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Overseas R&D Activities by Multinational Enterprises: Evidence from Japanese Firm-Level Data*

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Abstract

This paper investigates both the determinants and the impact of overseas subsidiaries' R&D activities, using firm-level panel data for Japanese multinational enterprises. We distinguish between overseas innovative and adaptive R&D and find substantial differences between the two types of R&D. The evidence suggests that overseas innovative R&D aims at the exploitation of foreign advanced knowledge, and by doing so, it helps to raise the productivity of the parent firm. In contrast, the primary role of overseas adaptive R&D is to enhance the productivity of overseas subsidiaries through the use of parent firms' knowledge. In addition, we find no complementarity between home and overseas innovative R&D, i.e., no evidence that overseas innovative R&D raises the marginal effect of home R&D on home productivity.

Keywords: overseas R&D activities, multinational enterprises, total factor productivity.

JEL classifications: F23, O30.

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1 Introduction

Overseas R&D activities by multinational enterprises (MNEs) have expanded significantly in recent years (Kuemmerle, 1999; Granstrand, 1999; Patel and Vega, 1999; Pearce, 1999; Pearce and Papanastassiou, 1999; Le Bas and Sierra, 2002). The literature also indicates that there are two types of overseas R&D: one for the utilization and acquisition of foreign advanced knowledge that would otherwise be unavailable in the home country,[1] and another for the adaptation of existing technologies and products to the local conditions of the host country.[2] We will hereafter denote the former type of overseas R&D as innovative R&D and the latter as adaptive R&D.[3]

These two types of R&D are quite different in nature and we would therefore expect that their determinants are also quite different. For example, innovative overseas R&D is most likely to be performed in technologically advanced countries. In contrast, adaptive R&D probably depends less on the level of technology and more on the market size of the host country. In addition, the impact on the productivity of the overseas subsidiary itself and of the parent firm is also likely to differ depending on which type of overseas R&D is involved. A priori, we would expect, that innovative R&D is likely to have a positive impact on the productivity of parent firms, but this is not the case with adaptive R&D.

However, such differences between the two types of overseas R&D are often ignored in the existing literature.[4] The purpose of this study therefore is to examine what factors determine firms' overseas R&D activities and how such overseas R&D activities affect the productivity of the foreign subsidiary itself and of the parent firm. In particular, we are interested in how these determinants of overseas R&D and the effects of overseas R&D differ between the two different types of R&D. To address these issues, we take advantage of a rich firm-level panel dataset for Japanese parent firms in R&D-intensive manufactur-

[1] Jaffe, Trajtenberg, and Henderson (1993) find that knowledge diffusion tends to be geographically localized.

[2] Examining U.S. MNEs, Teece (1977) finds that the costs of such adaptations account for 19 percent of total investment costs.

[3] Existing studies typically denote the former type as demand-led, home-base-exploiting, or research-oriented R&D, and the latter as supply-led, home-base-augmenting, or local-support-oriented R&D.

[4] An exception is the study by Iwasa and Odagiri (2004). See the discussion below.

ing industries and their overseas subsidiaries in both developed and developing countries for the period 1996-2001. An advantage of the dataset used in this study is that it contains information that allows us to classify each overseas subsidiary's R&D activities as innovative or adaptive R&D.

Our findings indicate wide discrepancies between overseas innovative and adaptive R&D. First, whereas the size of overseas innovative R&D is positively correlated to the host country's total factor productivity (TFP), the size of adaptive R&D is unrelated to the TFP level. Second, overseas innovative R&D improves parent firms' TFP growth as much as home R&D does; in contrast, overseas adaptive R&D has no impact on home TFP growth. Finally, overseas subsidiaries' innovative R&D does not improve subsidiaries' own TFP growth, whereas their adaptive R&D has a positive effect.

These results suggest that overseas innovative R&D is mainly aimed at the exploitation of foreign advanced knowledge and helps to raise productivity in Japan by introducing foreign knowledge at the parent firm. In contrast, the primary role of overseas adaptive R&D is to contribute to productivity in the host country by utilizing the knowledge of the parent firm rather than knowledge to be found in the host country.

We also examine whether overseas innovative R&D interacts with home R&D, or, more specifically, whether overseas innovative R&D raises the marginal effect of home R&D on home productivity growth. We call this relation the complementarity between home and overseas innovative R&D. Using the interaction term between home and overseas innovative R&D to measure this effect, we find no evidence of any such complementarity. This result suggests that parent firms and their overseas subsidiaries perform R&D independently of each other, without much interaction between them. This conclusion is supported by survey responses from Japanese MNEs (Kiba, 1996) and interviews with managers of Japanese MNEs in the United States (Tanaka, Negishi, and Sakakibara, 2000) that report weak interaction between home and overseas R&D.[5]

[5]Kiba (1996) asked 19 Japanese MNEs about the interaction between home and overseas R&D and whether this was (a) large, (b) small, (c) beginning to emerge, or (d) nonexistent. The number of replies for each of these answers was zero, five, nine, and five, respectively. Tanaka, Negishi, and Sakakibara (2000) cite the manager of the R&D institute of a Japanese electronics firm in the United States as saying that it is difficult for the R&D institute to

