology level with higher stage of economic development.

JEL classification: F1, O1, O3, O4

Keywords: Technology Differentiation, R&D spillovers, Economic Development, Human Capital.

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1. Introduction

Endogenous growth models put an emphasis on innovation and trade as engines for technological progress as well as growth (Rivera-Batiz and Romer, 1991; Grossman and Helpman, 1991b). In the endogenous growth literature that introduces horizontally or more important role in technological progress. In the product cycle framework, with trade opened, a developing country tends to specialize in exporting low-technology goods, and a developed country tends to specialize in exporting high-technology goods (Krugman, 1979; Grossman and Helpman, 1991c).

However, in the process of development, developing countries will adopt higher levels of technology through learning-by-doing or investment in human capital. Lau and Wan (1993) point out that the benefits from attempting to borrow technology vary across countries, depending on their technical capabilities and their opportunities for borrowing. The high-growth economies like Japan and the East Asian countries are in a position to be technology followers, in their middle phase of development. Based on this theoretical background, this paper attempts to examine the sources of differentiated technology in R&D spillovers from North to South and within the North.

The second contribution of this paper is in constructing the foreign R&D capital stock. Previous empirical studies (CH, 1995; CHH, 1997) use aggregated average import shares as weight, and R&D data are also aggregated. In this case, R&D stock of the high-technology sector will be included in the construction of the foreign R&D stock, even though there has been no trade in this sector with advanced countries. Thus, foreign R&D stock may not be correctly constructed. To reduce this problem, the present paper constructs foreign R&D capital stock from the actually realized industry-based trade and R&D capital stock of advanced countries.

One of the main findings is that R&D spillovers from North to South occur mainly in the medium-high-technology sector, followed by the medium-low- and the high-technology sectors. There is a relatively weak R&D spillover in the low-technology sector. The product cycle models may explain this. In the product cycle literature, a developing country tends to specialize in low-technology goods and to export them. Thus, R&D spillovers in the low-technology sector from the North may not be substantial. Second, as per capita income increases, relatively higher levels of technology are involved in R&D spillovers. These results may support a relationship between phase of economic development and technology differentiation in R&D spillovers. Furthermore, human capital has a positive effect on productivity when it interacts with foreign R&D capital stock. It plays a stronger role in R&D spillovers from the high-technology sector in upper-middle- and high-income groups.

The paper is organized as follows. The next section presents the hypothesis to be examined. Section 3 describes the framework of analysis and empirical specification. The fourth section explains the data sources and construction of variables, and Section 5 provides a descriptive summary of the data. The empirical results will be presented in Section 6, and the last section is the conclusion.

2. A Testable Hypothesis

CH (1995) examined R&D spillovers within 21 OECD countries plus Israel. On the other hand, CHH (1997) investigated R&D spillovers from North to South through trade, using weighted bilateral machinery-and-equipment import shares among 21 OECD countries plus Israel. These two papers, using aggregated data, found that foreign R&D capital stock plays a substantial role in total factor productivity. Even in developed countries, foreign R&D stock is positively associated with productivity to the same extent as domestic R&D stock. Keller (2002) also investigated the effects of R&D spillovers on total factor productivity within eight OECD countries using thirteen industry-level data. He found strong productivity effects both from own R&D expenditures and foreign R&D stock. Engelbrecht (1998) confirmed the results of CH (1995), adding human capital into their preferred empirical models. Lichtenberg and Potterie (1998, henceforth LP) proposed

The World Bank (2002) divides world economies into four income groups according to gross national income per capita of 2000. The groups are (1) low income with US$ 755 or less, (2) lower-middle income with US$ 756-2,995, (3) upper-middle income with US$ 2,996-9,265, and (4) high income with US$ 9,266 or more.

