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Reconsidering the Effects of Intranational and International R&D Spillovers: Firm-level Evidence from Japan*

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Abstract

In 2000, 71.8 percent of Japanese 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 high productivity growth without any R&D investments. The results indicate that, in addition to the firm's own R&D activities, international R&D spillovers through foreign direct investment and machinery imports have significantly positive effects on productivity growth. The effects of intranational R&D spillovers are generally positive but not significant. My results thus imply that the majority of firms do without R&D investment because of international R&D spillover effects. (96 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, most firms do not conduct R&D investment even in developed countries. Figure 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 Japan. In 2000, 71.2 percent of firms are non-R&D firms. More than half are non-R&D firms in manufacturing while 87.8 percent are non-R&D firms in non-manufacturing. Why are so many firms doing without R&D investments?

=== Figure 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 international as well as intranational 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 analysis technology diffusion theory, see Grossman and Helpman (1991) 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 to 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 intranational and international R&D spillovers on the patent activities of Japanese and U.S. firms. His results indicated that the intranational spillovers were more important than international spillovers. In his regressions, the estimated coefficients of intranational 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), and Javorcik (2004) 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) and Javorcik (2004) 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 intranational and international R&D spillovers on productivity growth at the firm level and builds upon the previous research just noted. The contribution of this study is twofold. First, this paper examines spillovers through FDI, imports, *and* patents, at the same time. Previous studies recognize these three channels as the primary channels for international R&D spillovers but they are examined differently. My results suggest that, in addition to the firm's own R&D activities, international R&D spillovers through FDI have positive effects on productivity growth in both manufacturing and non-manufacturing industries. Besides, R&D spillovers through imports have significantly positive effects in manufacturing. On the other hand, intranational R&D spillovers

[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.

have positive effects, but they are not significant.

Second, this study provides a detailed robustness check and identifies reasons why the existing literature presents different results. I examine the effects of endogeneity, time lag, the effects on longer-term growth, measurement issues, omitted variable bias, and limited coverage of the data. The robust results are obtained in the R&D spillovers through trade and firm-level FDI except when the coverage of the data is narrow. The industry-level spillovers through FDI are sensitive to its measurement, and the coefficients of patent variables are sensitive to the omission of variables. The results of the analysis based on the limited sample could be different from the results obtained from the broader sample.

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 three 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 22,000 firms annually. Finally, the data can provide an overall picture of Japanese firms, covering manufacturing and a large part of non-manufacturing sectors. The broad coverage of the data enables me to examine why my results are different from those of previous studies.

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 implications.

2 Baseline Model

I begin with setting up a simple model of productivity convergence, following Bernard and Jones (1996). The strength of this approach is that the specification does not depend on the form of production function, which is summarized as follows.

Denote TFP for a firm i in year t by θ_{it}. The TFP growth is assumed to be described as:

$$\ln \theta_{it} = \gamma_i + \lambda \left\{ \ln \theta_{1t-1} - \ln \theta_{it-1} \right\} + \ln \theta_{it-1} + \ln \epsilon_{it}, \tag{1}$$

where $\ln \theta_{1t-1} - \ln \theta_{it-1}$ represents a catch-up variable, which represents the distance in productivity between the most productivity firm, denoted by 1, and firm i. The speed of catching-up thefore is captured by λ while the asymptotic rate of productivity growth of firm i is denoted by γ_i. Finally, $\ln \epsilon_{it}$ represents disturbance term.

This framework yields the following catch-up path of productivity:

$$\ln \hat{\theta}_{it} = (\gamma_i - \gamma_1) + (1 - \lambda) \ln \hat{\theta}_{it-1} + \ln \hat{\epsilon}_{it},$$

where $\hat{\theta}_{it} = \theta_{it}/\theta_{1t}$ and $\hat{\epsilon}_{it} = \epsilon_{it}/\epsilon_{1t}$, respectively. In the long-run, the annual average TFP growth rate of firm i relative to firm 1 between year 0 and year T is written as:

$$\frac{1}{T}(\ln\hat{\theta}_{iT} - \ln\hat{\theta}_{i0}) = -\frac{1-(1-\lambda)^T}{T}\ln\hat{\theta}_{i0} + \frac{1}{T}\sum_{\tau=1}^{T}(1-\lambda)^{T-\tau}(\gamma_i - \gamma_1 + \ln\hat{\epsilon}_{i\tau}).$$

This is the basis of familiar convergence model of long-run average growth on initial level and I specify a baseline model as follows.

$$\Delta\ln\hat{\theta}_{iT} = \frac{1}{T}(\ln\hat{\theta}_{iT} - \ln\hat{\theta}_{i0}) = \beta_0 + \beta_1\ln\hat{\theta}_{i0} + \mu_{iT}, \quad (2)$$

where catch-up is denoted by a negative coefficient of $\beta_1 = -\{1-(1-\lambda)^T\}/T$. I assume $\mu_{iT} \sim N(0, \sigma)$.

Several models have been proposed to explain intranational and international R&D spillovers, but there is no consensus on the existence of the spillovers. Following Keller and Yeaple (2004), I take a broad view on how R&D spillovers might affect the productivity of firms. That is, instead of modeling a particular mechanism of R&D spillovers, my approach is simply to ask whether firms can achieve higher productivity growth when there are R&D spillovers, adding spillover effects to equation (1) as control variables:

$$\Delta\ln\hat{\theta}_{iT} = \beta_0 + \beta_1\ln\hat{\theta}_{i0} + \sigma f_{i0} + \omega g_{i0} + \phi h_{i0} + \mu_{iT}, \quad (3)$$

where f_{i0}, g_{i0}, and h_{i0} represent firm i's own R&D activity, intranational, 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 Research and Statistics Department, Ministry of Economy, Trade and Industry (METI) (1996-2002). 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 list of industries is presented in Appendix Table 1. 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 the years from 1994 to 2000. 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, value-added (sales minus purchases), or the number of workers are not positive and in cases with incomplete replies. The number of firms exceeds 22,000 for each year.[6]

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 extended by Good, Nadiri, Roller, and Sickles (1983).[7] The 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:

$$\begin{aligned} \ln \theta_{it} \approx\ & \left(\ln Q_{it} - \overline{\ln Q}_t\right) + \sum_{\tau=1}^{t} \left(\overline{\ln Q}_\tau - \overline{\ln Q}_{\tau-1}\right) \\ & - \sum_{j=1}^{J} \frac{1}{2} \left(s_{ijt} + \bar{s}_{jt}\right) \left(\ln X_{ijt} - \overline{\ln X}_{jt}\right) \\ & + \sum_{\tau=1}^{t} \sum_{j=1}^{J} \frac{1}{2} \left(\bar{s}_{j\tau} + \bar{s}_{j\tau-1}\right) \left(\overline{\ln X}_{j\tau} - \overline{\ln X}_{j\tau-1}\right), \end{aligned} \tag{4}$$

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 year t.