Our analysis builds on various strands of literature on R&D. First, this paper is most closely related to Iwasa and Odagiri (2004), who investigate the impact of R&D performed by Japanese MNEs in Japan and the United States on the extent of innovation as measured by the number of patent applications in the two countries. The second strand of literature, going back to Griliches (1980) and summarized by Mairesse and Sassenou (1991), examines the impact of own R&D at the firm level. Fors (1997) expands on this line of research by examining the impact of overseas R&D on parent firms' productivity growth using Swedish firm-level data. Third, a number of studies, using Japanese firm-level data (Odagiri and Yasuda, 1996; Belderbos, 2001) or industry-level data for the United States and Japan (Kumar, 2001), examine what determines whether MNEs engage in overseas R&D. It should be noted, however, that with the exception of Iwasa and Odagiri (2004), none of the studies cited above distinguish between innovative and adaptive R&D. Moreover, none of them consider any possible complementarity between home and overseas R&D.[6]

In addition, our study is related to the literature on international knowledge diffusion.[7] Eaton and Kortum (1996, 1999) show that knowledge flows from foreign countries are an important source of productivity growth even in technologically advanced countries. However, Jaffe, Trajtenberg, and Henderson (1993) and Branstetter (2001) find that knowledge spillovers are geographically localized, suggesting that international knowledge diffusion is costly. Empirical evidence suggests that possible channels of international knowledge diffusion include trade (Coe and Helpman, 1995; Bayoumi, Coe, and Helpman, 1999) and foreign direct investment (Lichtenberg and de la Potterie, 1998; Branstetter, 2000). Our results show a positive effect of overseas innovative R&D on home productivity growth, providing indirect evidence of knowledge diffusion from the host country to parent firms through overseas R&D. However, the extent

conduct joint research with the R&D unit of the parent firm in Japan due to the geographic and mental distance.

[6]Our paper also differs from Iwasa and Odagiri (2004) in a number of ways. For example, Iwasa and Odagiri (2004) do not examine the determinants of each type of overseas R&D. In addition, they limit their analysis to Japanese MNEs in the United States, whereas our sample includes MNEs around the world.

[7]See Saggi (2002) and Keller (2004) for comprehensive surveys of the literature on international knowledge diffusion.

of such knowledge diffusion may not be large, since we also find that overseas R&D does not improve the marginal effect of home R&D on home productivity growth.

The remainder of the paper is organized as follows. Section 2 presents the theoretical framework to generate the equations used in the estimation. The equations themselves are presented in Section 3 together with an outline of the estimation methods. Section 4 provides an explanation of the data and the variables used, while Section 5 reports our estimation results and relates them to preceding studies. Section 6 concludes.

2 Theoretical Framework

To derive estimation equations, we consider a simple theoretical framework in which MNEs improve the quality of their products by engaging in home and overseas R&D activities. The characteristics of quality improvement are similar to those in quality-ladder growth models such as that in Aghion and Howitt (2005).

We assume two countries, the home and the foreign country, without any international trade in goods. The home country is an advanced country in which parent firms have production sites, and the foreign country can be either an advanced or a less advanced country where subsidiaries of the parent firms operate.

We assume that following an improvement of the quality of their product as a result of R&D, firms enjoy monopoly power with regard to their product in the home or the foreign country for one period. Thus, each firm determines its output and price to maximize profits from production given the demand for its product. Since demand is assumed to be increasing in both the quality of the product and aggregate market size, production profits are also increasing in these two variables. Thus, we assume that the production profits for parent firm i in the home country and for its subsidiary in the foreign country in period t are given by $\pi_{it}^p = A_{it}^p y_t^p$ and $\pi_{it}^s = A_{it}^s y_t^s$, respectively. A_{it}^p and A_{it}^s are the quality of good i that is achieved by the parent firm in the home country and its subsidiary in the foreign country, respectively, in period t, whereas y_t^p and

y_t^s represent the aggregate market size of the home and the foreign country, respectively. For simplicity, we do not derive these profit functions from microfoundations, but similar results are obtained in quality-ladder growth models such as those developed by Acemoglu, Aghion, and Zilibotti (2002) and Aghion and Howitt (2005). Although firm i produces the same good in the two countries, the quality of the good may differ across countries since international knowledge diffusion is costly. For example, the quality of a Toyota Corolla made in Japan is likely to be higher than the quality of a Corolla made in Thailand.

Three types of R&D activity for quality improvement in the home and the foreign country can be distinguished: (1) R&D for innovation carried out in the home country; (2) R&D for innovation carried out in the foreign country; and (3) R&D in the foreign country for adaptation of existing technologies and products to local conditions.[8]

Each type of R&D differs in terms of what knowledge stock it utilizes and in which country it contributes to quality improvements, as summarized in Table 1. First, parent firms' innovative R&D employs their own knowledge and improves both their own product quality and that of their overseas subsidiaries. Innovative R&D at the parent firm thus involves the diffusion of knowledge from the parent firm to its subsidiary. Second, since innovative R&D in the overseas subsidiary is performed to exploit advanced knowledge that is publicly available in the foreign country, innovative R&D utilizes the public knowledge of the foreign country rather than the subsidiary's own firm-specific knowledge.[9] We assume that without overseas innovative R&D, firms in the home country have no access to the knowledge available in the foreign country. Through the exploitation of foreign knowledge, innovative R&D in the subsidiary leads to quality improvements both in the parent firm and the subsidiary. Finally, adaptive R&D carried out by foreign subsidiaries uses parent firms' knowledge and results in quality improvements in the subsidiary. However, such R&D does not

[8] A fourth type of R&D is that carried out in the home country for the adaptation of technologies and products to foreign markets. However, we do not consider this type of innovation because our dataset for Japanese firms does not allow us to distinguish between expenditures on innovative R&D and R&D for adaptation to foreign markets.