To test the above hypothesis, groups (1)-(4) are separated into three groups: Groups (1) and (2) will be classified as the first stage of economic development, group (3) will be considered the middle stage of development, and group (4) is considered to be in the last stage of development. Four countries (Hong Kong, Israel, Singapore and Taiwan) belong to the high-income group on the basis of the World Bank, but these countries are included in the group (3) here, because these countries are usually classified as developing countries. The classification for stages of economic development may not exactly represent the degree of economic development and we may have to consider some other variables related to economic development. However, because of data limitations, we will use this classification as a proxy for stages of economic development.

3. Framework of Analysis

In traditional growth theory, exogenous technology shock is necessary for sustainable economic growth. In the new theory of endogenous growth (Romer, 1990; Grossman and Helpman, 1991a, 1991b and 1991c), technological progress is determined endogenously, and sustainable long-run growth can be obtained without exogenous technology shock. There are two types of endogenous growth models: the varieties growth model (or horizontally differentiated model), and the quality-ladders growth model (or vertically differentiated model), both of which model the relationship between technological change and R&D outlays.

In the framework of the varieties model (Romer, 1990; Grossman and Helpman, 1991b, Ch.3), a simple specification of output, *Y*, is given as a Dixit-Stiglitz (1977) production function,

$$Y = AL^{\alpha} d^{1-\alpha}, \quad 0 < \alpha < 1, \tag{1}$$

where *A* is a positive constant, *L* is labor input, and *d* is a composite input consisting of horizontally differentiated goods *x* of variety *i*:

$$d = \left(\int_0^v x(i)^{1-\alpha} \, di \right)^{1/(1-\alpha)} \tag{2}$$

T4Tj0 6 consisting of

d, this reduced form (3) is homogeneous of degree (1+α) in *v*, *L* and *K*.

An alternative endogenous growth model for a model of North-South interactions is the quality-ladders model, in which the number of intermediate inputs is fixed and technological progress arises from improvement in the quality or productivity of these intermediate goods (Aghion and Howitt, 1992; Grossman and Helpman, 1991b).

To test the hypothesis in this paper, we assume there are two different types of intermediates: high R&D-intensive intermediate inputs, or high-quality inputs, d_H, and low R&D-intensive intermediate inputs, or low-quality inputs, d_L, but the intermediate goods are horizontally differentiated within each R&D intensity.[1] Thus, two vertically differentiated intermediate inputs as well as horizontally differentiated intermediate inputs within each sector are explicitly introduced into the production function.

Suppose now that the production function is modified from equation (1).

$$Y = AL^{\alpha} d_H^{\ \beta} d_L^{\ 1-\alpha-\beta}, \quad 0 < \alpha < 1 \text{ and } 0 < \beta < 1, \tag{4}$$

This production function is homogeneous of degree 1 in *L* 0009 Tw[(0009.0009 Tw. c0 Tw(1mf409 T8215 0

In equilibrium, each intermediate is employed at the same level, $\bar{x}_H$ and $\bar{x}_L$, in each sector. Thus capital stock in each sector at any point or the total quantity of intermediate inputs employed is given by $K_H = v_H \bar{x}_H$ and $K_L = v_L \bar{x}_L$. Solving those for $\bar{x}_H$ and $\bar{x}_L$ and substituting them into equations (5), then

$$d_H = K_H (v_H)^{(1-\beta)/\beta} \tag{5-1$'$}$$

$$d_L = K_L (v_L)^{(\alpha+\beta)/(1-\alpha-\beta)} \tag{5-2$'$}$$

Substituting equations (5-1)′ and (5-2)′ into equation (4) leads to

$$Y = A(v_H)^{1-\beta} (v_L)^{\alpha+\beta} L^{\alpha} K_H^{\beta} K_L^{1-\alpha-\beta} \tag{6}$$

In practice, if we have only aggregated capital stock in an economy, then we can assume that $K_H = K_L = K$. Thus, the above equation finally will be

$$Y = A(v_H)^{1-\beta} (v_L)^{\alpha+\beta} L^{\alpha} K^{1-\alpha} \tag{6$'$}$$

If total factor productivity is defined as $\quad^{\alpha} \quad ^{-\alpha}$

determined technology and thus TFP is positively related to high R&D-intensive and low R&D-intensive outlays, respectively. However, the own R&D expenditures of developing countries were less than 10% of the world's R&D spending in 1991 (CHH, 1997). There are also data limitations to collecting the R&D data of developing countries. For these reasons, the present paper assumes that v_H and v_L are dependent on the trade-related spillovers of the foreign R&D stock.

