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Reconsidering the Effects of Intranational and International R&D Spillovers on Productivity Growth: Firm-level Evidence from Japan †

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Abstract

Surprisingly, more than half of Japanese manufacturing firms do not invest in Research and Development (R&D). Using firm-level longitudinal data in Japan, this paper asks why many firms can achieve productivity growth without any R&D investments. We found the positive effects of intranational and international R&D spillovers on productivity growth both at the firm level (between a parent firm and its affiliate) and the industry level (among firms in the same industry). The effects of international R&D spillovers are much stronger than those of intranational spillovers. Even firms in developed countries like Japan have benefit from international R&D spillovers. (99 words)

Key Words: Productivity, R&D Spillovers, Foreign Direct Investment, International Trade, Patents

JEL Classification Code: F10 (International Trade, General); F23 (Multinational Firms; International Business); O3 (Technological Change; Research and Development)

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1 Introduction

Research and development (R&D) is regarded as a key factor of productivity growth. However, a large number of firms do not conduct R&D investment even in developed countries. Table 1 indicates the share of firms that invest in R&D (hereafter, R&D firms) and firms that do not (hereafter, non-R&D firms) in manufacturing in Japan from 1995 to 2002. Surprisingly, more than half of Japanese manufacturing firms are non-R&D firms throughout the period. Why are so many firms doing without R&D investments?

=== Table 1 ===

One possible reason is technology diffusion, or R&D spillovers. Indeed, the link between R&D spillovers and productivity growth is central to many questions in endogenous growth theory.[1] If the imitation and implementation of new technology are cheaper than innovation, and if new technology made in leading countries spill over, follower countries could rapidly catch up to the leaders without their own R&D investment. The same is true at the firm level. That is, R&D spillovers make it possible for follower firms to catch up to leading firms without conducting R&D. An analysis of R&D spillovers at the firm level should contribute in clarifying the micro-foundation of technology diffusion, accordingly.

Several empirical studies have investigated the effects of intranational (local) and international R&D spillovers, whose approach is divided into two groups.[2] The first group focuses on national-level spillovers. There are three types of national-level studies. One investigates the R&D spillovers through international trade. Coe, Helpman, and Hoffmaister (1997) confirmed the positive effects of R&D spillovers on total factor productivity (TFP) growth through machinery and equipment trade. Similarly, Lee (1995) found positive impacts of R&D spillovers through capital goods trade on per-capita income. The underlying argument is that the large variety of intermediate products and capital equipment embodies foreign knowledge. Hence, the imports of these products enable countries to boost their productivity growth.[3]

[1]For theoretical studies on technology, see Aghion and Howitt (1998, Chapter 3) and Barro and Sala-i-Martin (2004, Chapter 8).

[2]See Barba Navaretti and Venables (2004, Chapters 7 and 9) and Keller (2004), for an extensive survey of the related literature.

[3]Coe and Helpman (1995) also examined the effects of R&D spillovers through international trade using overall imports rather than machinery and equipment imports as a weight of explanatory variable and found positive effects of international R&D spillovers through imports on productivity growth. However, Keller (1998) later questioned the results of Coe and Helpman, showing that the international spillover effects on productivity growth using randomly generated trade shares can lead to similar or even higher effects than those using actual trade shares. On the other hand, Kiyota (2005) has confirmed the importance of R&D spillovers through machinery trade, showing that the R&D spillovers embodied in Japanese merchandise exports amounted to 27.0 billion US dollars in 1995, 84.3 percent of which was channeled through machinery exports.

Second type investigates the spillovers through foreign direct investment (FDI). Pottelsberghe de la Potterie and Lichtenberg (2001) analyzed the effects of FDI on productivity growth of home and host countries. Based on the data for 13 OECD countries from 1971 to 1990, they found that FDI toward R&D intensive countries contributed to the productivity growth of home countries. However, they could not find any positive effects on the growth of host countries.

Third type examines international patenting. Eaton and Kortum (1999) estimated the relationship among research employment, productivity levels, and international patenting for five leading research countries: France, Germany, Japan, the United Kingdom, and the United States. They have found that research performed abroad is about two-thirds as potent as domestic research. Furthermore, at least two-thirds of the growth in each of five countries was driven by the United States and Japan together.

The second group is firm level (or establishment level), which mainly focused on the spillovers related to patents and FDI. For example, Branstetter (2001) examined the impacts of local and international R&D spillovers on the patent activities of Japanese and U.S. firms. His results indicated that the local spillovers were more important than international spillovers. In his regressions, the estimated coefficients of local R&D spillover variables had significantly positive signs while the international spillover variables had either negative or insignificant signs.

Recent firm-level studies by Aitken and Harrison (1999), Haskel, Pereira, and Slaughter (2002), Keller and Yeaple (2004), Javorcik (2004), and Takii (2005) have focused on the role of FDI.[4] Although Aitken and Harrison (1999) and Haskel, Pereira, and Slaughter (2002) did not find any evidence to support the spillovers from foreign-owned firms to domestic firms, Keller and Yeaple (2004), Javorcik (2004), and Takii (2005) confirmed that FDI led to substantial productivity gains for domestic firms.[5] Keller and Yeaple also examined the effects of international trade as well as FDI. They confirmed that the positive impacts of FDI-related R&D spillovers lasted far longer than those of import-related R&D spillovers. They concluded that import-related R&D spillovers accelerated productivity growth, but the effects of import-related R&D spillovers were weaker than those of FDI.

This paper examines the effects of local and international R&D spillovers on productivity growth at the firm level and builds upon the previous research just noted. Various definitions of R&D spillovers are used in previous studies. We focus on three channels of R&D and its spillovers, which is summarized in Figure 1: 1) firm's own R&D activities; 2) direct purchase of technology; and 3) R&D spillovers. With a convention of international trade studies, both imports of (general) machinery that embodies advanced technology and FDI are classified into spillover channels.

=== Figure 1 ===

[4] Görg and Strobl (2001) provided extensive survey on spillovers through FDI.

[5] Keller and Yeaple (2004) pointed out several reasons why their results are different from those of previous studies and found that their results could be attributed to improved measurement of foreign multinational activity. On the other hand, Javorcik (2004) found that R&D spillovers were originated from shared domestic and foreign ownership but not from fully owned foreign affiliates.

The contribution of this study is threefold. First, this paper examines spillovers through FDI and imports at the same time, in addition to control for the effects of patents. Previous studies recognize these three factors as major channels of technology transfer but they are examined differently. This study examines these three channels at the same time, integrating the previous firm-level studies into one comprehensive analytical framework. Second, this study provides a detailed robustness check and identifies reasons why the existing literature presents different results. I examine the effects of endogeneity, measurement issues, omitted variable bias, time lag, and the effects on loger-term growth. The detailed robustness check enables us to identify the reasons why the effects of international R&D spillovers are ambiguous in previous studies. Finally, this study is the first study to examine the intranational and international R&D spillovers in detail based on the large-scale firm-level data in Japan. This study thus contributes to the literature, adding another national perspective to available evidence.

The analysis is based on the confidential firm-level data that are collected by the Japanese Ministry of Economy, Trade, and Industry (METI). In addition to its high reliability, these data have two advantages. First, firm-level data make it possible to measure firm productivity more correctly. Firm-level data can capture not only the activity of production plants but also that of headquarters, sales branches, and research institutions that belong to the same firm. Since non-manufacturing establishments are not covered in the plant-level manufacturing census, the firm-level data are more appropriate than plant-level data to capture the overall activities of the firm. Second, the large sample can provide more reliable econometric analysis, insofar as the data cover more than 14,000 firms annually.