[9] For example, researchers in Japanese MNEs in Silicon Valley may be able to obtain knowledge from engineers in other firms in the Valley through formal and informal discussions.

employ the public knowledge of the foreign country since it does not target the exploitation of such foreign knowledge. Also, adaptive R&D does not employ any firm-specific knowledge of the subsidiary, since we assume that the more advanced knowledge of the parent firm is freely available to its subsidiary.

More specifically, we assume the following quality improvement functions:

$$A^p_{i,t+1} - A^p_{it} = \delta^p f\left(A^p_{it} \cdot R\&D^p_{it},\, A^{host}_{it} \cdot R\&D^{sI}_{it}\right)(A^p_{it})^{-\phi}, \tag{1}$$

and

$$A^s_{i,t+1} - A^s_{it} = \Big(\delta^s f(A^p_{it} \cdot R\&D^p_{it},\, A^{host}_{it} \cdot R\&D^{sI}_{it}) + \gamma^s(A^p_{it} \cdot R\&D^{sA}_{it})^{\lambda}\Big)(A^s_{it})^{-\phi}, \tag{2}$$

where $\delta^p > 0$, $\delta^s > 0$, $\phi \geq 0$, and $0 < \lambda < 1$. $R\&D^p_{it}$ denotes the R&D expenditure by parent firm i in the home country in period t, whereas $R\&D^{sI}_{it}$ and $R\&D^{sA}_{it}$ are the expenditures on innovative and adaptive R&D by overseas subsidiary i, respectively. A^p_{it} (A^s_{it}), defined as the quality level of the good produced in parent firm i (subsidiary i), also represents the parent firm's (the subsidiary's) current knowledge level. A^{host}_{it} represents the level of knowledge publicly available in the foreign country. The arguments of f indicate that the combination of research effort ($R\&D$) and the current knowledge (A) raises quality levels,[10] assuming $f_1 > 0$ and $f_2 > 0$. The last terms of equations (1) and (2), $(A^p_{it})^{-\phi}$ and $(A^s_{it})^{-\phi}$, indicate that as quality improves, further quality improvements become more costly due to the exhaustion of ideas. Parameter ϕ represents the magnitude of this "idea-exhaustion" effect.

Function f has two possible forms, depending on how innovative R&D at home and abroad interact with one another. In the first case, innovative R&D by the parent firm raises the marginal effect of innovative R&D conducted by its overseas subsidiary on the product quality in the subsidiary, and, conversely, innovative R&D by the subsidiary raises the marginal effect of innovative R&D by the parent on the product quality in the parent. If this relation is satisfied, f_{12}, the cross derivative of f, should be positive. We call this relation the

[10] This is a standard assumption in R&D-based growth models such as those developed by Romer (1990), Acemoglu, Aghion, and Zilibotti (2002), and Aghion and Howitt (2005). Although we specifically assume a linear combination between the As and $R\&D$ variables, assuming a nonlinear combination, for example $(A^p_{it})^{\psi} R\&D^p_{it}$, would yield the same conclusions.

complementarity between home and overseas R&D. Specifically, we assume a Cobb-Douglas form in the case of such R&D complementarity:

$$f(\bullet) = (A_{it}^{p} \cdot R\&D_{it}^{p})^{\alpha\lambda}(A_{it}^{host} \cdot R\&D_{it}^{sI})^{(1-\alpha)\lambda}, \tag{3}$$

where $0 < \alpha < 1$. The second functional form f can take represents the case in which innovative R&D by the parent firm and its subsidiary are not related to each other. In this case, i.e. where no complementarity is present, we assume

$$f(\bullet) = \alpha(A_{it}^{p} \cdot R\&D_{it}^{p})^{\lambda} + (1-\alpha)(A_{it}^{host} \cdot R\&D_{it}^{sI})^{\lambda}. \tag{4}$$

Each MNE performs home and overseas R&D in every period, since it would otherwise lose its monopoly power. Given the current public knowledge levels in the home and the foreign country and equations (1) and (2), MNE i maximizes the sum of its monopoly profits from production in the home and the foreign country minus the total costs of R&D:

$$\max_{\{R\&D_{it}^{p},\, R\&D_{it}^{sI},\, R\&D_{it}^{sA}\}} A_{i,t+1}^{p} y_{t+1}^{p} + A_{i,t+1}^{s} y_{t+1}^{s} - R\&D_{it}^{p} - R\&D_{it}^{sI} - R\&D_{it}^{sA}. \tag{5}$$