[6] In the questionnaire, the definitions of "imports" (and "exports") are slightly changed after 1997. The sales and purchases of affiliates abroad are included before 1996 while they are excluded after 1997. The average ratio of the latter value to the former value between 1997 and 1999 is 0.621 for imports (and 0.658 for exports). I use the product of trade values and these shares before 1996 so that trade values are consistent throughout the period.

[7] 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 our baseline model. Moreover, because of the limited availability of intermediate inputs, their method was not feasible. Therefore, I employ a multilateral index method in the present study.

The first term of the first line indicates the deviation of the firm i's output from the output of the hypothetical firm in year t. The second term means the cumulative change in the output of the hypothetical firm from year 0 to year t. The same operations are applied to each input j in the second and the third lines, weighted by the average of the cost shares. Outputs are defined as value-added while inputs are capital and labor. As for other additional data and their manipulation, I adopt the methodology described in Nishimura, Nakajima, and Kiyota (2005).

3.3 Measurement of Intranational and International R&D Spillovers

Several channels of intranational and international R&D spillovers are examined, controlling the firm's own R&D activity and observable firm specific characteristics.

Firm's own R&D investment

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

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

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 discuss this matter later in Section 5.

Intranational R&D spillovers

To capture the effects of intranational R&D spillovers, I employ two variables. One is industry-level R&D that captures the domestic R&D spillovers within a given industry,[8] and this is defined as the sum of R&D expenditures divided by the sum of sales in the same industry:

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

where M and N represent a set of foreign-owned firms and all firms in the same industry, respectively. The firm's own R&D expenditure and the foreign-owned firm's R&D activity are excluded from intranational R&D spillovers and are included as international R&D spillovers. A foreign-owned firm is defined as a firm where more than 50 percent of the equity is foreign-owned (majority-owned firms).

[8] 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.

The other is firm i's payments to domestic patents, $Patent_{it}^{D}$. 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 (2000) focused on the role of patents as a channel of technology diffusion. I measure patent variable as patent payments scaled by sales.

International R&D spillovers

The effects of international R&D spillovers are captured by machinery imports, the patent payments to foreign firms, and FDI. Machinery imports, IMP_{it}, are firm i's imports of machinery products scaled by sales. Since firm-level machinery imports are not available in the survey, I first calculate the share of machinery inputs by each industry using input coefficients from the Japanese Input-Output table,[9] and then multiply the firm's imports by this share. Firm i's payments to foreign patents, $Patent_{it}^{F}$, represents the patent payments to foreign firms divided by sales.

Two FDI variables are used. One is to capture the firm-level effect and the other is to capture the industry-level effect. The firm-level effect is captured by the degree of foreign ownership, or foreign equity share, FDI_{it}^{firm}. 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 by the R&D expenditures of foreign-owned firms divided by the sum of sales in the same industry:

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

I also include firm characteristics, Z_{it}, to control for observable firm specific factors and individual firm effect, η_i, to control for unobservable firm heterogeneity. In sum, the baseline model between year t and $t+1$ is specified as follows.

$$\begin{aligned} \Delta \ln \hat{\theta}_{it+1} \;\; = \;\; & \beta_0 + \beta_1 \ln \hat{\theta}_{it} + \sigma R\&D_{it}^{O} + \omega_1 R\&D_{it}^{D} + \omega_2 Patent_{it}^{D} \\ & + \psi_1 IMP_{it} + \psi_2 Patent_{it}^{F} + \psi_3 FDI_{it}^{firm} + \psi_4 FDI_{it}^{ind} \\ & + \kappa Z_{it} + \eta_i + \mu_{it+1} \end{aligned} \quad (5)$$

I use the number of workers, firm age, and capital-labor ratio as firm characteristics, Z_{it}. In the estimation, I use θ_{it} instead of $\hat{\theta}_{it}$ for simplicity. This does not cause any problems, since it simply shifts β_0. Machinery imports are used only for manufacturing firms because the effects of R&D spillovers through machinery imports are limited to manufacturing sectors.

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

[10] Alternative measures of FDI are examined in the Appendix.

4 Results

4.1 Basic Facts

Before going into the dynamic 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 have examined the relationship between industry and R&D. But R&D firms are in fact quite spread out across industries, especially in the manufacturing sectors.

Figure 2 illustrates the distribution of industries by the shares of R&D firms. Each of the 117 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 is 47 percent in all industry, 55.9 percent in manufacturing, and 37.9 percent in non-manufacturing, respectively.[11] Therefore, it is difficult to know to which industry R&D firms belong, especially for manufacturing industries.

=== Figure 2 ===

Table 1 presents the R&D premium for TFP and labor productivity.[12] The premium means the productivity gap between R&D firms and non-R&D firms in the same industry and the same year. The benefit of R&D is clear in non-manufacturing but not in manufacturing firms. In the manufacturing sector, though the coefficients of TFP and labor productivity of R&D firms show positive signs, they are not statistically significant. On the other hand, in the non-manufacturing sector, I observe a significant difference in productivity between R&D firms and non-R&D firms. Both TFP and labor productivity indicate positive and significant signs. The productivity gaps between R&D firms and non-R&D firms are about 2 percent.

=== Table 1 ===

Table 2 presents the trends of TFP and R&D variables. The difference between manufacturing and non-manufacturing is clear, especially for R&D variables. The firm's own R&D in manufacturing is eight times as much as that in non-manufacturing. Similarly, all R&D spillover variables in manufacturing are larger than those in non-manufacturing. This means that R&D activity in manufacturing is different from R&D activity in non-manufacturing. Therefore, in the following section, I conduct separate regressions for manufacturing and non-manufacturing.

=== Table 2 ===

[11] The fractions of industries that are equal to zero for R&D firms are 0 percent in manufacturing and 24 percent in non-manufacturing, respectively.

[12] 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: $\ln Z_{it} = \alpha_0 + \alpha_1 Y_{it} + \epsilon_{it}$, where Z is productivity (either TFP or labor productivity), 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 and industry dummies are also included. A fixed-effects model is employed for the estimation (based on the results of the Hausman specification test).

4.2 Effects of R&D Spillovers on Productivity Growth

Table 3 shows the results of equation (4) estimated by a maximum likelihood random-effect model. I employ random-effect rather than fixed-effect because, in my baseline model, fixed-effect implies that each firm has a different asymptotic rate of productivity growth (i.e., $\gamma_i \neq \gamma_1$) even if they belong to the same industry. This makes it difficult to interpret the results in the context of productivity convergence. Hence I assume that asymptotic rate of TFP growth is the same within the narrowly defined (3-digit level) industries and include industry dummies instead of fixed-effect. The basic indicators of variables are summarized in Appendix Table 2.

=== Table 3 ===

Table 3 presents two types of results. One includes firm characteristics and the other does not. Adding firm characteristics improves both Akaike Information Criterion (AIC) and Schwarz (Bayesian) Information Criterion (BIC), suggesting that the part of productivity growth is explained by firm characteristics.