Based on the derivation of equation (7), a simple regression specification for the panel data is as follows:[2]

$$lnTFP_{ct} = \alpha + \alpha_c + \alpha_t + \sum_r \alpha_r lnR\&D_{ct}^{F-r} + \varepsilon_{ct} \qquad (8)$$

where $r = \{HI, MH, ML, LW\}$, which denote four different types of technology: high (HI), medium-high (MH), medium-low (ML) and low (LW) technologies. $lnR\&D^{F-r}$ is the natural logarithm of the foreign R&D capital stock of each technology level r. α, α_c and α_t are constant term, country and year dummies to be estimated. $lnTFP_{ct}$ is the natural logarithm of TFP of country c at year t. ε_{it} is disturbance, which is not captured by country- and time-specific effects.

One possible extension of the above model is to introduce human capital, in which human capital is technology-specific. Human capital is introduced as follows:[3]

$1/\beta$

β

0

$$= \left(\int_0 [\quad (\ ) \bullet \exp(\quad)]^{1-\alpha-\beta} \quad \right)^{1/(1-\alpha-\beta)}$$

stock on productivity will be larger the more educated is the domestic work force, as pointed out in CHH (1997). Thus, another model is given by

$$\begin{aligned} lnTFP_{ct} = \alpha + \alpha_c + \alpha_t + \alpha_E EDU_{ct} + \sum_r \alpha_r lnR\&D_{ct}^{F-r} \\ + \sum_r \alpha_{Er} EDU_{ct} lnR\&D_{ct}^{F-r} + \varepsilon_{ct} \end{aligned} \quad (13)$$

where $_{ct}$ $^{F\ \ r}_{ct}$

prices (RGDPCH) by population reported in PWT 6. The number of workers is also calculated implicitly using real GDP per worker, population and RGDPCH available in PWT 6. Physical capital stock and R&D capital stock are estimated by a perpetual inventory approach using investment data in PWT 6, and R&D expenditure data from the ANBERD database (OECD, 2000), respectively. Following CH (1995), the current physical and R&D capital stocks, K_t, are determined as follows:

$$K_t = I_{t-1} + (1 - \delta)K_{t-1} \tag{14}$$

where δ is the depreciation rate, which is assumed to be 10 percent, and I_{t-1} and K_{t-1} are investment and capital stock at previous period in an economy, respectively. The initial capital stocks of both, K_0, are estimated by the procedure used in CH (1995):

$$K_0 = I_0 / (g + \delta) \tag{15}$$

where g is the average annual growth rate of per capita income for initial physical capital stock and the average annual growth rate of R&D expenditures for initial R&D capital stock over the period available, and I_0 is initial investment available. Initial physical investment data are available from 1950 or 1960 and initial R&D expenditures are available since 1973 in the ANBERD database.

In the ANBERD database, nominal R&D expenditures of 14 OECD countries[5] are deflated by each country's price index of gross domestic products at 1996 base year. These real R&D expenditures in national currency are converted into international constant values using each country's purchasing power parity exchange rate of 1996 to obtain the

[5] These countries are Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, the United Kingdom and the United States.

internationally comparable data of R&D expenditures.[6]