From the first-order conditions, it is not difficult to show the effects of the exogenous variables on expenditures on innovative and adaptive R&D in the foreign country. The signs of some of these effects are independent of whether home and overseas innovative R&D are complementary (i.e., f is given by equation [3] or [4]), as the following inequalities indicate:

$$\frac{\partial R\&D_{it}^{sI}}{\partial A_{it}^{s}} \leq 0, \quad \frac{\partial R\&D_{it}^{sI}}{\partial A_{it}^{host}} > 0, \quad \frac{\partial R\&D_{it}^{sI}}{\partial y_{i,t+1}^{s}} > 0, \tag{6}$$

$$\frac{\partial R\&D_{it}^{sA}}{\partial A_{it}^{s}} \leq 0, \quad \frac{\partial R\&D_{it}^{sA}}{\partial A_{it}^{host}} = 0, \quad \frac{\partial R\&D_{it}^{sA}}{\partial y_{i,t+1}^{s}} > 0, \quad \frac{\partial R\&D_{it}^{sA}}{\partial A_{it}^{p}} > 0. \tag{7}$$

The first inequalities of (6) and (7) are derived from the idea-exhaustion effect. The inequalities show that an increase in the quality level in subsidiary firms raises the costs of further quality improvements and thus lowers overseas R&D expenditures, unless $\phi = 0$, or there is no idea-exhaustion effect. The second inequalities of (6) and (7) indicate the effects of the public knowledge available in the foreign country. The effect of the public knowledge level on overseas innovative R&D is positive, since an expansion of public knowledge raises the marginal gains from innovative R&D. However, the effect of the public knowledge level on adaptive R&D is zero, since the public knowledge is not an input to adaptive R&D. The third inequalities show that the market size of the foreign country always has a positive effect on both foreign subsidiaries' innovative and adaptive R&D expenditures simply because gains from overseas R&D depend on the size of the host country market. The last inequality of (7) indicates that the knowledge of parent firms has a positive impact on the size of overseas adaptive R&D, since parent firms' knowledge is a primary input to adaptive R&D.

In contrast to these unambiguous effects, the effect of the knowledge level of each parent firm, A^p_{it}, on its overseas innovative R&D activities varies depending on whether home and overseas innovative R&D are complementary to one another. In the presence of such complementarity, we obtain

$$\frac{\partial R\&D^{sI}_{it}}{\partial A^p_{it}} \begin{cases} > 0 & \text{if} \quad \alpha\lambda - \phi > 0 \\ < 0 & \text{otherwise.} \end{cases} \tag{8}$$

There are two opposing forces that lead to this result: the effect of idea-exhaustion in parent firms with regard to product quality improvements in parent firms, which lowers the effect of A^p_{it} on $R\&D^{sI}_{it}$, and complementarity between home and overseas innovative R&D, which raises it. Therefore, the overall effect is positive if the elasticity of A^p_{it}, $\alpha\lambda$, is sufficiently large, and it is negative if the magnitude of the idea-exhaustion effect, ϕ, is sufficiently large. By contrast, in the absence of complementarity, the idea-exhaustion effect dominates, and thus we have

$$\frac{\partial R\&D^{sI}_{it}}{\partial A^p_{it}} \leq 0, \tag{9}$$

where the equality holds when $\phi = 0$. In summary, the effect of parent firms' knowledge level on the size of subsidiaries' overseas innovative R&D is positive if home and overseas innovative R&D are complementary and the idea-exhaustion effect is small.

3 Estimation Equations and Methodology

We consider three sets of estimation equations to examine the determinants of overseas R&D by Japanese MNEs and the impact of overseas R&D on parent firms' and overseas subsidiaries' productivity growth.

3.1 Determinants of Overseas R&D Activities

Inequalities (6)-(8) lead to the following equation that examines the determinants of overseas R&D:

$$\frac{R\&D^{sX}_{ijt}}{Y^s_{ijt}} = \beta^X_1 \ln A^p_{it} + \beta^X_2 \ln A^s_{ijt} + \beta^X_3 \ln A^{host}_{jt} + \beta^X_4 \ln Y^{host}_{jt} + \delta^X_{0t} + \delta^X_{1i} + \varepsilon^X_{ijt}, \tag{10}$$

for $X = I$, A, where $R\&D^{sI}_{ijt}$ and $R\&D^{sA}_{ijt}$ are expenditures on innovative and adaptive R&D by parent firm i's subsidiary in country j in year t, respectively, and Y^s_{ijt} is the subsidiary's value added.[11] Our strategy to adopt the ratio of R&D expenditure to value added represents a considerable improvement on previous studies which, due to the lack of data, had to use the number of overseas R&D units as the dependent variable (Odagiri and Yasuda, 1996; Belderbos, 2001). A^p_{it} and A^s_{ijt} are represented by the TFP levels of parent firm i and its subsidiary in country j, respectively. A^{host}_{jt} is the aggregate TFP level of country j in year t, representing the public knowledge level of the host country. Y^{host}_{jt} is the GDP of country j, indicating the market size for any good. The theoretical considerations above suggest that we should use the expected market size in the coming year, but for simplicity we assume that the expectation of each firm corresponds to the current GDP level. We also include a time-specific constant term, δ^X_{0t}, and an industry-specific constant, δ^X_{1i}, in each equation.