In what follows, Section 2 presents the model. Section 3 discusses the data and the measurement issues of productivity and R&D spillovers. Presentation of econometric results follows in Section 4. Section 5 examines the robustness of the results. I conclude in Section 6 with a summary of the major findings and a discussion of their potential policy implication.

2 Model

I begin with setting up a simple model. The model is a productivity catch-up model proposed by Bernard and Jones (1996) and extended by Nishimura, Nakajima, and Kiyota (2005a). This paper employs a simplified version of the model of Nishimura, Nakajima, and Kiyota (2005a), which is summarized as follows. Denote total factor productivity (TFP) for a firm i in year t as θ_{it}. Suppose that TFP growth is described as follows.

$$\ln \theta_{it} = \gamma_i + \lambda\{\ln \theta^*_{it-1} - \ln \theta_{it-1}\} + \ln \theta_{it-1} + \ln \epsilon_{it}, \tag{1}$$

where θ^*_{it-1} is the best productivity level that the firm i can achieve in year $t-1$. This is a "target" productivity level.[6] The speed of catch-up is thus measured by λ while the

[6] If I assume that firms produce homogeneous products with identical technology, the "target" productivity level is equivalent to the productivity level of the most productive firm: $\theta^*_{it-1} = \theta^*_{1t-1}$, denoting the

asymptotic rate of productivity growth of firm i is denoted by γ_i. A disturbance term is represented by $\ln \epsilon_{it}$.

Suppose that firm's best productivity level θ^*_{it} depends on firm's own R&D activities, spillovers, and the best productivity level in last period $t-1$. Specifically,

$$\ln \theta^*_{it} = \Theta^*_{it} + \ln \theta^*_{it-1} + \ln \epsilon^*_{it}, \tag{2}$$

where $\Theta^*_{it} = f(\mathbf{R}_{it})$ and $\mathbf{R}_{it}$ is a vector of firm's own R&D and R&D spillovers. $\ln \epsilon^*_{it}$ is a disturbance term. From equations (1) and (2),

$$\ln \hat{\theta}^*_{it} = \gamma_i - \Theta^*_{it} + (1-\lambda) \ln \hat{\theta}^*_{it-1} + \ln \hat{\epsilon}^*_{it},$$

where $\hat{\theta}^*_{it} = \theta_{it}/\theta^*_{it}$ and $\hat{\epsilon}^*_{it} = \epsilon_{it}/\epsilon^*_{it}$. This implies that

$$\ln \hat{\theta}^*_{iT} - \ln \hat{\theta}^*_{i0} = \sum_{\tau=1}^{T} (1-\lambda)^{T-\tau} (\gamma_i - \Theta^*_{i,T+1-\tau} + \ln \hat{\epsilon}^*_{i,T+1-\tau}) - \{1-(1-\lambda)^T\} \ln \hat{\theta}^*_{i0}. \tag{3}$$

From equation(2), I have $\ln \theta^*_{iT} = \sum_{\tau=1}^{T} (\Theta^*_{i,T+1-\tau} + \ln \epsilon^*_{i,T+1-\tau}) + \ln \theta^*_{i0}$. Thus,

$$\ln \theta^*_{iT} - \ln \theta^*_{i0} = \sum_{\tau=1}^{T} \Theta^*_{i,T+1-\tau} + \sum_{\tau=1}^{T} \ln \epsilon^*_{i,T+1-\tau}. \tag{4}$$

From equations (3) and (4),

$$\begin{aligned} \ln \theta_{iT} - \ln \theta_{i0} &= (\ln \hat{\theta}^*_{iT} - \ln \hat{\theta}^*_{i0}) + (\ln \theta^*_{iT} - \ln \theta^*_{i0}) \\ &= \sum_{\tau=1}^{T} (1-\lambda)^{T-\tau} (\gamma_i - \Theta^*_{i,T+1-\tau}) + \sum_{\tau=1}^{T} \Theta^*_{i,T+1-\tau} + \{1-(1-\lambda)^T\} \ln \theta^*_{i0} \\ &\quad -\{1-(1-\lambda)^T\} \ln \theta_{i0} \\ &\quad + \sum_{\tau=1}^{T} (1-\lambda)^{T-\tau} \ln \hat{\epsilon}^*_{i,T+1-\tau} + \sum_{\tau=1}^{T} \ln \epsilon^*_{i,T+1-\tau}. \end{aligned}$$

Note that the first three terms are rewritten as:

$$\sum_{\tau=1}^{T} \Theta^*_{i,T+1-\tau} \left\{ \frac{\sum_{\tau=1}^{T} (1-\lambda)^{T-\tau} (\gamma_i - \Theta^*_{i,T+1-\tau})}{\sum_{\tau=1}^{T} \Theta^*_{i,T+1-\tau}} + 1 + \frac{1-(1-\lambda)^T}{\sum_{\tau=1}^{T} \Theta^*_{i,T+1-\tau}} \ln \theta^*_{i0} \right\}. \tag{5}$$

This implies that, as long as the productivity difference $\gamma_i - \Theta^*_{i,T+1-\tau}$ and the initial productivity level θ^*_{i0} are small *vis-à-vis* the accumulated productivity changes $\sum_{\tau=1}^{T} \Theta^*_{i,T+1-\tau}$, it is

most productive firm as firm 1 and equation (1) becomes the same model as that of Bernard and Jones (1996).

possible to approximate these three terms in the curly braces as a constant $\bar{c}$: $\bar{c}\sum_{\tau=1}^{T}\Theta^*_{i,T+1-\tau}$. Using a linear approximation, equation (5) is described as:

$$\bar{c}\sum_{\tau=1}^{T}\Theta^*_{i,T+1-\tau} = \beta_0 + \phi R_{i0T} + \omega R^D_{i0T} + \psi R^F_{i0T} + \eta_i,$$

where R_{i0T}, R^D_{i0T}, and R^F_{i0T} represent accumulated firm i's own R&D activity, local, and the international R&D spillover variables, respectively. Unobservable random firm-specific shocks are captured by η_i. My baseline model is thus described as:

$$\Delta \ln \theta_{iT} = \frac{1}{T}(\ln \theta_{iT} - \ln \theta_{i0}) = \beta_0 + \beta_1 \ln \theta_{i0} + \phi \bar{R}_{i0T} + \omega \bar{R}^D_{i0T} + \psi \bar{R}^F_{i0T} + \eta_i + \mu_{iT}, \qquad (6)$$

where $\beta_1 = -\{1-(1-\lambda)^T\}/T$. $\bar{R}_{i0T}$, $\bar{R}^D_{i0T}$, and $\bar{R}^F_{i0T}$ represent the annual average of firm i's own R&D activity, local, and the international R&D spillover variables, respectively.

3 Data, Measurement, and Empirical Specification

3.1 Data

I use the micro database of *Kigyou Katsudou Kihon Chousa Houkokusho* (*The Results of the Basic Survey of Japanese Business Structure and Activities*) prepared by the METI (1996-2004, hereafter the METI database). This survey was first conducted in 1991, again in 1994, and annually afterwards. The main purpose of the survey is to capture statistically the overall picture of Japanese corporate firms in light of their activity diversification, globalization, and strategies on R&D and information technology.