Using real R&D expenditures of twenty-two industries[7] in fourteen OECD countries, R&D capital stocks are estimated over 1973-1996 using the perpetual inventory method discussed above, and the foreign R&D stocks by industry for each of 81 countries are constructed based on the method of LP (1998). In CH (1995), the foreign R&D capital stock is defined as the import-share-weighted average of the domestic R&D capital stocks of trade partners. On the other hand, in the method of LP (1998), the foreign R&D stock of industry *i* in country *c* at time *t*, S_{cit}^{f}, is calculated as follows:

$$S_{cit}^{f} = \sum_{j=1}^{14} S_{cijt}^{f} = \sum_{j=1}^{14} \frac{m_{cijt}}{y_{ijt}} S_{ijt}^{d} \qquad \text{for industry } i \text{ of country } c \text{ at year } t \qquad (16)$$

where $i = \{1, 2, \ldots, 22\}$. S_{ijt}^{d} is the domestic R&D stock of industry *i* of trade partner *j*, m_{cijt} is the flow of imports of industry *i* in country *c* from trade partner *j*, and y_{ijt} is the output level of industry *i* of trade partner *j*. LP (1998) argued that the procedure in CH (1995) is not invariant to the level of data aggregation, while their formulation reflects both the R&D intensity and direction of international R&D spillovers. In this paper, the foreign R&D capital stocks are constructed on the basis of the method of LP (1998).[8]

The production data of 22 industries used in equation (16) are taken from the STAN database (OECD, 2000) and the trade data used in calculating the bilateral trade shares of 22 industries come from the World Trade Flows Database CD-ROM (Feenstra et al., 1997;

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[6] The data of the deflators of gross domestic products and purchasing power parity exchange rates of 14 OECD countries are downloadable from http://www.oecdsource.org.

[7] See Appendix B for the industry classification used for R&D and trade data.

[8] If the present paper follows the Coe and Helpman method (1995), total imports from 14 trading partners for each industry will be used instead of y_{ijt}. That is, m_{cit} = sum of m_{cijt} over trading partner *j* for each industry *i*.

Feenstra, 2000). The industry code of trade data is SITC (Standard International Trade Classification) 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.[9] Then, according to Hatzichronoglou (1997), 22 manufacturing industries are reclassified into four different levels of technology: high-technology (4 industries), medium-high-technology (6 industries), medium-low-technology (8 industries), and low-technology industries (4 industries).

Since the OECD ANBERD and STAN databases are matched with the classification in Hatzichronoglou (1997), trade data (Feenstra et. al, 1997 and Feenstra, 2000) of SITC Rev. 2 are matched with the industry codes of ISIC Rev. 2. Finally, the source of education data is Barro and Lee (2000). Since these data are reported every five years, the interpolation method is applied to estimate annual data between two periods.

The total factor productivity of each country *c* is estimated by the traditional Solow residual, which imposes conventional values for factor shares. These are given by

$$lnTFP_{ct} = lnY_{ct} - \alpha \, lnK_{ct} - (1-\alpha) \, lnL_{ct} \tag{17}$$

where α is the capital's income share in GDP which is assumed to be 0.35 or 0.4. lnY_{ct}, lnK_{ct}, and lnL_{ct} are the natural logarithms of output, physical capital stock, and the number of workers, respectively. These data are taken from PWT 6.

5. Descriptive Summary

In the present paper, one of the main issues is how to classify the sample countries

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[9] See Appendix B for more details.

into different stages of economic development. Because of data limitations, the present paper uses classification by per capita income from World Bank (2002), as mentioned before. However, this classification may not exactly represent the degree of economic development. Some countries may shift from the first stage to a higher stage of development, or *vice versa* over the long term. Therefore, we first rank the sample of 81 countries by per capita nominal income for 1973, 1978, …, 1993, and 1996, and calculate the correlation coefficient for these ranks in Table 1 to examine the fluctuation of the ranks over time.

The correlation coefficients in Table 1 are positively significant at the 1% level. In general, the correlation coefficients are relatively smaller between two periods which are longer, but the minimum correlation coefficient is .891 between the ranks of 1973 and 1996. This implies that there is some fluctuation of the ranks by country, but it is not really a significant change over time.