Three findings are evident in this table. First, the firm's own R&D activity has significantly positive effects on productivity growth in both manufacturing and non-manufacturing. The coefficients of a firm's own R&D activity indicate positive and significant signs. Second, I confirm the positive effects of intranational R&D spillovers only in the non-manufacturing sector. In manufacturing, both industry R&D and patents do not have any significant effects on productivity growth, as the coefficients of intranational R&D spillovers are positive but not significant. In non-manufacturing, domestic patents contribute to productivity growth. The coefficients of patent payments to domestic firms show positive and significant signs.

Third, international R&D spillovers generally have positive effects on productivity growth. Among the spillover variables, trade and FDI are particularly important. The R&D spillovers through machinery imports have positive effects in manufacturing. Besides, the impacts of firm-level R&D spillovers through FDI, or foreign ownership, have positive and significant effects in non-manufacturing as well as in manufacturing.[13] However, industry-level R&D spillovers through FDI exist only in manufacturing. Foreign patents do not have significant effects on productivity growth in manufacturing and non-manufacturing.

I also apply instrumental variable (IV) methods to remove the possible effects of endogeneity. I use lagged spillover variables and all other exogenous variables as instruments, treating all spillover variables as endogenous variables. Because of the use of lagged variable, I lose 14,475 firms for manufacturing and 13,834 firms for non-manufacturing. The IV estimation results presented in Table 1 suggest that the effects of endogeneity do not cause serious problems. The results are relatively robust, especially for manufacturing firms. The next section examines the robustness of these results in more detail.

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

5 Alternative Specifications: Comparisons of Results with Other Studies

The detailed results of a robustness check are reported in the Appendix below. The main conclusions are summarized as follows. First, the firm's own R&D and international R&D spillovers, especially firm-level spillovers through trade (machinery imports) and FDI (foreign ownership), are significant channels of productivity growth both in manufacturing and non-manufacturing sectors. I confirm that these results are robust. On the other hand, intranational R&D spillovers do not present robust results on productivity growth in general.

Second, the measurement affects the results of industry-level R&D spillovers. While this paper captures R&D spillovers through FDI by foreign firms' R&D expenditures, previous studies used the employment of foreign firms. When I follow the measures employed in previous studies, the industry-level R&D spillover variables through FDI no longer show positive effects. In the manufacturing sector, my measurement presented in Section 4 performs better than the measurement used in previous studies. In the non-manufacturing sector, however, the measurement of previous studies performs better than the measurement used in my study. Since the previous studies used employment to capture the effects of FDI, my results might indicate that the spillover channels are different between manufacturing and non-manufacturing. While R&D activity is an important channel in manufacturing sector, employment is more important than R&D activity as a channel of the spillovers.

Finally, the coefficients of patent variables are sensitive to omitted variables. The coefficients of foreign patents become significantly positive once I drop some of the other international spillover variables. However, the baseline model in Section 4 performs better than the models without some variables. This indicates that to control various channels is important in analyzing spillover effects. This result also suggests that it matters a great deal how FDI is measured and which variables are included in inferring the effects of R&D spillovers.

The results represented above confirm that international R&D spillovers are important channels compared with intranational R&D spillovers. Although my results partly support the results of Keller and Yeaple (2004), they contradict the findings of other previous studies such as Branstetter (2001), Aitken and Harrison (1999), and Haskel, Pereira, and Slaughter (2002). I will discuss why my results are different from those of other studies.

There are a couple of things to be noticed. First, as Keller and Yeaple (2004) claimed, the measurement of FDI matters a great deal. As confirmed in the Appendix, the coefficients of industry-level FDI are affected by measurement. Indeed, if I follow their measurement, my results become consistent with the findings of previous studies.

Second, the quality and coverage of data are also important. My data cover all manufacturing and relatively small firms. Studies that focus on some specific industries and/or large firms may cause a sort of sample selection bias. For instance, if high-tech firms face more foreign exposure, the analysis that selects high-tech sectors does not fully capture the relative importance of high-tech sectors in the economy. Such analysis can reveal the relative importance of international spillovers within high-tech industries but not across industries. To check the effect of sample selection, I ran regressions for high-tech industries according to the different levels of employment scale. High-tech industries are defined as chemicals, machinery, electronics, transportation, and precision instruments manufacturing industries, following Branstetter (2001). Large firms are defined by the size of employment, and I examine the firms with more than 300 workers, 500 workers, 1000 workers, and 2000 workers.

Table 4 presents the regression results for high-tech sectors. The larger the firms chosen, the more the effects of intranational R&D spillovers appear, which is consistent with the findings of Branstetter (2001). The coefficients of domestic patents are significant for firms with more than 1,000 workers and 2,000 workers. On the other hand, the effects of a firm's own R&D activity and international R&D spillovers weaken. Since most large firms in high-tech sectors face more foreign exposure than firms in other sectors, regression analysis that is based only on these firms might mask the benefits of international R&D spillovers. My results strongly suggest that the discussion based on the analysis with limited samples cannot be generalized, and the broad coverage of samples is important.

=== Table 4 ===

Third, country specific factors also play important roles in international R&D spillovers. For instance, in Japan, 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.[14] The small amount of FDI might have positive effects at the firm-level but not enough to affect results at the industry-level. Similarly, the effects of import-related R&D spillovers could be small in the countries with lower trade intensities. The relative scales of trade and FDI could be important factors to get the benefit of international R&D spillovers.

Finally, the speed of intranational R&D spillovers could be faster than international spillovers. As Branstetter (2001) pointed out, the time required for new innovation to spill over is short.[15] If the intranational technology diffusion occurred within one year, the studies based on annual data might not fully capture such effects.

6 Concluding Remarks

The majority of firms apparently do without R&D investment because of international R&D spillover effects. In the present study, firm-level longitudinal data from 1994 to 2000 in Japan were used. I found that firm-level FDI had positive impacts on productivity growth in

[14] 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).

[15] "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)

both manufacturing and non-manufacturing industries. In manufacturing, import-related R&D spillovers also have significantly positive effects on productivity growth. On the other hand, intranational R&D spillovers were not significant in general. The results thus suggest that international R&D spillovers through trade and FDI have significant effects on productivity growth.

The results of R&D spillovers through trade and firm-level FDI appear robust. However, other variables are sensitive to the measurement issues and omitted variables. My measurement of industry-level R&D spillovers through FDI, which directly captures the R&D activity of foreign-owned firms, performs better than the measurement used in the previous studies in analyzing the manufacturing sector. In the non-manufacturing sector, however, the measurements by Aitken and Harrison (1999) and Keller and Yeaple (2004) perform better than the measurement used in my study. Further, patent variables are sensitive to the omission of other variables.

The broad coverage of the data is important. The analysis based on the limited sample produces different results from the analysis based on the broader sample. The domestic patents do not affect the R&D spillovers, which is inconsistent with the results of Branstetter (2001). However, once I limit the sample to large firms in high-tech sectors as Branstetter (2001), my results become consistent with those of Branstetter (2001): domestic patents have significantly positive effects on spillovers. The empirical studies of R&D spillovers therefore must pay more attention to the measurement issues, omitted variable bias, and the coverage of the data.