The strength of the survey is its sample coverage and reliability of information. The survey is comprised of all firms with more than 50 employees and with capital of more than 30 million yen, covering both manufacturing and non-manufacturing firms, although some industries such as finance, insurance, and software services are not included. Industry is available at a 3-digit level. The limitation of the survey is the lack of some information on financial and institutional features such as *keiretsu*. Some information on finance, location, and intermediate inputs is not available, either.

From this survey, I have developed a longitudinal (panel) data set for manufacturing firms from 1995 to 2002. The list of industries is presented in Table A1. I drop the firms from my sample set for which the age data (the year of the survey minus the year of establishment), total wages, tangible assets, or the number of workers are not positive and in cases with incomplete replies.[7] The number of firms is about 10,000 for each year.

3.2 Measurement of TFP

To make comparisons of productivity across firms and time-series, I employ the multilateral index method in computing TFP developed by Caves, Christensen, and Diewert (1982) and

[7] This implies that re-entry firms that disappear once and re-appear are also excluded from my sample.

extended by Good, Nadiri, Roller, and Sickles (1983).[8] An advantage of multilateral index is that I do not assume *any* specific production function, which is in line with the baseline model described in Section 2. This multilateral index uses a hypothetical firm that has the arithmetic mean values of log output, log input, and input cost shares over firms in each year. Each firm's output and inputs are measured relative to this hypothetical firm. The hypothetical firms are chain-linked over time. Hence, the index measures the TFP of each firm in year t relative to that of the hypothetical firm in year 0 (initial year).

Specifically, the TFP index for firm i in year t is defined as:

$$\begin{aligned} \ln \theta_{it} \approx & \left(\ln Q_{it} - \overline{\ln Q}_t\right) + \sum_{\tau=1}^{t} \left(\overline{\ln Q}_\tau - \overline{\ln Q}_{\tau-1}\right) \\ & - \sum_{j=1}^{J} \frac{1}{2} \left(s_{ijt} + \bar{s}_{jt}\right) \left(\ln X_{ijt} - \overline{\ln X}_{jt}\right) \\ & + \sum_{\tau=1}^{t} \sum_{j=1}^{J} \frac{1}{2} \left(\bar{s}_{j\tau} + \bar{s}_{j\tau-1}\right) \left(\overline{\ln X}_{j\tau} - \overline{\ln X}_{j\tau-1}\right), \end{aligned} \quad (7)$$

where $\ln Q_{it}$, $\ln X_{ijt}$, and s_{ijt} are the log output, log input of factor j, and the cost share of factor j for firm i, respectively. $\overline{\ln Q}_t$, $\overline{\ln X}_{jt}$, and $\bar{s}_{jt}$ are the same variables for the hypothetical firm in year t and are equal to the arithmetic mean of the corresponding variable over all firms in a certain industry in year t.

The first term of the first line in the above equation is the deviation of the firm's output from the output of the reference point in the industry in year t, and the second term is the cumulative change in the output reference point between year t and the initial year, $t = 0$. The two terms in the second line perform the same operation for each factor input j, and are weighted by the average of the cost shares for firm i and the reference point in year t. Hence, the index measures the TFP of each firm in each year relative to that of the hypothetical firm in the initial year. Output is defined as gross output while inputs are capital, labor, and intermediate inputs. As for other additional data and their manipulation, see Appendix.

3.3 Measurement of R&D and R&D Spillovers

Several channels of local and international R&D spillovers are examined, controlling the firm's own R&D activity and unobservable firm specific effects.

[8] There is an alternative method that is based on the econometric estimation of production functions, which is proposed by Olley and Pakes (1996) and extended by Levinsohn and Petrin (2003). However, this framework has to specify a production function, which is not consistent with the model. This paper thus employs a multilateral index method in the present study.

Firm's own R&D investment

The firm's own R&D investment, $R\&D_{it}$, is measured the by R&D expenditure-sales ratio:

$$R\&D_{it} = \frac{R\&D_{it}}{PQ_{it}},$$

where $R\&D_{it}$ represents firm i's R&D expenditure and PQ_{it} represents firm i's sales. The use of R&D flows, however, could be a problem if investments in R&D take some time to bear fruit. I will address this issue later in Section 5.

Direct technology purchase

To control for the effects of direct technology purchases, I employ firm i's payments to foreign patents, $Patent^F_{it}$. The interpretation of patent payments is fairly straightforward because the use of patents means the direct purchase of technology through market transaction. Indeed, several studies such as Branstetter (2005) focused on the role of patents as a channel of technology diffusion. I measure patent variable as patent payments scaled by sales. Although patents can be purchased from domestic firms, I do not include the domestic patent variable since the effect through domestic patents can be captured by domestic R&D spillover variables.

R&D spillovers

The effects of R&D spillovers are captured at the firm and inudstry level. Two types of firm-level effects are examined. One is intra-firm group local spillover that takes place between a parent firm in Japan and its affiliates. The other is intra-firm group international spillover that occurs between a parent firm in a foreign country and its affiliates in Japan and is regarded as firm-level FDI spillover. The strength of the relationship between a parent and its affiliates can be measured by the degree of ownership, or equity share. But note that there are several Japanese firms where more than one-third of equity is owned by foreign investors. For instance, the equity share of foreign investors is 48.1 percent for SONY, 48.7 percent for FUJIFILM, and 37.9 percent for NINTENDO.[9] In order to capture the effect of foreign ownership, therefore, I focus on a firm where more than 50 percent of the equity is owned by a domestic parent firm, $DOWN_{it}$, and a foreign parent firm, FDI^{firm}_{it}.

As for industry-level effect, various measures are used in the previous studies. While the previous studies mainly used the employment of foreign-owned firms as the activity of foreign-owned firms in a given industry (e.g., Aitken and Harrison, 1999; Keller and Yeaple, 2004; Javorcik, 2004),[10] this paper directly tries to capture the R&D activity of foreign-owned firms. Specifically, the R&D activity of foreign-owned firms is measured

[9] *Nikkei newspaper*, June 28, 2005. (In Japanese)

[10] Alternative measures of FDI are examined in Section 5.

by the R&D expenditures of foreign-owned firms divided by the sum of sales in the same industry:

$$FDI_{it}^{ind} = \frac{\sum_{k\in M} R\&D_{kt}}{\sum_{k\in N} PQ_{kt}}.$$

Similarly, the R&D spillovers through other domestic firms are measured by the R&D expenditures of other domestic firms divided by the sum of sales in the same industry:

$$R\&D_{it}^{ind} = \frac{\sum_{k\neq i, k\notin M} R\&D_{kt}}{\sum_{k\in N} PQ_{kt}},$$

where M and N represent a set of foreign-owned firms and all firms in the same industry, respectively.[11] The firm's own R&D expenditure and the foreign-owned firm's R&D activity are excluded from local R&D spillovers.