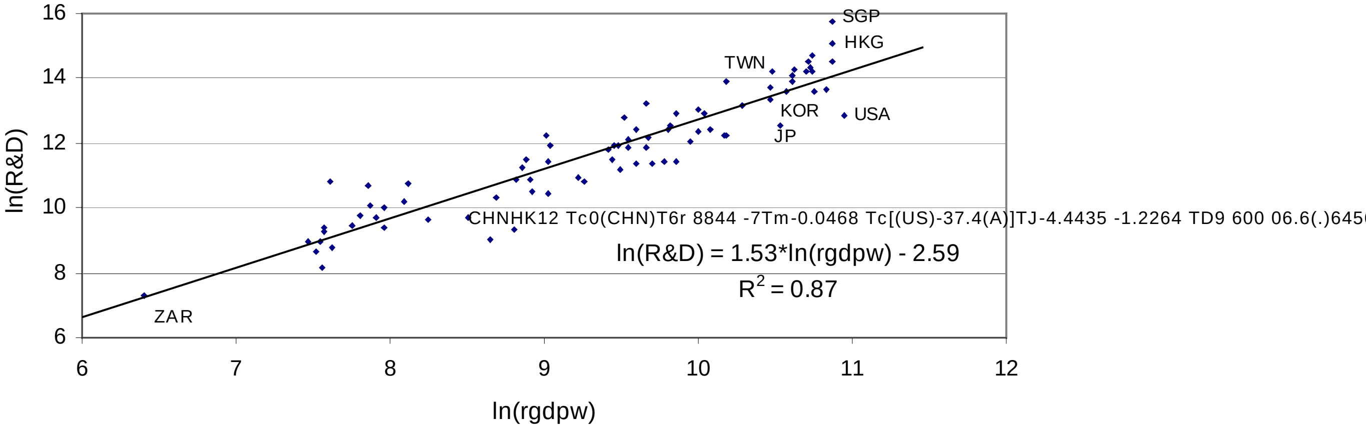
Figures 1a to 1e represent a distribution between foreign R&D stock per worker and real GDP per worker, for total foreign R&D stocks and by technology levels in 1996. The figures indicate a very strong linear relationship between these two variables in terms of logarithm. The slopes are positive and become smaller when technology level becomes lower. In this simple regression, for the 1% increase in real GDP per worker, foreign R&D stock of high technology increases by 1.56%, while foreign R&D stock of low technology increases by 1.30%.

These may be related to the elasticities of demand for the high-technology and low-technology products. The elasticity of demand for the high-technology product may be larger than that of the low-technology product. The values of R^2 also decline with lower levels of technology. This may imply that there is a relatively stronger linear relationship between the foreign R&D stock and per capita income in higher level of technology rather than in relatively lower level technology.

In the comparison of overall foreign R&D stock per worker in 81 individual countries, Singapore (SGP) has the highest foreign R&D stock per worker, followed by Hong Kong (HKG). The foreign R&D stocks per worker of the USA and Japan are almost the same (The logs of the foreign R&D stock are 12.88 and 12.56, respectively.). We can observe these trends in the individual technology level of the foreign R&D stock.

In general, the foreign R&D stocks per worker of four East Asian economies (TWN, Taiwan; KOR, Korea) are larger than those of Latin American countries (MEX, Mexico; ARG, Argentina; BRA, Brazil), while China (CHN) is located in the middle group and Zaire (ZAR) has the smallest foreign R&D stock except foreign R&D stock of the low technology. India (IND) has the smallest foreign R&D stock of low technology in 1996.

Figure 1a. Total foreign R&D stock vs. real GDP per worker (1996)



This result may come from different trade pattern between these countries. Especially, Hong Kong and Singapore have very high trade shares in GDP.

Table 2 shows average annual growth rates of TFP, GDP per worker, physical capital stock and labor force by income group and by some selected individual countries of our data. In general, over the entire period of 1973-1996, the upper-middle-income group has achieved the highest growth rates in TFP, GDP per worker and physical capital stocks, but this may result from the performance of East Asian countries. In the comparison across individual countries, among East Asian countries, Hong Kong achieved the highest growth rate of TFP, and the performance of East Asian economies is distinct from those of Latin American economies except in the growth rates of the labor force. On the other hand, the annual growth rate of TFP in the low-income group is negative for the entire period. However, there is no significant difference in the growth rate of the labor force across income groups except in the high-income group.