The theoretical results lead to the following parametric conditions. First, we expect β^I_1, the effect of the knowledge level of the parent firm on overseas innovative R&D, to be positive in the presence of complementarity between home and overseas innovative R&D and a weak idea-exhaustion effect, as indicated by inequality (8). However, β^I_1 is zero or negative in the absence of complementarity (inequality [9]). By contrast, β^A_1, the effect of the knowledge level of the parent firm on adaptive R&D, should always be positive, as shown in the last inequality of (7). These results are based on the fact that parent

[11] Although in the theoretical framework the absolute value of R&D expenditure is used, we divide R&D expenditure by value added. The reason is that although in the model firms are assumed to produce only one product, in practice the number of products a firms makes is likely to be proportional to its value added.

firms' knowledge unambiguously raises the gains from overseas adaptive R&D, but the effect of parent firms' knowledge on overseas innovative R&D depends on the presence of complementary. Second, β_2^I and β_2^A, the coefficients on subsidiaries' knowledge, are expected to be negative due to the idea-exhaustion effect. Third, β_3^I, the effect of public knowledge in the host country on overseas innovative R&D, is expected to be positive, since the prime objective of overseas innovative R&D is the exploitation of foreign advanced knowledge. However, the effect of the public knowledge in the host country on adaptive R&D, β_3^A, should be zero, since the key input in adaptive R&D is parent firms' knowledge rather than foreign public knowledge. Finally, β_4^I and β_4^A should be positive, reflecting the positive effects of the market size of the host country on the size of overseas R&D.

Since many overseas subsidiaries in our sample reported zero R&D expenditures, we start with a Tobit model to estimate equation (10). One problem with this method is that the regressors are mostly endogenous and possibly correlated with the error term. To alleviate this problem, we apply Amemiya Generalized Least Squares (AGLS) developed by Amemiya (1979), using the one-year lagged regressors as instruments.

3.2 The Impact of Overseas R&D on Home and Overseas Productivity

Next, we estimate equations (1) and (2) to examine the impact of overseas R&D on home and overseas productivity growth. Because parent firms' and subsidiaries' knowledge, A_{it}^p and A_{it}^s, determine their R&D expenditures, we reduce equations (1) and (2) to functions of $R\&D_{it}^p$, $R\&D_{it}^{sI}$, and $R\&D_{it}^{sA}$.

Accordingly, the estimation equations are given by

$$\ln A^p_{ij,t+1} - \ln A^p_{ijt} = \gamma^p_1 \frac{R\&D^p_{it}}{Y^p_{ijt}} + \gamma^p_2 \frac{\sum_j R\&D^{sI}_{ijt}}{Y^p_{ijt}} + \gamma^p_3 \frac{\sum_j R\&D^{sA}_{ijt}}{Y^p_{ijt}}$$
$$+ \gamma^p_4 \left(\frac{R\&D^p_{it}}{Y^p_{ijt}} \times \frac{\sum_j R\&D^{sI}_{ijt}}{Y^p_{ijt}} \right) + \eta^p_{0t} + \eta^p_{1i} + \nu^p_{i,t+1}, \qquad (11)$$
$$\ln A^s_{ij,t+1} - \ln A^s_{ijt} = \gamma^s_1 \frac{R\&D^p_{it}}{Y^s_{ijt}} + \gamma^s_2 \frac{R\&D^{sI}_{ijt}}{Y^s_{ijt}} + \gamma^s_3 \frac{R\&D^{sA}_{ijt}}{Y^s_{ijt}}$$
$$+ \gamma^s_4 \left(\frac{R\&D^p_{it}}{Y^s_{ijt}} \times \frac{R\&D^{sI}_{ijt}}{Y^s_{ijt}} \right) + \gamma^s_5 \left(\frac{R\&D^p_{it}}{Y^s_{ijt}} \times \frac{R\&D^{sA}_{ijt}}{Y^s_{ijt}} \right)$$
$$+ \eta^s_{0t} + \eta^s_{1i} + \nu^s_{i,t+1}, \qquad (12)$$

where η^k_{0t}, η^k_{1i}, and $\nu^k_{i,t+1}$ for $k = p, s$ are time- and firm-specific constant terms and the error term, respectively. $R\&D^p_{it}$ is represented by the R&D expenditure of parent firm i. $\Sigma_j R\&D^{sI}_{ijt}$ and $\Sigma_j R\&D^{sA}_{ijt}$ indicate the total expenditures on innovative and adaptive R&D of all of firm i's overseas subsidiaries, while Y^p_{it} and Y^s_{ijt} are the value added of parent firm i and its subsidiary in country j. Note that we use the ratio of R&D expenditures to value added to correct for variations in firm sizes, an approach that is widely used in studies on the impact of R&D on production or productivity (see, e.g., Griliches, 1980). This approach assumes a Cobb-Douglas production function and a constant ratio of R&D stocks to value added.

We expect that in equation (11) γ^p_1, the direct effect of parent firms' R&D activities on their own productivity growth, is positive. Also, γ^p_2 is positive if overseas innovative R&D has a direct effect on productivity growth at the parent firm. In addition, γ^p_3 is expected to be zero, since overseas adaptive R&D should have no impact on productivity growth at the parent firm. Finally, the coefficient on the interaction term between home and overseas innovative R&D, γ^p_4, is positive only in the presence of complementarity between home and overseas innovative R&D, as equation (3) indicates. When complementarity is absent, or equation (4) holds, γ^p_4 is expected to be zero.