I also examine the effects of imports that embody the advanced technology, IMP_{it}. The effects of imports are measured by general machinery imports and are defined as firm i's imports of general machinery products scaled by sales. Since firm-level machinery imports are not available in the METI database, I first calculate the share of general machinery inputs by each industry using input coefficients from the Japanese Input-Output table,[12] and then multiply the firm's imports by this share. In sum, the baseline model between year t and $t+1$ is specified as follows:

$$\begin{aligned}\Delta \ln \theta_{it+1} \;=\; & \beta_0 + \beta_1 \ln \theta_{it} \underbrace{+\phi_1 R\&D_{it}}_{\text{firm's own R\&D}} \underbrace{+\phi_2 Patent_{it}^{F}}_{\text{direct technology purchase}} \\ & \underbrace{+\omega_1 DOWN_{it} + \omega_2 R\&D_{it}^{ind}}_{\text{local R\&D spillovers}} \underbrace{+\psi_1 FDI_{it}^{firm} + \psi_2 FDI_{it}^{ind} + \psi_3 IMP_{it}}_{\text{international R\&D spillovers}} \\ & +\eta_i + \mu_{it+1}, \qquad (8)\end{aligned}$$

where $DOWN_{it}$ and $R\&D_{it}^{ind}$ capture the local spillover effects while FDI_{it}^{firm}, FDI_{it}^{ind}, and IMP_{it} do the international spillover effects. All R&D and spillover variables are averaged between years t and $t+1$.

4 Results

4.1 Basic Facts

Before going into the productivity growth analysis, let me review the data and the static difference of firm performance between R&D firms and non-R&D firms. Previous studies

[11]Regional spillover is also important (Aitken, Hanson, and Harrison, 1997; Keller, 2002). However, the regional R&D spillovers are important at the plant or establishment level rather than firm level, and the headquarters do not have to locate near production sites. In fact, the headquarters of firms in Japan concentrate in Tokyo. Besides, the information on location is not available in my data set because of confidentiality. Hence, the focuses here are on industry lines of R&D spillovers.

[12]Ministry of Internal Affairs and Communication (2004).

have examined the relationship between industry and R&D. But R&D firms are in fact quite spread out across industries.

Figure 2 illustrates the distribution of industries by the shares of R&D firms in 2002. Each of the 58 3-digit industries is placed in one of ten bins according to the percentage of R&D firms in that industry. The fraction of R&D firms that lies between 10 and 50 percent (shaded area) is 51.7 percent.[13] Therefore, it is difficult to know to which industry do R&D firms belong.

=== Figure 2 ===

Table 2 presents the R&D premium.[14] The premium means the productivity gap between R&D firms and non-R&D firms in the same year. Surprisingly, the benefit of R&D is not very large. The coefficient shows positive and significant signs but the gaps between R&D firms and non-R&D firms are only 1.0-1.1 percent. Although the gaps imply that firms have some incentives to invest in R&D, the effects of R&D are relatively small, suggesting the possibility of R&D spillovers. Next section addresses this issue in more detail.

=== Table 2 ===

Table 3 presents the trends of TFP and R&D spillover variables. Three findings stand out from this table. First, the average size of firm's own R&D expenditure is small, indicating less than one percent of total sales. Besides, the size of R&D expenditure is stable from 1995 to 2002. Second, the use of foreign patents is limited, accounting for less than 0.05 percent of total sales throughout the period. Finally, while industry-level R&D spillover variables are constant throughout the period, firm-level spillover variables indicate increasing trends as the share of parent ownership is increasing. The average of domestic parent ownership grows from 22.4 percent in 1995 to 26.6 percent in 2002. The average of foreign ownership doubled from 0.9 percent to 1.8 percent.

=== Table 3 ===

4.2 Effects of R&D Spillovers on Productivity Growth

Table 4 shows the results of equation (7) estimated by a random-effect model. I employ random-effect rather than fixed-effect because, as was confirmed in Table 3, firm's own R&D investment and industry-level R&D spillovers are relatively stable throughout the period, which in turn implies that (time) fixed-effect might correlate with these independent variables. The basic indicators of variables are summarized in Table A2.

[13] The fractions of industries that are equal to zero for R&D firms are 1.7 percent (only one industry).

[14] R&D premium is computed using the same framework as the export premium in Bernard and Jensen (1999). The premium is the coefficients on an R&D firm dummy in a regression of the form: $\ln \theta_{it} = \alpha_0 + \alpha_1 Y_{it} + \epsilon_{it}$, where θ is TFP, Y is R&D firm status that takes value one if the firm is an R&D firm, and ϵ is an error term. Year dummies are also included. Since the use of fixed-effect model implies that premium can be captured only when firms switch their status between 1995 and 2002, the premium is estimated by random-effect model.

=== Table 4 ===

First two columns (Model 0 and 1) in Table 4 are the results of random-effect model and are different in terms of the inclusion of year dummy. Five messages are evident in this table. First, the firm's own R&D activity has significantly positive effects on productivity growth. The coefficients of a firm's own R&D activity indicate positive and significant signs. As I found the R&D premium in Table 2, the result clearly indicates the benefit of R&D. The result thus suggests that the scale of R&D is an important factor for productivity growth. The benefit of R&D investment exists even after controlling for R&D spillover effects, which in turn gives incentives for firms to do R&D by themselves.

Second, the coefficients of domestic parent firm's ownership and those of R&D by other domestic firms in the same industry indicate positive and significant signs. These results suggest that the intranational technology spillovers exist both at the firm level and the industry level. It is often argued that Japanese firms are strongly tied by their parent-affiliate business relationship, so-called *keiretsu*. However, the the positive effects of intranational R&D spillovers are not limited between a parent and its affiliate relationship.

Third, international R&D spillovers through FDI generally have positive effects on productivity growth. The impacts of R&D spillovers through foreign ownership and industry-level R&D activities by foreign-owned firms patents have positive and significant effects.[15] Besides, the coefficients of R&D spillovers are large both at the firm level and the industry level, implying that the effects of international R&D spillovers are much larger than those of intranational spillovers. This result has an important implication in Japan since the amount of inward FDI is still extremely small compared with other OECD countries. The share of inward FDI stock positions compared to GDP in 1999 is only 1.4 percent, which is far below the OECD average.[16] The result suggests that the potential benefits of inward FDI is extremely large.

Fourth, foreign patent purchases have positive and significant effects on TFP growth. The results suggest that firm can also achieve the productivity growth by purchasing technologies from firms abroad.

Finally, among international R&D spillover variables, the coefficients of general machinery imports do not indicate any significant signs. This result is not surprising, though. Since most of Japanese manufacturing firms have higher technology than other firms in the world, there are few rooms to improve their productivity by the spillovers through machinery imports. This result implies that the positive effects of R&D spillovers are not strong enough to accelrate the productivity growth in developed countries like Japan.

Next, I consider the effects on longer-term growth. The benefit of considering longer-term growth is that it reduces the influence of noise while the cost of doing so reduces the number of observations. As a compromise, I experimented with 2- and 3-year productivity growth. Models 3 and 4 of Table 4 show the results. Notice that I lose 12,698 firms for

[15] The positive effects of foreign ownership on productivity growth are also confirmed in other studies. See, for instance, Kimura and Kiyota (2005).

[16] The OECD average is 12.1 percent, which is defined as the sum of inward FDI positions divided by the sum of GDP for OECD countries. For more detail, see OECD (2001).

2-year growth and 24,303 for 3-year growth if I use longer-term growth as a dependent variable. Independent variables except the inital TFP level are now 2-year and 3-year averages, respectively. In both models, the results are almost the same as those of baseline model (Model 1). Although the coefficients of foreign patents no longer indicate significant effects, those of firm's own R&D activity and both intranational and international R&D spillovers present significantly positive signs. The positive effects of R&D and its spillovers are not sensitive to the longer-term growth.