Table 3 presents the trends of educational attainment for the population aged 15 and over by education level across income groups and individual countries in 1973 and 1996, with its relative ratio of the average years of 1996 to the average years of 1973.[11] In the comparison of education attainment across income groups, the low-income group shows relatively higher growth in primary and secondary education, but its average years of education are still far behind from those of other income groups.

In the comparison of the average years of schooling of developing groups with those of high-income group, with higher per capita income, the average years of schooling

[11] Barro and Lee (2000) point out that the part of the population aged 15 and over would be a better measure for the labor force for many developing countries.

Table 2: Average annual growth rates of TFP, GDP per wo[illegible]apital and workers

	TFP (α = 0.35)			TFP (α = 0.40)			[illegible]P per worker			Capital stock			Workers		
Period	73-96	73-84	85-96	73-96	73-84	85-96	[illegible]	73-84	85-96	73-96	73-84	85-96	73-96	73-84	85-96
By [illegible] group															
Low (25) [1)]	-0.52	-0.19	-0.83	-0.56	-0.31	-0.78	[illegible]	0.66	-1.14	3.36	4.64	2.19	2.68	2.24	3.09
Lower-middle (25)	0.48	0.01	0.90	0.39	-0.17	0.91	[illegible]	1.30	0.84	4.27	6.28	2.44	2.60	2.59	2.61

Table 3. Trends of average years of schooling for population aged 15 and over

Education / Income groups	Primary	Secondary	Higher

years of the three schooling levels of Korea in 1996 are higher than those of Japan in 1996, with higher growth of education relative to other countries. The average years of primary and secondary schooling of Korea are closer to those of the United States, but the average years of higher education of Korea (0.77) in 1996 are still almost half those of the United States (1.45).

Table 4 shows the average annual import and export shares of each income group by technology level within the total imports and exports of the 14 high-income countries. First, most trade has occurred within high-income countries. For example, during 1985-1996, the portion of imports within 14 advanced countries is 75.62% and the export share is 79.15%. Second, in trading by technology level, medium-high technology has the highest import share in every income group, while medium-low technology has the second highest import share except in the high-income group. The export share is largest in the low technology sector in three income groups, but not in the high-income group. These trends explain the trade pattern between the North and the South. The North exports high-quality products and the South exports low-quality products (Flam and Helpman, 1987). But the main technology that the South imports from the North is medium-high technology rather than high technology.

The import shares of the high-technology sector of low- and lower-middle-income groups from the high-income group have remained unchanged (.25 ! .26) or increased (.54 ! .77) in the second period, while those of other technology sectors as well as overall import shares have decreased in the second period relative to the first. On the other hand, import shares of all technology sectors except the medium-low technology sector of the upper-middle income group have increased in the second period.

Table 4: Average annual Import and export shares in 14 OECD trade partners by income group(%)

Group	Industry	Import Share		Export Share	
		1973-84	1985-96	1973-84	1985-96
Low income (25)[1]	Hi Tech (4)[2]	0.25	0.26	0.01	0.03
	Medium Hi Tech (6)	1.62	1.31	0.05	0.10
	Medium Low Tech (8)	0.66	0.43	0.68	0.43
	Low Tech (4)	0.49	0.25	1.00	1.10
	sub total [a]	**3.02**	**2.25**	**1.74**	**1.67**
Lower-middle income (25)	Hi Tech	0.54	0.77	0.02	0.21
	Medium Hi Tech	3.92	3.70	0.30	0.51
	Medium Low Tech	1.77	1.25	0.64	0.89
	Low Tech	1.08	0.87	1.22	1.90
	sub total [b]	**7.31**	**6.59**	**2.18**	**3.50**
Upper-middle income (18)	Hi Tech	1.23	2.07	0.82	2.54
	Medium Hi Tech	8.06	8.91	1.61	4.10
	Medium Low Tech	2.93	2.72	3.41	3.79
	Low Tech	1.72	1.83	4.98	5.26
	sub total [c]	**13.94**	**15.53**	**10.82**	**15.69**
High income (14)	Hi Tech	6.52	10.31	7.32	10.80
	Medium Hi Tech	36.45	39.01	41.02	40.82
	Medium Low Tech	15.70	12.15	17.69	12.72
	Low Tech	17.07	14.15	19.22	14.81
	sub total [d]	**75.74**	**75.62**	**85.25**	**79.15**
total [=a+b+c+d]		100.01	99.99	99.99	100.01