With regard to equation (12), we expect that γ^s_1, γ^s_2, and γ^s_3 , which represent the direct effects of home and overseas R&D on overseas subsidiaries' productivity growth, are positive. The coefficient on the interaction term between home and overseas innovative R&D, γ^s_4, is positive only when home and overseas innovative R&D are complementary. By contrast, γ_5^s, the coefficient on the interaction term between home R&D and overseas adaptive R&D, should be unambiguously positive, since parent firms' knowledge always raises the marginal gains from overseas adaptive R&D.

By comparing the results of the estimation of equations (11) and (12) with the results of the estimation of the determinants of overseas R&D, we can check whether the three sets of results are consistent with each other. In particular, one of our primary interests is in whether or not home and overseas innovative R&D are complementary. By examining the signs of β_1^I in equation (10), γ_4^p in (11), and γ_4^s in (12), we can easily determine whether the three sets of regression results are consistent.

We start with an ordinary least squares (OLS) estimate of equations (11) and (12) and then employ a fixed-effects (within) estimation to eliminate the firm-specific constant terms. However, the regressors may not be strictly exogenous but may be predetermined in the sense that the regressors for time t, such as $R\&D_{it}^p$, are not correlated with $\nu_{i,t+1}$ but with ν_{it}. Therefore, eliminating firm-specific constants by within-transformation or first-differencing yields correlation between the error term and the regressors in the transformed regression, even though the original regression equations (11) and (12) do not have this endogeneity problem.

To eliminate any possible endogeneity, we apply the differenced generalized method of moments (GMM) estimation developed by Arellano and Bond (1991) and the system GMM developed by Blundell and Bond (1998). In the case of the differenced GMM, we take first differences of both sides of equations (11) and (12) to eliminate the firm-specific constant terms and then apply GMM estimations to the first-differenced equation, using the lagged regressors as instruments. In the system GMM estimation, we also estimate the original equations (11) and (12) by GMM, using the lagged first-differenced regressors as instruments, together with the estimation of the first-differenced equation as in the differenced GMM. The major advantage of the system GMM over the differenced GMM is that in the latter, instruments are weak if regressors have near unit root properties, whereas this problem can be alleviated in the former.

We apply two-step estimations of the differenced and system GMM to obtain larger efficiency. In addition, we use the methodology of robust standard errors developed by Windmeijer (2000), which are consistent in the presence of any pattern of heteroskedasticity and autocorrelation[12] and correct for finite sample biases found in the two-step estimations.

4 Data

4.1 Description of the Datasets

For the estimation in this paper, we combine two firm-level datasets for the period 1996-2001, one for Japanese firms, *Kigyo Katsudo Kihon Chosa* (Basic Survey of Enterprise Activities) and the other for Japanese MNEs, *Kaigai Jigyo Katsudo Kihon Chosa* (Basic Survey of Multinational Enterprises). Both datasets are collected annually by the Ministry of Economy, Trade and Industry. The year 1996 is the earliest year for which data for overseas R&D are available and the distinction between overseas innovative and adaptive R&D in a consistent manner is possible. Since the role of R&D activities may vary substantially across industries, we focus on the four 2-digit manufacturing industries with the largest average R&D expenditure (as measured by the R&D expenditure-value added ratio) among the total of 17 industries for which data are available. These four industries - chemicals, electronic and other electrical equipment, transportation equipment, and precision machinery - account for 83 percent of the total overseas value added and for 85 percent of the total overseas R&D expenditures of Japanese firms. Details of the datasets and variables used are presented in the Appendix.

Since the surveys include questions on the role of overseas R&D activities, we can classify the R&D activities of each subsidiary as innovative or adaptive according to firms' survey response.[13] Specifically, we define the R&D expendi-

[12] The differenced and the system GMM yield biases due to autocorrelation if the error term in the original equation is serially correlated so that the error term in the first-differenced equation is also serially correlated.

[13] Although data for overseas R&D are also available for 1995, the survey question asking about the role of overseas R&D was slightly different from that in other years. Probably for this reason, there was a wide discrepancy between the share of innovative R&D in total overseas R&D expenditures in 1995 and in other years. Therefore, we do not use the data for 1995.

tures reported by overseas subsidiaries as expenditures on innovative R&D if the reported functions of those R&D activities include basic research, applied research, or development for the world market. Otherwise, R&D expenditures are considered to be for adaptive R&D. Note that expenditures on innovative R&D according to this definition are likely to be overstated. This is because our data do not allow us to distinguish between expenditure on innovative and adaptive R&D at overseas subsidiaries that engage in both types. In other words, if a subsidiary reports that it engages in innovative R&D, all R&D expenditure is counted as innovative R&D expenditure though some part of the expenditure may in fact be spent on adaptive R&D.