I also apply instrumental variable (IV) methods to remove the possible effects of endogeneity (Model 4). I use lagged spillover variables and all other exogenous variables as instruments, treating all independent variables as endogenous variables. Because of the use of lagged variable, I lose 24,452 firms. The IV estimation results presented in Table 4 suggest that the effects of endogeneity do not cause serious problems. The results are fairly robust. The next section examines the robustness of these results in more detail.

5 Robustness

5.1 Alternative Measurement of FDI

I first consider the issue of FDI measurement. As Keller and Yeaple (2004) argued, measurement might matter. The mismeasurement of independent variables will tend to bias the coefficient estimate toward zero. It is not easy to determine the appropriate measure of R&D spillovers through FDI, but I could investigate how the results are sensitive to the measurement. I test three alternative measures of technology spillovers through FDI, focusing on employment of foreign-owned firms.[17] The first measure is the definition adopted by Keller and Yeaple (2004). I define FDI as the employment share of foreign-owned firms and represent it as $FDI\_KY_{it}^{ind}$:

$$FDI\_KY_{it}^{ind} = \frac{\sum_{k \in M} L_{kt}}{\sum_{k \in N} L_{kt}}.$$

The second measure is the same definition of Aitken and Harrison (1999), which is defined as foreign equity share over plants in the firm, weighted by each firm's share in sectoral employments:

$$FDI\_AH_{it}^{ind} = \frac{\sum_{k \in N} L_{kt} \times FS_{kt}}{\sum_{k \in N} L_{kt}},$$

where FS_{it} is the foreign equity share of foreign-owned firm i. Third measure examines the difference between shared- and fully-owned firms. As Javorcik (2004) found, the R&D spillovers could take place not by fully foreign-owned firms but by partially foreign-owned firms:

$$FDI\_Jp_{it}^{ind} = \frac{\sum_{k \in N} L_{kt} \times FS_{kt} \times PO_{kt}}{\sum_{k \in N} L_{kt}} \text{ and } FDI\_Jf_{it}^{ind} = \frac{\sum_{k \in N} L_{kt} \times FS_{kt} \times FO_{kt}}{\sum_{k \in N} L_{kt}},$$

[17] For a recent discussion of the relationship between FDI and spillovers through workers, see Fosfuri, Motta, and Ronde (2001).

where PO_{it} and FO_{it} are dummy variables for partially and fully foreign-owned firm i, respectively.

Models 5-8 in Table 5 present the results of alternative measures of FDI. The results are generally the same as those of the baseline model (Model 1 in Table 4). In both models 5 and 6, the coefficients of industry-level FDI indicate positive and significant signs. In model 7, I find much larger positive effect of full foreign ownership than that of partial ownership. This result implies that R&D spillovers associated with fully owned foreign investments have much stronger effects than spillovers associated with shared domestic and foreign ownership. The positive effects of shared ownership might be limited within a parent and its affiliate relationship in Japan.

=== Table 5 ===

I also use the different measure of machinery imports, focusing on precision as well as general machinery products. As the baseline model, I first calculate the share of general and precision machinery inputs by each industry using input coefficients and then multiply the firm's imports by this share. The results are presented in Model 8, which is almost the same as Model 1. Even when I include precision machinery imports, the effects of machinery imports are not significant. In terms of R-squared, Models 5-7 perform slightly worse than the baseline model (Model 1 in Table 4) as R-squared in Models 5-7 is smaller than those which obtained in the baseline model. R-squared in Model 8 is as high as R-squared in the baseline model. My results thus are not sensitive to the measurement issues.

5.2 Sensitivity to Omitted Variables

Next, I turn to the effects of omitted variables. So far I have examined several channels of local and international R&D spillovers, some of which have not been examined in previous studies. If the regression equation is estimated without relevant variables, there will be a so-called omitted variable bias problem. To examine the sensitivity to omitted variables, I estimate the baseline model, dropping some of the spillover variables from the baseline model.

Models 9-14 in Table 6 presents the estimation results, which indicate how sensitive the coefficients are when some variables are omitted. I obtain relatively robust results for almost all variables. Although the coefficients present changes slightly, the results are almost the same as those that obtained in the baseline model, retaining high significance levels. My results thus suggest that the effects of omitted variable bias are not serious, which also implies that the correlation among spillover variables is not very high one another.

=== Table 6 ===

5.3 Absorptive Capacity

One may concern the complementarity between firm's own R&D and spillovers. The more the absorptive capacity a firm has, the more the benefit of spillovers the firm might have. Although it is not easy to measure the absorptive capacity, one possible proxy is the firm's R&D activities since the R&D make it possible to introduce various technologies smoothly as well as the new technology development.[18] To control for the effects of absorptive capacity, therefore, I introduce cross terms between firm's own R&D activities and R&D spillover variables. The regression equation is:

$$\begin{aligned}\Delta \ln \theta_{it+1} &= \text{Eq.}(8) + \xi_1 R\&D_{it} \times DOWN_{it} + \xi_2 R\&D_{it} \times FDI_{it}^{firm} \\ &+ \xi_3 R\&D_{it} \times R\&D_{it}^{ind} + \xi_4 R\&D_{it} \times FDI_{it}^{ind} + \xi_5 R\&D_{it} \times IMP_{it}. \quad (9)\end{aligned}$$

By the same token, the negative coefficients of cross terms imply the substitution between firm's own R&D and spillovers.

Models 15-19 in Table 7 present the results that control for the absorptive capacity. The coefficients of the cross term between firm's R&D and domestic industry-level R&D spillovers indicate significantly negative signs. The results suggest that there is a substitution effect between firm's R&D and domestic industry-level R&D spillovers.

=== Table 7 ===

6 Concluding Remarks

More than half of firms apparently do without R&D investment because of local and international R&D spillover effects. In the present study, firm-level longitudinal data from 1995 to 2002 in Japan were used. The major findings of this paper are summarized as follows. First, the effects of firm's own R&D activities were positive and significant. Second, the the positive effects of intranational and international R&D spillovers are not limited between a parent and its affiliate relationship. Third, the effects of international R&D spillovers are much larger than those of intranational spillovers. The results suggested that even firms in developed countries like Japan have benefit from international R&D spillovers.

The detailed robustness check suggests that my results are relatively robust in terms of longer-term effects, endogeneity, measurement issues, omitted variables, and additional control variables such as absorptive capacity. My results thus imply that country and/or period specific factors might play important roles in international R&D spillovers, which is a reason why previous studies presented different results. We should be careful in discussing the effects of international R&D spillovers in comparing different countries and periods.

Policy implication may be suggested from my analysis. Policy makers should recognize that FDI can be alternative avenues to the productivity growth. Even small countries that cannot invest in R&D have opportunities to achieve productivity growth through

[18]See, for instance, Kinoshita (2000).

international R&D spillovers. Inward FDI can be the engine of growth. The combination of spillovers through foreign firms as well as innovation might enable us to achieve faster productivity growth.

In closing, I may note some directions for future research. My results indicate that the effects of intranational R&D spillovers are much smaller than those of international R&D spillovers. One possibility of this result is that the speed of domestic R&D spillovers are so fast that the annual data cannot capture the effects correctly. As Branstetter (2001) pointed out, the time required for new innovation to spill over is short.[19] If the local technology diffusion occurred within one year, the studies based on annual data might not fully capture such effects. It is therefore an important research direction to estimate the speed and magnitude of spillovers.