Three policy implications may be suggested from our analysis. First, tightening intellectual property rights should be discussed more carefully. While the intellectual property rights could promote innovation (through R&D), the lack of technology diffusion prevents followers from catching up a leading firm. Since followers are likely to be new entrants and small- and medium-sized firms, strong protection on intellectual property could be harmful for their growth.

Second, policy makers should recognize that trade and FDI can be alternative avenues to the productivity growth. Even small countries that cannot invest in R&D have opportunities to achieve higher productivity growth through international R&D spillovers. Imports of merchandise and inward FDI can be the engine of growth. The promotion of innovation is an important policy but we do not have to invent everything by ourselves. The combination of spillover as well as innovation enables us to use limited resources more effectively.

Finally, the construction of reliable data is important to capture the spillover effects correctly. In the present study, the broad coverage of observations removes the possible problems caused by limited samples, and the high availability of various items enables me to check how the results are sensitive to the measurement.

In closing, I may note some directions for future research. If spillovers occur easily, firms do not have any incentive to innovate new technologies by themselves. It is important therefore to estimate the speed of spillovers. 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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Appendix Robustness Check

Time Lag of R&D Spillovers

I first consider timing. As discussed earlier, the use of R&D flows could be a problem if investments in R&D take some time to bear fruit. There are two ways to remedy this problem. One is to include lagged values of past R&D investments, and the other is to construct an R&D stock. Since my sample period covers only seven years, it is difficult to construct the appropriate R&D stocks at the firm-level. As a compromise, I lagged all R&D spillover variables by one year to check robustness.

Model 2 in Appendix Table 3 presents the estimation results for one year lagged independent variables. Note that lagging independent variables by one year means that I lose 13,547 observations for manufacturing and 11,398 observations for non-manufacturing. By and large, the results are similar to those obtained in Table 3 although some variables lose their significance level. In manufacturing, robust results are obtained in a firm's own R&D activity, machinery imports, firm-level FDI, and industry-level FDI. In non-manufacturing, robust results are obtained in a firm's own R&D activity and firm-level FDI. Positive spillovers through domestic and foreign patents are no longer confirmed in non-manufacturing firms.

=== Appendix Table 3 ===

Next, I consider the effects on longer-term growth. The benefit of considering longer-term growth is that it reduces the influence of noise. The cost of doing so reduces the number of observations. As a compromise, I experimented with three-year productivity growth. Model 3 of Appendix Table 3 shows the results of longer-term growth. Note that I lose 27,013 firms for manufacturing and 24,631 firms for non-manufacturing if I use three-year growth as a dependent variable. Independent variables except the inital TFP level are now 3-year average between year t and year $t + 2$.

In manufacturing, the results are almost the same as those of Model 1 in Table 3, indicating positive and significant signs in a firm's own R&D activity, machinery imports, and both firm-level and industry-level FDI. On the other hand, in non-manufacturing, robust results are obtained only in a firm's own R&D and imports.

Alternative Measurement of FDI

Next, I turn to the issue of FDI measurement. As Keller and Yeaple (2004) argued, measurement matters. 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 techonology spillovers through FDI, focusing on employment of foreign-owned firms.[16] 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 firm i.[17] 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.

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

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

Models 4-6 in Appendix Table 3 present the results of alternative measures of FDI. In both manufacturing and non-manufacturing, the results are generally the same as those of the baseline model (Model 1) except for the effects of industry-level R&D spillovers through FDI. In manufacturing, the coefficient indicates positive sign though it is not significant. In non-manufacturing, negative and significant effects of FDI are observed.

These results become generally consistent with the findings of Keller and Yeaple (2004) and Aitken and Harrison (1999). However, I could not find positive effects of partial foreign ownership. In terms of AIC and BIC, Models 4-6 perform worse than the baseline model (Model 1 in Table 3) in manufacturing but not in non-manufacturing. In manufacturing, both AIC and BIC in Models 4-6 are much higher than those which obtained in the baseline model. In non-manufacturing, however, AIC and BIC obtained in Models 4-6 are

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

[17]Since my data set cannot distinguish FDI from portfolio investment, I aggregate the foreign equity share for firms with more than 10 percent equity share by foreign firms to remove the effects of portfolio investments.

slightly lower than those which in the baseline model. Thus my results might indicate that the spillover channels are different between manufacturing and non-manufacturing. R&D activity is an important channel in manufacturing sector. On the other hand, employment is more important than R&D activity as a channel of the spillovers.

Omitted Variable Bias

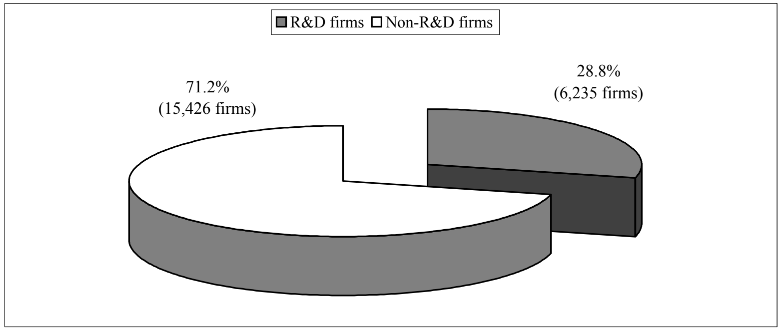
Finally, I examine the effects of omitted variables. So far I have examined several channels of intranational and international R&D spillovers, some of which have not been examined in previous studies. If the regression equation is estimated without relevant variables, there will be a so-called omitted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

Appendix Table 4 presents the estimation results, which indicate how sensitive the coefficients are when some variables are omitted. I obtain relatively robust results for all but patent variables. Although the coefficients of machinery imports and FDI present change slightly, the results are almost the same as those that obtained in the baseline model, retaining high significance levels. On the other hand, the coefficients of domestic and foreign patent variables are sensitive to the omission of other variables as both of the patent variables become significantly positive in manufacturing while foreign patent variables become significantly positive in non-manufacturing. My results thus suggest that the effects of omitted variable bias exist: the coefficients of patent variables are sensitive to the omitted variable while those of trade and FDI are not. Furthermore, both AIC and BIC presented in Appendix Table 4 are higher than those which obtained in the baseline model, implying that the baseline model performs better than the models without some variables.