4.2 Measuring Productivity Levels

In our estimation, the knowledge level of parent firms and overseas subsidiaries, A^p_{it} and A^s_{ijt}, is represented by their TFP levels. Firm-level TFP is given by

$$\ln A^k_{it} = \ln Y^k_{it} - \beta_K \ln K^k_{it} - \beta_L \ln L^k_{it} \qquad k = p,\, s, \tag{13}$$

where Y^k, K^k, and L^k are the real values of value added and the capital stock as well as the labor force in each firm. We assume $\beta_K = 0.289$ and $\beta_L = 0.682$, which are based on all firms in Japan for which data were available, using the methodology developed by Olley and Pakes (1996). The merit of this method is that we can eliminate biases resulting from the endogeneity of inputs and attrition of firms from the sample.[14] According to Monte Carlo studies carried out by Van Biesebroeck (2004), this method in most cases provides better estimates of TFP levels than methods using, for example, index numbers, GMM, or stochastic frontiers. These estimates suggest that the production function is very close to constant returns to scale, although we statistically reject constant returns to scale.

The aggregate TFP level of country j at time t is given by

$$\ln A^{host}_{jt} = \ln Y^{host}_{jt} - \tilde{\alpha} \ln K^{host}_{jt} - (1 - \tilde{\alpha}) \ln L^{host}_{jt}, \tag{14}$$

[14] We do not use data for overseas subsidiaries to estimate β_K and β_L, because the exit of subsidiaries may not reflect their TFP level but conditions at the parent firm. Thus, a major assumption in the Olley-Pakes procedures would be violated for overseas subsidiaries if data for overseas subsidiaries were used.

where Y_{jt}^{host}, K_{jt}^{host}, and L_{jt}^{host} are the real GDP, the real capital stock, and the labor force of country j, taken from the Penn World Tables Version 6.1 that update Summers and Heston (1991). Aiyar and Dalgaard (2004) find that for cross-country TFP, the simple method using equation (14) with $\tilde{\alpha} = 1/3$ is "a very good approximation to a more general formulation under which countries have different aggregate production functions which do not require a constant elasticity of substitution between factors" (ibid.: 15). Following cross-country estimates by Islam (2003), we assume $\tilde{\alpha} = 0.3742$, which might be a better estimate of $\tilde{\alpha}$ than 1/3.

4.3 Summary Statistics

Our unbalanced panel data for overseas subsidiaries to examine the determinants of overseas R&D has 2,017 observations. Of these, 621 subsidiaries reported positive R&D expenditures whereas the rest reported zero R&D expenditures. Among the 621 observations, 330 reported positive innovative and 332 reported positive adaptive R&D expenditure.[15] 364 out of the 621 subsidiaries with positive R&D expenditures were located in OECD countries, with 209 performing innovative and 186 performing adaptive R&D. Summary statistics of the variables used in the estimation are shown in Table 2. On average, overseas subsidiaries spent 1.16 percent of value added on R&D in total, which divides into 0.70 percent for innovative and 0.46 percent for adaptive R&D. It should be noted, however, that the standard deviation of these percentages is large, indicating a substantial variation among subsidiaries.

When estimating the impact of overseas R&D on home and overseas productivity growth, we use balanced panels of Japanese parent firms and overseas subsidiaries. By using balanced rather than unbalanced panels, we can use the same number of instruments for each observation in the same year in the differenced and system GMM estimations. The panel data for parent firms includes observations on 133 firms, while that for subsidiaries includes observations on 82 firms. The number of firms in the panels is substantially smaller than in the

[15]The sum of the number of observations for firms with innovative and adaptive R&D expenditure exceeds the total number of firms reporting positive R&D expenditure because some subsidiaries engage in innovative R&D in one branch and in adaptive R&D in another.

original datasets because very few firms reported R&D expenditures in every year during the period 1996-2001.

Among the 665 ($= 133 \times 5$) observations for Japanese parent firms for the period 1996-2000, the reported R&D expenditures for all observations are positive, whereas the reported R&D expenditures by overseas subsidiaries are positive for 245 observations. Summary statistics of the variables used are shown in Table 3. The average R&D expenditure of parent firms is 10.7 percent of value added, while the average overseas R&D expenditure is 0.48 percent of parent firms' value added. These figures suggest that the level of overseas R&D is substantially smaller than the level of home R&D, although, as can be seen in Table 4, overseas R&D has been increasing over time.

In the balanced panel of overseas subsidiaries, 199 observations among 410 ($= 82 \times 5$) show positive R&D expenditures. The summary statistics are presented in Table 5. The average ratio of overseas R&D expenditures to the value added of overseas subsidiaries is 1.9 percent, which is larger than the average ratio in the unbalanced panel for the regression of the determinants of overseas R&D. This probably reflects the tendency that firms which report R&D expenditures every year are more R&D-intensive than those that report only occasionally.

5 Estimation Results

5.1 Determinants of Overseas R&D Activities

The results on the determinants of overseas R&D activities using the unbalanced panel data are reported in Table 6 and are mostly consistent with the theoretical predictions derived from inequalities (6)-(9). We first focus on the estimates for innovative R&D. The results using Tobit and AGLS are reported in columns (1) and (2). The first row shows that parent firms' TFP level, A^p, has no significant effect on overseas subsidiaries' expenditures on innovative R&D. According to the theoretical results shown by equations (8) and (9) in Section 2, this result suggests that parent firms' knowledge has no impact on the marginal effect of overseas innovative R&D on the TFP growth in parent firms, or innovative R&D in Japan and abroad are not complementary.