Another important direction is to investigate the detailed mechanisms from spillovers to productivity growth. Notice that spillovers themselves do not necessarily mean the adoption of new technology since a firm does not necessarily succeed to adopt new technology even when spillovers exist. Although my study could not confirm the effects of absorptive capacity, technology adoption might be accelerated not by firm's own R&D but by other processes such as learning-by-doing.[20] In this connection, it is also desirable to clarify the backward and forward linkages of technology diffusion, which have not been covered in the present analysis.

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[19] "Empirical research suggests that the time required for new innovation to "leak out" is quite short. ... 70% of new product innovation "leak out" within one year and only 17% take more than 18 months. ... some 71% of Japanese firms and 69% of U.S. firms receive useful information about the R&D activities of their competitors on a *monthly* basis." (Branstetter, 2001, p. 60)

[20] Nakamura and Ohashi (2005) focused on learning-by-doing as a new technology adoption process.

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Appendix Construction of Multilateral TFP index

Output

There are two ways to define output: gross output and net output, or value-added. It is clear that gross output based production function is less restrictive formulation in inputs. Besides, the studies based on micro level data preferred gross output rather than value-added because the double counting of intermediate outputs does not become a severe problem at the micro level where there is little intra-industry transactions.[21] This study thus uses gross output.

Gross output is defined as: (sales - operating cost + personnel cost + depreciation cost) / output price index. Output price index is from SNA output price deflator obtained from the Economic and Social Research Institute (ESRI) website.[22]

Inputs

[21] At the macro level, where the outputs of an industry can be used as inputs by another industry in assembling final goods, value-added measure is preferred because value added net out the transactions of intermediate outputs. For more detail on this issue, see McGuckin and Nguyen (1993).

[22] Gross Domestic Product and Factor Income Classified by Economic Activities (Deflators on Outputs) <http://www.esri.cao.go.jp/en/sna/h17-nenpou/n90fcs2d_en.xls>

Inputs are consists of labor, capital, and intermediate input. Labor is defined as man-hour. Working hour data are from the Ministry of Health, Labour and Welfare (2005).[23] Capital stock is estimated from tangible assets, following Nishimura, Nakajima, and Kiyota (2005b). Intermediate input is defined as: (operating cost - personnel cost - depreciation cost) / input price index.[24] Input price index is SNA input price deflator obtained from the ESRI website.[25]

Costs

Labor cost is defined as total wage payments. Capital cost is defined as real capital stock K_{it} times user cost p_{Kit}. Following Kiyota and Okazaki (2005), I define the user cost as:

$$p_{Kit} = p_{it}\left(\frac{1-\tau_t\phi_i}{1-\tau_t}\right)\left(r_t+\delta_{it}-\frac{\Delta p_{It}}{p_{It}}\right)$$

where p_{It} is investment goods deflator obtained from Toyo Keizai (2005); τ_t is corporate tax rate on business income from the Ministry of Finance website;[26] r_t is interest rate that is defined as 10-year bond yield (annual average) and from Toyo Keizai (2005); δ_{it} is depreciation rate and from the KEO Data Base; ϕ_i is derived so that the following equations are satisfied:

$$\phi_i = \sum_{t=1}^{T}\frac{(1-\delta_{it})^{t-1}\delta_{it}}{(1+r_i)^{t-1}} \quad \text{and} \quad (1-\delta_{it})^T \approx 0.05$$

The second equation means that the end point of the depreciation period is defined as the time when the accumulated depreciation cost approximately equal to 95 percent of the initial investment.

[23] Ministry of Health, Labour and Welfare (2005) Table 127 Average monthly working days and actual working hours by industry and size.

[24] Operating cost = cost of sales + selling and general administrative expenses.

[25] Gross Domestic Product and Factor Income Classified by Economic Activities (Deflators on Inputs) <http://www.esri.cao.go.jp/en/sna/h17-nenpou/n90fcs2d_en.xls>

[26] <http://www.mof.go.jp/jouhou/syuzei/siryou/houzin/hou03.htm>

Figure 1. Classification and Definition of Spillovers

Classification	Measure
Firm's own R&D activities	Firm's own R&D expenditures
Direct technology purchase	
Patent purchases	
Domestic patents	Patent purchases from domestic firms
Foreign patents	Patent purchases from foreign firms
R&D Spillovers	
Firm-level spillovers	
Intra-firm local spillovers	Domestic parent firm's ownership
Intra-firm international spillovers	Foreign ownership (firm-level FDI)
Industry-level spillovers	
Intra-industry local spillovers	R&D by other domestic firms in the same industry
Intra-industry international spillovers	R&D by foreign-owned firms in the same industry (industry-level FDI)
International spillovers through international trade	
Imports of products that embody advanced technology	General machinery imports

Figure 2. Industry Intensity of R&D Firms in 2002

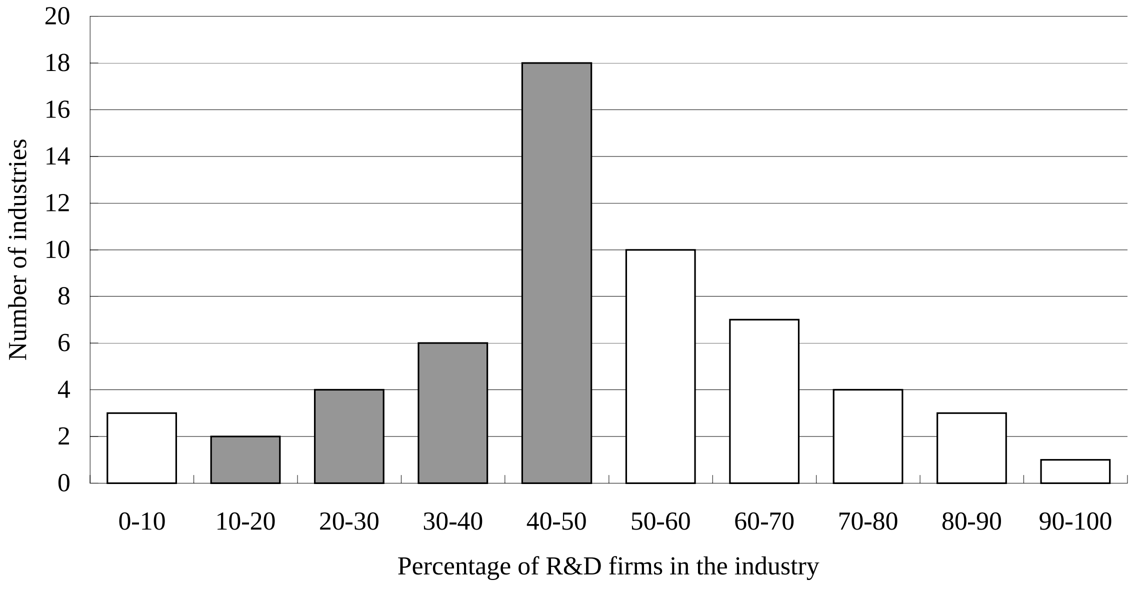

Table 1. Share of R&D Firms

	1995	1996	1997	1998	1999	2000	2001	2002
Number of R&D firms	5,180	5,048	4,997	4,941	4,883	4,717	4,723	4,515
Number of Non-R&D firms	5,786	5,860	5,850	5,753	5,574	5,551	5,332	5,089
Total	10,966	10,908	10,847	10,694	10,457	10,268	10,055	9,604
Share of R&D firms (%)	47.2	46.3	46.1	46.2	46.7	45.9	47.0	47.0
Share of Non-R&D firms (%)	52.8	53.7	53.9	53.8	53.3	54.1	53.0	53.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note: R&D firm is defined as a firm that invests R&D while Non-R&D firm is defined as a firm that does not.
Source: METI Database.