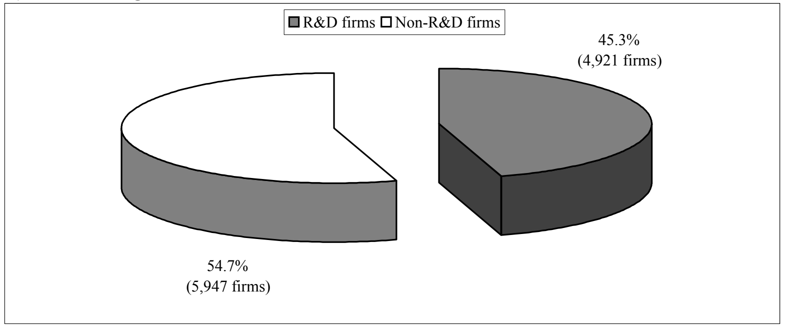
=== Appendix Table 4 ===

Figure 1. R&D Firms Versus Non-R&D Firms

A) All industry



B) Manufacturing



C) Non-manufacturing

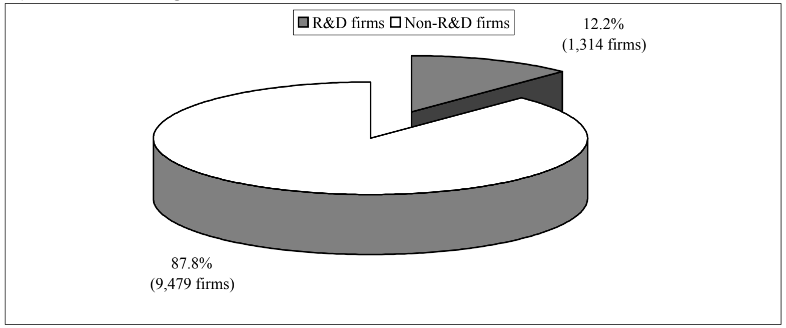
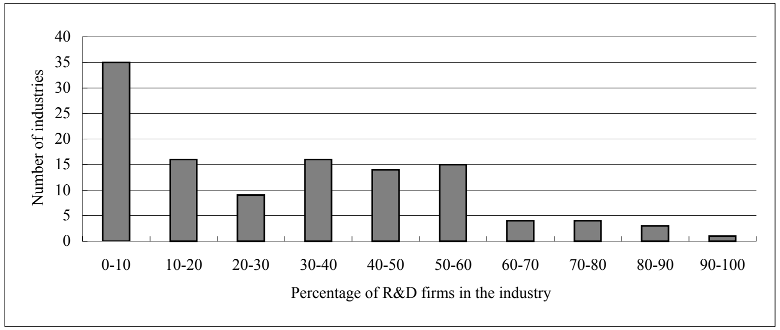
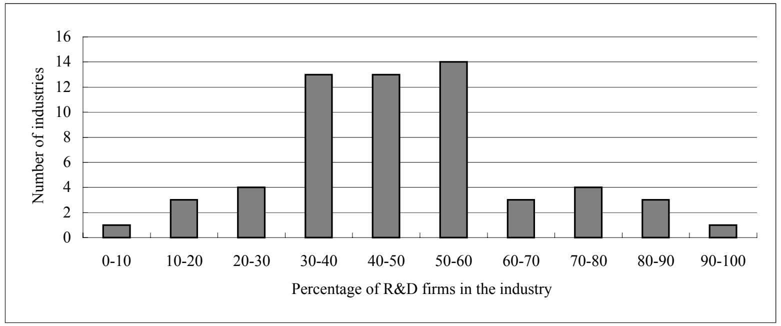


Figure 2. Industry Intensity of R&D Firms

A) All industry



B) Manufacturing



C) Non-manufacturing

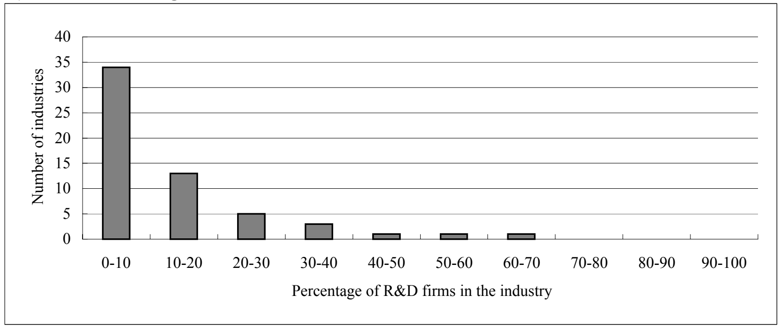


Table 1. Performance Gap between R&D Firms and Non-R&D Firms

All industry	coefficient	standard errors (s.e.)	N	R^2
TFP	0.01*	[0.004]	153,147	0.02
Labor productivity	0.01*	[0.004]	153,147	0.01
Manufacturing	coefficient	s.e.	N	R^2
TFP	0.01	[0.005]	82,043	0.02
Labor productivity	0.01	[0.005]	82,043	0.02
Non-manufacturing	coefficient	s.e.	N	R^2
TFP	0.02*	[0.007]	71,104	0.02
Labor productivity	0.02*	[0.008]	71,104	0.00

Notes: 1) Fixed-effect model is used for estimation. All regression includes year and industry dummies (not reported).
2) * indicates level of significance at 5%.
3) Estimated coefficients indicate the gaps of each variable between R&D firms and non-R&D firms.
4) Labor productivity is defined as per-capita value-added.

Source: METI Database.

Table 2. Total Factor Productivity (TFP) and R&D Spillover Variables

(Mean)

Manufacturing		1994	1995	1996	1997	1998	1999	2000
TFP	lnTFP	-0.062	-0.042	-0.020	-0.051	0.013	0.059	0.023
$R\&D^O$	Firm's own R&D (% of sales)	0.868	0.842	0.848	0.858	0.946	0.951	0.914
$R\&D^D$	Industry R&D (% of sales, industry average)	1.361	1.743	1.757	1.685	1.550	1.344	1.389
$Patent^D$	Patent payments to domestic firms (% of sales)	0.017	0.014	0.012	0.012	0.014	0.016	0.014
IMP	Machinery imports (% of sales)	0.064	0.082	0.107	0.140	0.153	0.169	0.189
$Patent^F$	Patent payments to foreign firms (% of sales)	0.014	0.014	0.016	0.014	0.014	0.012	0.013
FDI^{firm}	Foreign equity share (%)	1.754	0.929	0.901	0.901	1.455	1.645	1.594
FDI^{ind}	R&D by foreign-owned firms (% of sales, industry average)	0.680	0.416	0.270	0.454	0.740	0.944	1.111
Non-manufacturing		1994	1995	1996	1997	1998	1999	2000
TFP	lnTFP	-0.092	-0.034	0.006	0.030	-0.016	0.009	0.068
$R\&D^O$	Firm's own R&D (% of sales)	0.108	0.118	0.107	0.111	0.121	0.126	0.138
$R\&D^D$	Industry R&D (% of sales, industry average)	0.111	0.170	0.153	0.175	0.163	0.134	0.232
$Patent^D$	Patent payments to domestic firms (% of sales)	0.002	0.001	0.003	0.008	0.003	0.006	0.002
IMP	Machinery imports (% of sales)	0.004	0.004	0.005	0.006	0.006	0.007	0.007
$Patent^F$	Patent payments to foreign firms (% of sales)	0.001	0.002	0.002	0.002	0.002	0.002	0.002
FDI^{firm}	Foreign equity share (%)	1.447	0.980	0.901	0.772	1.699	1.869	1.748
FDI^{ind}	R&D by foreign-owned firms (% of sales, industry average)	0.105	0.093	0.072	0.106	0.127	0.149	0.136

Note: TFP is a chain index from the hypothetical firm in 1994 (equal to zero: TFP=1 and therefore lnTFP=0).