Source: The author's calculation from trade data of Feenstra et. al (1997) and Feenstra (2000).

high-technology sectors. Its export share of high technology increased by 1.72 percent points from 0.82% to 2.54%, and its export share of medium-high technology increased by 2.49 percent points. By contrast, the overall export share of the high-income group decreased by 6.10 percent points from 85.25% to 79.15%.

In summary, Table 4 shows that most imports of developing countries from advanced countries are in the medium-high technology sector, and thus R&D spillovers from advanced countries will be the same as the import pattern.

6. Empirical Results

A fixed-effect model for the panel data (considering country-specific effect) has been employed for 68 developing countries plus 13 developed countries over 1973-1996. [12] In order to reduce any possible simultaneity bias between TFP and the foreign R&D stock, the data are selected from the initial observations of every 5-year period since 1973; that is, the initial observations of 1973, 1978, 1983, 1988, 1993 and 1996 for every country are chosen for regression.[13]

The purpose of the regression models is to examine the international R&D spillovers from the North to the South in terms of stage of economic development and technology differentiation. For this purpose, 81 developing countries are broken down into three groups based on per capita income as of 2000 according to World Bank (2002). The

[12] We have considered the time-specific effects by introducing time dummy variables in the regression model. However, these time dummies are not significantly different from zero. Thus, the year dummies are excluded from the regression models.
[13] For the four countries in the low-income group, Central African Rep., Congo, Rep. of, Niger and Rwanda, there are missing data for 1973. Therefore, the total sample size is 482 for 81 countries over 6 periods.

first group is combined from the low-income (25 countries) and lower-middle-income groups (25 countries). Hereafter this combined group is called the low-income group, and it is suggested to reflect the beginning stage of economic development. The second group consists of the upper-middle-income countries and four high-income ones (18 countries). We assume this second group is in the middle stage of development. Lastly, 13 developed countries are considered to represent the last stage of development.

Table 5 shows the regression results of a simple model without the distinction of foreign R&D stock by technology levels. Since we are mainly concerned with R&D spillovers of developing countries in the present paper, the first three columns only show developing countries, excluding the high-income group. The estimation results show that there exist R&D spillovers from the North to the South. The coefficient of foreign R&D stock is .142, statistically significant from zero at the 1% level.

The first column in each income group has only the education variable. This education variable has positive signs and is statistically significant at the 1% or 5% level. The coefficient is the largest in the upper-middle-income group (.201), followed by the high-income group (.107).

The second column in each group tests the foreign R&D spillovers only. The estimates of the (log of) $R\&D^F$ are all positive and statistically different from zero at the 1% significance level in every regression model ranging from .125 in the low-income group to .193 in the upper-middle-income group. These results suggest that we observe R&D spillovers from North to South and within the North. The R&D spillovers from the North to the upper-middle-income group are larger than the R&D spillovers within the North, but the spillovers from the North to the low-income group are smaller than within

Table 5: Empirical results without distinction of technology levels

Sample	Developing countries (68, 404)[1)]			Low and Lower-middle Income Group (50, 296)		
EDU	.119 ***		-.442 ***	.058 **		-.553***
	(5.57)		(4.19)	(2.02)		(2.60)
$LnR\&D^F$		.142***	.089 ***		.125***	.092***
		(8.69)	(4.62)		(6.43)	(4.14)
$lnR\&D^F$ *EDU			.041 ***			.050***
			(5.09)			(2.81)
Adj. R^2						

plays a positive role in TFP, but to play this role, it needs human capital stock.