Table 2. Performance Gap between R&D Firms and Non-R&D Firms

	R&D dummy	standard errors (s.e.)	*N*	Industry dummy	Year dummy	R^2
lnTFP	0.011	[0.001]	83,799	No	Yes	0.04
lnTFP	0.010	[0.001]	83,799	Yes	Yes	0.09

Notes: 1) Random-effect model is used for estimation.
2) Coefficients are significant at 1% level.
3) Estimated coefficient indicates the gaps of each variable between R&D firms and non-R&D firms.
Source: METI Database.

Table 3. Total Factor Productivity (TFP) and R&D Spillover Variables

(Mean)

		1995	1996	1997	1998	1999	2000	2001	2002
TFP	lnTFP	-0.051	-0.041	-0.039	-0.061	-0.046	-0.007	-0.027	-0.053
R&D	Firm's own R&D expenditures (% of sales)	0.86	0.86	0.87	0.97	0.97	0.91	1.01	0.99
$Patent^F$	Patent purchases from foreign firms (% of sales)	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
DOWN	Domestic parent firm's ownership (%)	22.44	23.04	24.42	24.55	24.82	25.35	26.14	26.56
FDI^{firm}	Foreign ownership (firm-level FDI, %)	0.90	0.87	0.89	1.45	1.64	1.61	1.66	1.75
$R\&D^{ind}$	R&D by other domestic firms in the same industry (% of sales, industry average)	2.12	1.99	2.14	2.30	2.25	2.20	2.43	2.32
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI, % of sales, industry average)	0.09	0.07	0.08	0.09	0.31	0.25	0.10	0.14
IMP	General machinery imports (% of sales)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03

Note: TFP is a chain index from the hypothetical firm in 1995 (equal to zero: TFP=1 and therefore lnTFP=0).
Source: METI Database.

Table 4. Effects of R&D Spillovers on Productivity Growth

Dependent variable: TFP growth		Model 1 1-year growth	Model 2 2-year growth	Model 3 3-year growth	Model 4 1-year growth
lnTFP		-0.370**	-0.319**	-0.223**	-0.108**
		[0.003]	[0.002]	[0.002]	[0.005]
Firm's own R&D activity					
R&D	Firm's own R&D expenditures	0.232**	0.203**	0.160**	0.130**
		[0.016]	[0.012]	[0.010]	[0.021]
Direct purchase of technology					
$Patent^F$	Patent purchases from foreign firms	0.431*	0.263*	0.144	0.182
		[0.172]	[0.129]	[0.109]	[0.263]
R&D spillovers					
DOWN	Domestic parent firm's ownership	0.014**	0.011**	0.009**	0.008**
		[0.001]	[0.001]	[0.000]	[0.001]
FDI^{firm}	Foreign ownership (firm-level FDI)	0.042**	0.034**	0.028**	0.021**
		[0.004]	[0.003]	[0.002]	[0.004]
$R\&D^{ind}$	R&D by other domestic firms in the same industry	0.103**	0.095**	0.079**	0.205**
		[0.020]	[0.015]	[0.013]	[0.031]
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI)	0.753**	0.667**	0.402**	-1.177**
		[0.065]	[0.049]	[0.043]	[0.166]
IMP	General machinery imports	0.159	0.036	0.018	-0.442
		[0.165]	[0.024]	[0.021]	[0.231]
Year dummies		Yes	Yes	Yes	Yes
Observations		69,628	56,930	45,325	45,176
R-squared		0.198	0.249	0.192	0.173

Notes: 1) Models 0-3 are estimated by random-effect model. Model 4 is estimated by instrumental variable method.
2) ** and * indicate level of significance at 1% and 5% respectively. Figures in brackets indicate standard errors.

Source: METI Database.

Table 5. Robustness Check I: Alternative Measurement of FDI and Machinery Imports

Dependent variable: TFP growth		Model 5 Keller and Yeaple, 2003	Model 6 Aitken and Harrison, 1999	Model 7 Javorcik, 2004	Model 8 Precision machinery imports
lnTFP		-0.368**	-0.368**	-0.368**	-0.370**
		[0.003]	[0.003]	[0.003]	[0.003]
Firm's own R&D activity					
R&D	Firm's own R&D expenditures	0.231**	0.234**	0.234**	0.232**
		[0.016]	[0.016]	[0.016]	[0.016]
Direct purchase of technology					
$Patent^F$	Patent purchases from foreign firms	0.455**	0.467**	0.468**	0.435*
		[0.172]	[0.172]	[0.172]	[0.172]
R&D spillovers					
DOWN	Domestic parent firm's ownership	0.013**	0.013**	0.013**	0.014**
		[0.001]	[0.001]	[0.001]	[0.001]
FDI^{firm}	Foreign ownership (firm-level FDI)	0.042**	0.042**	0.042**	0.042**
		[0.004]	[0.004]	[0.004]	[0.004]
$R\&D^{ind}$	R&D by other domestic firms in the same industry	0.116**	0.128**	0.128**	0.104**
		[0.022]	[0.022]	[0.022]	[0.020]
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI)				0.751**
					[0.065]
IMP	General machinery imports	0.140	0.130	0.129	
		[0.165]	[0.164]	[0.164]	
IMP_P	General and precision machinery imports				0.005
					[0.126]
FDI_KY^{ind}	Employment by foreign-owned firms (Industry-level FDI) (Keller and Yeaple, 2003)	0.093**			
		[0.016]			
FDI_AK^{ind}	Foreign equity share (Industry-level FDI) (Aitken and Harrison, 1999)		0.085**		
			[0.019]		
FDI_Jf^{ind}	Foreign equity share, full ownership (Industry-level FDI) (Javorcik, 2004, full ownership)			0.096**	
				[0.030]	
FDI_Jp^{ind}	Foreign equity share, partial ownership (Industry-level FDI) (Javorcik, 2004, partial ownership)			0.071	
				[0.036]	
Year dummies		Yes	Yes	Yes	Yes
Observations		69,628	69,628	69,628	69,628
R-squared		0.198	0.198	0.198	0.198

Notes: 1) Models 5-7 test the alternative measure of industry-level FDI while Model 8 test the alternative measure of machinery imports.
2) For other notes and sources, see Table 4.