Source: METI Database.

Table 3. Effects of R&D Spillovers on Productivity Growth

Dependent variable: TFP growth		Manufacturing			Non-manufacturing		
		Model 0	Model 1	Model 1	Model 0	Model 1	Model 1
lnTFP		-0.290**	-0.297**	-0.285**	-0.217**	-0.239**	-0.239**
		[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]
Firm's own R&D activity							
$R\&D^{O}$	Firm's own R&D	0.892**	0.445**	0.728**	1.105**	1.216**	1.041**
		[0.084]	[0.087]	[0.135]	[0.188]	[0.188]	[0.373]
Intranational R&D spillovers							
$R\&D^{D}$	Industry R&D	0.058	0.390	4.833	0.605	0.468	-0.544
		[0.397]	[0.396]	[3.844]	[0.784]	[0.779]	[3.535]
$Patent^{D}$	Payments to domestic patents	1.297	1.363	3.909	2.019*	1.887*	0.278
		[0.729]	[0.727]	[2.067]	[0.951]	[0.945]	[2.486]
International R&D spillovers							
IMP	Machinery imports	1.109**	0.996**	0.850**			
		[0.212]	[0.212]	[0.297]			
$Patent^{F}$	Payments to foreign patents	2.178*	1.701	1.094	6.344*	6.308*	7.986
		[0.895]	[0.893]	[1.648]	[3.122]	[3.101]	[6.692]
FDI^{firm}	Foreign equity share (Firm-level FDI)	0.170**	0.134**	0.154**	0.189**	0.173**	0.181**
		[0.019]	[0.019]	[0.029]	[0.016]	[0.016]	[0.022]
FDI^{ind}	R&D by foreign-owned firms (Industry-level FDI)	0.976*	1.238**	10.198*	0.977	1.088	4.002
		[0.423]	[0.422]	[4.287]	[1.085]	[1.077]	[3.773]
Constant		-0.024	-0.183**	-0.189**	0.022	0.080	0.088
		[0.012]	[0.018]	[0.032]	[0.104]	[0.104]	[0.119]
Firm characteristics		No	Yes	Yes	No	Yes	Yes
Year dummies		Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies		Yes	Yes	Yes	Yes	Yes	Yes
Estimation method		ML	ML	IV	ML	ML	IV
Observations		64,617	64,617	50,142	44,397	44,397	30,563
Number of firms		14,205	14,205	12,875	12,379	12,379	10,613
Log-likelihood		-32419.8	-32227.5	---	-17508.3	-17204.2	---
Akaike Information Criterion (AIC)		64985.7	64607.0	---	35156.6	34554.4	---
Schwarz (Bayesian) Information Criterion (BIC)		65648.2	65296.8	---	35765.7	35189.5	---
R-squared		---	---	0.339	---	---	0.340

Notes: 1) ML: Maximum likelihood random-effect model is used for estimation. IV: Instrumental variable method is used for estimation.
2) All regressions include year and industry dummies (not reported).
3) ** and * indicate level of significance at 1% and 5% respectively, and figures in brackets indicate standard errors.
4) Firm characteristics are the number of workers, firm age, and capital-labor ratio.

Source: METI Database.

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

Dependent variable: TFP growth

		High-tech manufacturing industry			
	All workers	more than 300 workers	More than 500 workers	More than 1000 workers	More than 2000 workers
lnTFP	-0.332**	-0.346**	-0.338**	-0.328**	-0.236**
	[0.004]	[0.008]	[0.010]	[0.014]	[0.019]
Firm's own R&D activity					
$R\&D^O$ Firm's own R&D	0.618**	0.307	0.195	0.295	-0.007
	[0.101]	[0.159]	[0.194]	[0.245]	[0.347]
Intranational R&D spillovers					
$R\&D^D$ Industry R&D	0.389	0.180	-0.361	-1.739	-1.051
	[0.424]	[0.763]	[1.036]	[1.373]	[1.721]
$Patent^D$ Payments to domestic patents	1.648*	3.095	5.400	7.201*	14.172**
	[0.798]	[2.196]	[2.807]	[3.475]	[5.051]
International R&D spillovers					
IMP Machinery imports	1.123**	0.223	-0.098	-0.396	-1.209
	[0.215]	[0.368]	[0.479]	[0.578]	[0.654]
$Patent^F$ Payments to foreign patents	1.572	1.844	2.858	2.218	3.606
	[0.999]	[1.406]	[1.852]	[2.094]	[2.285]
FDI^{firm} Foreign equity share (Firm-level FDI)	0.136**	0.105**	0.081*	0.063	0.087
	[0.022]	[0.033]	[0.037]	[0.043]	[0.047]
FDI^{ind} R&D by foreign-owned firms (Industry-level FDI)	0.644	0.806	0.166	-2.028	-2.903
	[0.458]	[0.821]	[1.081]	[1.454]	[1.751]
Constant	-0.012	-0.052	-0.062	0.047	-0.160
	[0.027]	[0.056]	[0.080]	[0.121]	[0.222]
Firm characteristics	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes
Observations	29,497	8,948	5,654	2,801	1,282
Number of firms	6,530	1,872	1,157	584	260
Log-likelihood	-14708.6	-4229.1	-2805.9	-1277.2	-313.6
Akaike Information Criterion (AIC)	29495.2	8536.2	5689.9	2632.3	703.2
Schwarz (Bayesian) Information Criterion (BIC)	29818.6	8813.1	5948.8	2863.9	899.1

Notes: 1) Following Branstetter (2001), we define 'high-tech industry' as the chemicals, machinery, electronics, transportation, and precision instruments manufacturing industries.

2) For other notes and sources, see Table 3.