In general, the results of overall R&D spillovers from the North to the South are

$(\ln R\&D^{ML}$

foreign R&D capital stocks of different levels of technology play different roles at different stages of economic development. In the relatively beginning stage of economic development, the lower level of technology plays a more important role in R&D spillovers from the North, but as an economy shifts to further stages of development, higher technology becomes more important in R&D spillovers from the North. This finding role across income groups.

In the low-income group, education has a relatively stronger effect on R&D spillovers of medium-high and medium-low technology. Its coefficients of interaction terms are .044 in high technology, .097 in medium-high technology, and .069 in medium-low technology, and these coefficients are statistically significant from zero at the 1% level. On the other hand, it is more important to high technology in upper-middle- and high-income groups. The coefficients of interaction terms between education and high technology are .062 in the upper-middle-income group and .012 in the high-income group. These findings suggest that secondary and higher education plays an important role in technology spillover and it has a stronger effect on high technology in higher income groups.

7. Concluding Remarks

Recent literature on endogenous growth models has identified international R&D spillovers from North to South and with the North. However, the sources of technology in R&D spillovers have not been identified. This paper investigates the types of technology in international R&D spillovers and a relationship between technology levels and stage of economic development.

The results of this paper show that medium-high technology is the main source of technology diffusion in developing countries, and high technology is more important in advanced countries. Furthermore, the second important technology in R&D spillovers is different across different stages of economic development: medium-low technology in the low-income group and high technology in the middle-income group. Third, the role of high

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Appendix A: Country lists in the sample used

Country name	Income	Country name	Income	Country name	Income
Sub-Saharan Afr. (23)		Korea	3	Argentian	3
Benin	1	Malaysia	3	Brazil	3
Cameroon	1	Singapore *	3	Chile	3
Central African Rep	1	Taiwan *	3	Uruguay	3
Congo, Rep. of	1			Venezuela	3
Gambia	1	**South Asia (6)**			
Ghana	1	Bangladesh	1	**Mideast Asia & N. Afr. (8)**	
Guinea-Biss	1	India	1	Algeria	2
Kenya	1	Pakistan	1	Cyprus	2
Malawi	1	Sri Lanka	2	Egypt	2
Mali	1	Fiji	2	Iran	2
Mozambique	1	Papua N. Guine	2	Jordan	2
Niger	1			Syria	2
Rwanda	1	**Latin America (22)**		Israel *	3
Senegal	1	Nicaragua	1	Turkey	3
Sierra Leone	1	Barbados	2		
Togo	1	Dominican Rep.	2	**OECD (14)**	
Uganda	1	El Salvador	2	Canada	4
Zaire	1	Guatemala	2	USA	4
Zambia	1	Honduras	2	Japan	4
Zimbabwe	1	Jamaica	2	Denmark	4
Tunisia	2	Costa Rica	3	Finland	4
Mauritius	3	Mexico	3	France	4
South Africa	3	Panama	3	Germany	4
		Trinidad&Tobago	3	Italy	4
Asia (9)		Bolivia	2	Netherlands	4
Indonesia	1	Colombia	2	Norway	4
China	2	Ecuador	2	Spain	4
Philippines	2	Guyana	2	Sweden	4
Thailand	2	Parguay	2	U.K.	4
Hong Kong *	3	Peru	2	Australia	4

Notes: (1) In the income column, 1, 2, 3, and 4 indicate low-income, lower-middle-income, upper-middle-income, and high-income groups, respectively.
(2) Countries with * belongs to high-income countries (4) based on World Bank's classification.

Appendix B: Industry code by technology level in manufacturing sector

Industry description	ISIC Rev .2	SITC Rev. 2 for trade data