Table 6. Robustness Check II: Sensitivity to Omitted Variables

Dependent variable: TFP growth		Model 9 Without trade	Model 10 Without patents	Model 11 Without FDI	Model 12 Trade only	Model 13 Patents only	Model 14 FDI only
lnTFP		-0.370**	-0.370**	-0.365**	-0.361**	-0.361**	-0.366**
		[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Firm's own R&D activity							
R&D	Firm's own R&D expenditures	0.232**	0.235**	0.257**	0.300**	0.293**	0.244**
		[0.016]	[0.016]	[0.016]	[0.015]	[0.016]	[0.016]
Direct purchase of technology							
$Patent^F$	Patent purchases from foreign firms	0.436*		0.871**		0.921**	
		[0.172]		[0.169]		[0.170]	
R&D spillovers							
DOWN	Domestic parent firm's ownership	0.014**	0.014**	0.013**			
		[0.001]	[0.001]	[0.001]			
FDI^{firm}	Foreign ownership (firm-level FDI)	0.042**	0.044**				0.040**
		[0.004]	[0.004]				[0.004]
$R\&D^{ind}$	R&D by other domestic firms in the same industry	0.104**	0.104**	0.187**			
		[0.020]	[0.020]	[0.019]			
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI)	0.751**	0.760**				0.880**
		[0.065]	[0.065]				[0.062]
IMP	General machinery imports		0.170	0.269	0.309		
			[0.165]	[0.164]	[0.164]		
Year dummies		Yes	Yes	Yes	Yes	Yes	Yes
Observations		69,628	69,628	69,628	69,628	69,628	69,628
R-squared		0.198	0.198	0.196	0.191	0.191	0.194

For notes and sources, see Table 4.

Table 7. Effects of R&D Spillovers on Productivity Growth with Absorptive Capacity

		Model 15	Model 16	Model 17	Model 18	Model 19
Dependent variable: TFP growth						
lnTFP		-0.370**	-0.370**	-0.370**	-0.370**	-0.370**
		[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Firm's own R&D activity						
R&D	Firm's own R&D expenditures	0.360**	0.367**	0.360**	0.259**	0.358**
		[0.036]	[0.034]	[0.036]	[0.018]	[0.036]
Direct purchase of technology						
$Patent^F$	Patent purchases from foreign firms	0.497**	0.474**	0.497**	0.486**	0.496**
		[0.173]	[0.172]	[0.173]	[0.173]	[0.173]
R&D spillovers						
DOWN	Domestic parent firm's ownership	0.014**	0.014**	0.014**	0.014**	0.014**
		[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
R&D * DOWN		-0.046	-0.042	-0.046		-0.047
		[0.040]	[0.039]	[0.040]		[0.040]
FDI^{firm}	Foreign ownership (firm-level FDI)	0.044**	0.041**	0.044**	0.044**	0.044**
		[0.005]	[0.004]	[0.005]	[0.005]	[0.005]
R&D * FDI^{firm}		-0.109		-0.109	-0.101	-0.118
		[0.121]		[0.121]	[0.121]	[0.121]
$R\&D^{ind}$	R&D by other domestic firms in the same industry	0.127**	0.132**	0.127**	0.103**	0.127**
		[0.022]	[0.021]	[0.022]	[0.020]	[0.022]
R&D * $R\&D^{ind}$		-2.667**	-3.183**	-2.667**		-2.665**
		[0.876]	[0.710]	[0.876]		[0.876]
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI)	0.847**	0.810**	0.847**	0.882**	0.846**
		[0.077]	[0.066]	[0.077]	[0.076]	[0.077]
R&D * FDI^{ind}		-1.777		-1.777	-5.210**	-1.721
		[1.990]		[1.990]	[1.613]	[1.988]
IMP	General machinery imports	0.216	0.231	0.216	0.224	0.129
		[0.208]	[0.208]	[0.208]	[0.208]	[0.165]
R&D * IMP		-3.285	-3.605	-3.285	-3.280	
		[4.848]	[4.818]	[4.848]	[4.848]	
Year dummies		Yes	Yes	Yes	Yes	Yes
Observations		69,628	69,628	69,628	69,628	69,628
R-squared		0.198	0.198	0.198	0.198	0.200

For notes and sources, see Table 4.

Table A1. List of Industries

	Industry		Industry
1	Livestock products	30	Manufacture of leather tanning, leather products and fur skins
2	Seafood products	31	Glass and its products
3	Flour and grain mill products	32	Cement and its products
4	Miscellaneous foods and related products	33	Miscellaneous ceramic, stone and clay products
5	Soft drinks, carbonated water, alcoholic, tea and tobacco	34	Iron and steel
6	Prepared animal foods and organic fertilizers	35	Miscellaneous iron and steel
7	Silk reeling plants and spinning mills	36	Smelting and refining of non-ferrous metals
8	Oven fabric mills and knit fabrics mills	37	Non-ferrous metals worked products
9	Dyed and finished textiles	38	Fabricated constructional and architectural metal products, including fabricated plate work and sheet metal work
10	Miscellaneous textile mill products	39	Miscellaneous fabricated metal products
11	Textile and knitted garments	40	Metal working machinery
12	Other textile apparel and accessories	41	Special industry machinery
13	Sawing, planning mills and plywood products	42	Office, service industry and household machines
14	Miscellaneous manufacture of wood products, including bamboo and	43	Miscellaneous machinery and machine parts
15	Manufacture of furniture and fixtures	44	Industrial electric apparatus
16	Pulp and paper	45	Household electric appliances
17	Paper worked products	46	Miscellaneous electrical machinery equipment and supplies
18	Printing and allied industries	47	Communication equipment and related products
19	Chemical fertilizers and industrial inorganic chemicals	48	Electronic data processing machines, digital and analog computer, equipment and accessories
20	Industrial organic chemicals	49	Electronic parts and devices
21	Chemical fibers	50	Motor vehicles, parts and accessories
22	Oil and fat products, soaps, synthetic detergents, surface-active agents and paints	51	Miscellaneous transportation equipment
23	Drugs and medicines	52	Medical instruments and apparatus
24	Miscellaneous chemical and allied products	53	Optical instruments and lenses
25	Petroleum refining	54	Watches, clocks, clockwork-operated devices and parts
26	Miscellaneous petroleum and coal products	55	Miscellaneous precision instruments and machinery
27	Plastic products, except otherwise classified	56	Ordnance and accessories
28	Tires and inner tubes	57	Newspaper industries
29	Miscellaneous rubber products	58	Publishing industry

Table A2. Summary Statistics

Basic Statistics

Variable		*N*	Mean	S.E.
lnTFP		69,628	-0.037	0.102
Firm's own R&D activity				
R&D	Firm's own R&D expenditures	69,628	0.009	0.020
Direct purchase of technology				
$Patent^F$	Patent purchases from foreign firms	69,628	0.000	0.002
R&D spillovers				
DOWN	Domestic parent firm's ownership	69,628	0.244	0.398
FDI^{firm}	Foreign ownership (firm-level FDI)	69,628	0.013	0.086
$R\&D^{ind}$	R&D by other domestic firms in the same industry	69,628	0.022	0.018
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI)	69,628	0.001	0.005
IMP	General machinery imports	69,628	0.000	0.002

Correlation Matrix

N = 69,628		lnTFP	R&D	$Patent^F$	DOWN	FDI^{firm}	$R\&D^{ind}$	FDI^{ind}	IMP
lnTFP		1							
R&D	Firm's own R&D expenditures	0.194	1						
$Patent^F$	Patent purchases from foreign firms	0.068	0.132	1					
DOWN	Domestic parent firm's ownership	0.087	-0.049	-0.016	1				
FDI^{firm}	Foreign ownership (firm-level FDI)	0.122	0.133	0.248	-0.070	1			
$R\&D^{ind}$	R&D by other domestic firms in the same industry	0.123	0.352	0.085	0.074	0.097	1		
FDI^{ind}	R&D by foreign-owned firms in the same industry (industry-level FDI)	0.061	0.228	0.096	0.000	0.087	0.423	1	
IMP	General machinery imports	0.018	0.047	0.058	-0.019	0.127	0.040	-0.018	1

Note: For the definition of variables, see main text.