Appendix Table 1. List of Industries

Industry	Industry	Industry
Manufacturing	41 Miscellaneous fabricated metal products	81 Household appliance stores
1 Livestock products	42 Metal working machinery	82 Drug and toiletry stores
2 Seafood products	43 Special industry machinery	83 Fuel stores
3 Flour and grain mill products	44 Office, service industry and household machines	84 Miscellaneous retail trade
4 Miscellaneous foods and related products	45 Miscellaneous machinery and machine parts	85 General eating and drinking places
5 Soft drinks, carbonated water, alcoholic, tea and tobacco	46 Industrial electric apparatus	86 Agriculture
6 Prepared animal foods and organic fertilizers	47 Household electric appliances	87 Forestry
7 Silk reeling plants and spinning mills	48 Communication equipment and related products	88 Fisheries and aquaculture
8 Woven fabric mills and knit fabrics mills	49 Electronic data processing machines, digital and analog computer, equipment and accessories	89 Construction
9 Dyed and finished textiles	50 Electronic parts and devices	90 Gas, electricity and water supply
10 Miscellaneous textile mill products	51 Miscellaneous electrical machinery equipment and supplies	91 Road freight transport
11 Textile and knitted garments	52 Motor vehicles, parts and accessories	92 Warehousing
12 Other textile apparel and accessories	53 Miscellaneous transportation equipment	93 Travel agency
13 Sawing, planting mills and plywood products	54 Medical instruments and apparatus	94 Miscellaneous transport
14 Miscellaneous manufacture of wood products, including bamboo and	55 Optical instruments and lenses	95 Telecommunications
15 Manufacture of furniture and fixtures	56 Watches, clocks, clockwork-operated devices and parts	96 Finance and insurance
16 Pulp and paper	57 Miscellaneous precision instruments and machinery	97 Real estate agencies
17 Paper worked products	58 Ordnance and accessories	98 Real estate managers
18 Newspaper	59 Miscellaneous manufacturing industries	99 Laundries
19 Publishing industry	**Non-manufacturing**	100 Automobile parking
20 Printing and allied industries	60 Wholesale trade (textile products except apparel, apparel accessories and notions)	101 Photographic studios
21 Chemical fertilizers and industrial inorganic chemicals	61 Wholesale trade (apparel, apparel accessories and notions)	102 Hotels, boarding houses and other lodging places
22 Industrial organic chemicals	62 Wholesale trade (metal mining)	103 Legitimate theatres and performances and theatrical companies
23 Chemical fibers	63 Wholesale trade (coal and lignite mining)	104 Sports facilities
24 Oil and fat products, soaps, synthetic detergents, surface-active agents and paints	64 Wholesale trade (crude petroleum and natural gas production)	105 Automobile repair services
25 Drugs and medicines	65 Wholesale trade (non-metallic mineral mining)	106 Machinery and furniture repair services
26 Miscellaneous chemical and allied products	66 Wholesale trade (agricultural, animal and poultry farm and aquatic	107 Rental and leasing services
27 Petroleum refining	67 Wholesale trade (food and beverages)	108 Computer programming and other software services
28 Miscellaneous petroleum and coal products	68 Wholesale trade (building materials)	109 Data processing and information services
29 Plastic products, except otherwise classified	69 Wholesale trade (chemicals and related products)	110 Advertising
30 Tires and inner tubes	70 Wholesale trade (minerals and metals)	111 Engineering
31 Miscellaneous rubber products	71 Wholesale trade (recovered material)	112 Commercial and engineering design services
32 Manufacture of leather tanning, leather products and fur skins	72 Wholesale trade (machineries)	113 Building maintenance services
33 Glass and its products	73 Wholesale trade (furniture, fixtures and house furnishings)	114 Display services
34 Cement and its products	74 Wholesale trade (drugs and toiletries)	115 Education
35 Miscellaneous ceramic, stone and clay products	75 Wholesale trade (agents and brokers)	116 Research and development
36 Iron and steel	76 Miscellaneous wholesale trade	117 Amusement park
37 Miscellaneous iron and steel	77 Retail trade (dry goods, apparel and apparel accessories)	
38 Smelting and refining of non-ferrous metals	78 Retail trade (food and beverage)	
39 Non-ferrous metals worked products	79 Retail trade (motor vehicles and bicycles)	
40 Fabricated constructional and architectural metal products, including fabricated plate work and sheet metal work	80 Retail trade (furniture, household utensil and household appliance)	

Appendix Table 2. Summary Statistics

Basic Statistics

Variable		Manufacturing *N*	Mean	S.E.	Non-manufacturing *N*	Mean	S.E.
TFP	lnTFP	64,617	0.001	0.588	44,397	0.012	0.592
$R\&D^O$	Firm's own R&D	64,617	0.009	0.021	44,397	0.001	0.010
$R\&D^D$	Industry R&D	64,617	0.016	0.013	44,397	0.002	0.003
$Patent^D$	Payments to domestic patents	64,617	0.000	0.002	44,397	0.000	0.002
IMP	Machinery imports	64,617	0.001	0.008	44,397	0.000	0.000
$Patent^F$	Payments to foreign patents	64,617	0.000	0.002	44,397	0.000	0.001
FDI^{firm}	Foreign equity share	64,617	0.013	0.089	44,397	0.016	0.111
FDI^{ind}	R&D by foreign-owned firms	64,617	0.006	0.010	44,397	0.001	0.003

Correlation Matrix

		TFP	$R\&D^O$	$R\&D^D$	$Patent^D$	IMP	$Patent^F$	FDI^{firm}	FDI^{ind}
TFP	lnTFP	1	0.079	0.089	-0.004	0.098	0.018	0.167	0.102
$R\&D^O$	Firm's own R&D	0.136	1	0.056	0.036	0.052	0.126	0.053	0.117
$R\&D^D$	Industry R&D	0.100	0.315	1	0.014	0.018	0.010	0.016	0.209
$Patent^D$	Payments to domestic patents	0.020	0.086	0.035	1	0.045	0.266	0.046	0.024
IMP	Machinery imports	0.057	0.096	0.094	0.011	1	0.045	0.247	0.035
$Patent^F$	Payments to foreign patents	0.052	0.114	0.072	0.045	0.068	1	0.249	0.050
FDI^{firm}	Foreign equity share	0.107	0.134	0.080	0.009	0.145	0.054	1	0.042
FDI^{ind}	R&D by foreign-owned firms	0.070	0.206	0.246	0.010	0.139	0.019	0.060	1

Note: 1) Shaded cells indicate non-manufacturing sector.
2) Number of observations is 64,617 for manufacturing and 44,397 for non-manufacturing.

Appendix Table 3. Robustness Check: Effects of R&D Spillovers on Productivity Growth, Manufacturing

Dependent variable: TFP growth		Manufacturing					Non-manufacturing				
		Model 2 lagged-variables	Model 3 3-year growth	Model 4 Keller and Yeaple, 2003	Model 5 Aitken and Harrison, 1999	Model 6 Javorcik, 2004	Model 2 lagged-variables	Model 3 3-year growth	Model 4 Keller and Yeaple, 2003	Model 5 Aitken and Harrison, 1999	Model 6 Javorcik, 2004
lnTFP		-0.286**	-0.259**	-0.297**	-0.298**	-0.298**	-0.222**	-0.173**	-0.239**	-0.239**	-0.239**
		[0.003]	[0.002]	[0.003]	[0.003]	[0.003]	[0.004]	[0.003]	[0.003]	[0.003]	[0.003]
Firm's own R&D activity											
R&D^{O}	Firm's own R&D	0.573**	0.433**	0.446**	0.444**	0.445**	0.877**	0.593**	1.208**	1.210**	1.217**
		[0.097]	[0.070]	[0.087]	[0.087]	[0.087]	[0.216]	[0.129]	[0.188]	[0.188]	[0.188]
Intranational R&D spillovers											
R&D^{D}	Industry R&D	-0.004	0.207	-0.041	-0.609	-0.567	-0.204	0.734	0.236	0.261	0.385
		[0.286]	[0.190]	[0.369]	[0.337]	[0.340]	[0.533]	[0.395]	[0.782]	[0.777]	[0.781]
Patent^{D}	Payments to domestic patents	1.651*	0.047	1.358	1.371	1.370	0.276	0.068	1.864*	1.862*	1.865*
		[0.770]	[0.068]	[0.727]	[0.727]	[0.727]	[1.365]	[0.080]	[0.944]	[0.944]	[0.944]
International R&D spillovers											
IMP	Machinery imports	0.991**	0.611**	1.001**	0.999**	1.000**					
		[0.262]	[0.168]	[0.212]	[0.212]	[0.212]					
Patent^{F}	Payments to foreign patents	1.261	1.182	1.690	1.672	1.673	4.952	5.204*	6.323*	6.320*	6.322*
		[0.956]	[0.732]	[0.893]	[0.893]	[0.893]	[3.283]	[2.345]	[3.101]	[3.101]	[3.101]
FDI^{firm}	Foreign equity share (Firm-level FDI)	0.126**	0.103**	0.134**	0.136**	0.136**	0.159**	0.100**	0.174**	0.174**	0.175**
		[0.021]	[0.028]	[0.019]	[0.019]	[0.019]	[0.018]	[0.032]	[0.016]	[0.016]	[0.016]
FDI^{ind}	R&D by foreign-owned firms (Industry-level FDI)	1.153**	1.886**				1.000	1.417*			
		[0.314]	[0.210]				[0.829]	[0.673]			
FDI_KY^{ind}	Employment by foreign-owned firms (Industry-level FDI)			0.048					-0.067		
	(Keller and Yeaple, 2003)			[0.030]					[0.046]		
FDI_AK^{ind}	Foreign equity share (Industry-level FDI)				-0.055					-0.210*	
	(Aitken and Harrison, 1999)				[0.049]					[0.092]	
FDI_Jp^{ind}	Foreign equity share, partial ownership (Industry-level FDI)					-0.389					-0.441*
	(Javorcik, 2004, partial ownership)					[0.393]					[0.174]
FDI_Jf^{ind}	Foreign equity share, full ownership (Industry-level FDI)					-0.046					-0.132
	(Javorcik, 2004, full ownership)					[0.050]					[0.105]
Constant		-0.164**	-0.177**	-0.182**	-0.175**	-0.173**	0.080	0.084	0.079	0.081	0.081
		[0.020]	[0.014]	[0.018]	[0.018]	[0.018]	[0.111]	[0.070]	[0.104]	[0.104]	[0.104]
Firm characteristics		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations		51,070	37,604	64,617	64,617	64,617	32,998	19,766	44,397	44,397	44,397
Number of firms		12,992	11,747	14,205	14,205	14,205	10,905	9,079	12,379	12,379	12,379
Log-likelihood		-24811.4	18737.3	-32230.5	-32231.2	-32230.8	-12028.8	11501.0	-17203.6	-17202.1	-17200.9
Akaike Information Criterion (AIC)		49774.8	-37326.5	64613.0	64614.3	64615.6	24201.5	-22861.9	34553.2	34550.2	34549.7
Schwarz (Bayesian) Information Criterion (BIC)		50446.7	-36694.9	65302.8	65304.1	65314.5	24806.7	-22309.5	35188.4	35185.4	35193.6

Notes: 1) All independent variables except lnTFP and firm characteristics are lagged one-year in Model 2. The dependent variable is the annual average of three years rather than one year in Model 3. Models 4 and 5 test the alternative measure of industry-level FDI.

2) For other notes and sources, see Table 3.

Appendix Table 4. Effects of Omitted Variables

Dependent variable: TFP growth		Manufacturing						Non-manufacturing			
		Without trade	Without patents	Without FDI	Trade only	Patents only	FDI only	Without patents	Without FDI	Patents only	FDI only
lnTFP		-0.297**	-0.297**	-0.296**	-0.296**	-0.296**	-0.297**	-0.239**	-0.234**	-0.234**	-0.239**
		[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Firm's own R&D activity											
$R\&D^O$	Firm's own R&D	0.464**	0.464**	0.465**	0.494**	0.490**	0.484**	1.277**	1.270**	1.270**	1.277**
		[0.087]	[0.087]	[0.087]	[0.087]	[0.087]	[0.087]	[0.186]	[0.188]	[0.188]	[0.186]
Intranational R&D spillovers											
$R\&D^D$	Industry R&D	0.394	0.387	-0.423	-0.424	-0.435	0.390	0.511	0.438	0.438	0.511
		[0.396]	[0.396]	[0.287]	[0.287]	[0.287]	[0.396]	[0.779]	[0.776]	[0.776]	[0.779]
$Patent^D$	Payments to domestic patents	1.474*		1.476*		1.623*			1.822	1.822	
		[0.727]		[0.727]		[0.727]			[0.946]	[0.946]	
International R&D spillovers											
IMP	Machinery imports		1.020**	1.197**	1.256**						
			[0.211]	[0.210]	[0.209]						
$Patent^F$	Payments to foreign patents	1.814*		3.102**		3.383**			7.782*	7.782*	
		[0.893]		[0.871]		[0.870]			[3.103]	[3.103]	
FDI^{firm}	Foreign equity share (Firm-level FDI)	0.146**	0.143**				0.155**	0.175**			0.175**
		[0.019]	[0.018]				[0.018]	[0.016]			[0.016]
FDI^{ind}	R&D by foreign-owned firms (Industry-level FDI)	1.258**	1.232**				1.251**	1.050			1.050
		[0.422]	[0.422]				[0.422]	[1.077]			[1.077]
Constant		-0.186**	-0.183**	-0.179**	-0.179**	-0.182**	-0.185**	0.079	0.080	0.080	0.079
		[0.018]	[0.018]	[0.018]	[0.018]	[0.018]	[0.018]	[0.104]	[0.104]	[0.104]	[0.104]
Firm characteristics		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations		64,617	64,617	64,617	64,617	64,617	64,617	44,397	44,397	44,397	44,397
Number of firms		14,205	14,205	14,205	14,205	14,205	14,205	12,379	12,379	12,379	12,379
Log-likelihood		-32238.6	-32231.2	-32258.0	-32266.6	-32274.2	-32242.8	-17209.7	-17265.8	-17265.8	-17209.7
Akaike Information Criterion (AIC)		64627.1	64610.3	64663.9	64677.2	64694.4	64631.6	34561.4	34673.5	34673.5	34561.4
Schwarz (Bayesian) Information Criterion (BIC)		65307.9	65282.0	65335.5	65330.6	65357.0	65294.2	35179.2	35291.3	35291.3	35179.2

For notes and sources, see Table 3.