The second row indicates that the extent of overseas innovative R&D is negatively correlated with the current TFP level of the overseas subsidiary, A^s, indicating that R&D may be more costly due to the idea-exhaustion effect when the knowledge level is already high.

The third row shows that the public knowledge level of the host country, A^{host}, has a positive effect on the level of innovative R&D, suggesting that Japanese firms try to exploit foreign advanced knowledge through innovative R&D. This effect is substantial, implying that an increase in A^{host} by 44 percent, the standard deviation of A^{host} shown in Table 2,[16] raises the ratio of innovative R&D expenditures to value added by 1.9 percentage points.

Finally, the market size of the host country represented by its total GDP, Y^{host}, has a positive effect. This market-size effect is also substantial: an increase in Y^{host} by one standard deviation, 146 percent (see Table 2), is associated with a 1.6-percentage-point increase in the innovative R&D ratio.

Next, we examine the results for adaptive R&D, which are reported in columns (3) and (4) of Table 6. There are two major differences between the results for innovative and adaptive R&D. First, while parent firms' TFP level has no significant effect on overseas subsidiariesf innovative R&D level, it does have a significant positive effect on the level of adaptive R&D carried out by subsidiaries. This result is consistent with the theoretical prediction implied by the last inequality in (7) and confirms that parent firms' knowledge is the primary input to overseas adaptive R&D.

Second, the Tobit estimation indicates that the effect of host country TFP on adaptive R&D, though significant, is substantially smaller than on innovative R&D; moreover, the effect is statistically insignificant in the AGLS estimation. This finding suggests that overseas adaptive R&D does not employ public knowledge of the host country, or does so to a lesser extent than overseas innovative R&D, which, in turn, confirms that the primary role of this type of overseas R&D is adaptation rather than the exploitation of foreign knowledge.

The results for the coefficients on $\ln A^s$ and $\ln Y^{host}$ are not very different from the ones for innovative R&D. Namely, we find weak evidence of the

[16]This difference corresponds to the gap in the TFP level between, say, Algeria and the Republic of Korea in the year 2001.

idea-exhaustion effect: the coefficient on $\ln A^s$ is again negative, though it is insignificant in the AGLS estimation. Finally, as in the previous estimation, the market-size effect is positive, although it is slightly smaller than in the case of innovative R&D.

Since, as discussed above, the amount of innovative R&D expenditure by overseas subsidiaries is likely to be overestimated, we add together overseas innovative and adaptive R&D expenditures and estimate the determinants of total overseas R&D in order to check the robustness of our results. The results, reported in columns (5) and (6) of Table 6, generally fall between the results for innovative and adaptive R&D separately.

In summary, the major determinant of overseas innovative R&D by Japanese MNEs appears to be the level of public knowledge in the host country, whereas the most important determinant of adaptive R&D is the knowledge level of the parent firm. These findings are consistent with Iwasa and Odagiri (2004) who find that knowledge sourcing is the primary purpose of overseas innovative R&D but not of overseas adaptive R&D. The market size of the host country has an influence on the extent of both innovative and adaptive R&D, confirming the results obtained by Odagiri and Yasuda (1996), Belderbos (2001), and Kumar (2001).

5.2 The Impact of Overseas R&D on Home TFP Growth

To examine the direct effect of each type of overseas R&D on TFP growth of parent firms in Japan, we begin by excluding the interaction term from equation (11) for the sake of simplicity. Columns (1) to (4) of Table 7 report the results of the OLS, fixed-effects, and differenced and system GMM estimations.

In each GMM estimation, the Hansen J statistic (the minimized value of the two-step GMM criterion function) is reported to test overidentifying restrictions, or the orthogonality between instruments and the error term. In addition, the difference between the Hansen J statistics from the two types of GMM is reported to test whether additional instruments used in the system GMM are orthogonal to the error term. According to the Hansen statistics and their difference, the instruments used in both GMM estimations are valid. Moreover, the p value of the difference Hansen statistic is sufficiently large, suggesting that the additional instruments in the system GMM are valid. Therefore, the system GMM is the preferred specification among the four, and we will focus on the results from that method.

The effect of the size of parent firms' R&D activities, $R\&D^p/Y^p$, on their own TFP growth is positive and significant, indicating that an increase in R&D expenditures by one percentage point is associated with a 1.29-percent increase in the TFP level. This is larger than existing estimates for Japanese manufacturing firms, such as those by Odagiri and Iwata (1986) and Goto and Suzuki (1989), which arrive at an increase in the TFP level by less than 0.5 percent. However, because their estimates are obtained using OLS and our OLS result in column (1) is close to the estimates of those previous studies, the larger effect in the system GMM estimation may be the result of eliminating the firm-specific constant term and correcting for endogeneity.

Also, overseas innovative R&D, $\Sigma R\&D^{sI}/Y^p$, has a positive and significant effect on home TFP growth, and the effect is similar in magnitude to the effect of home R&D. By contrast, overseas adaptive R&D, $\Sigma R\&D^{sA}/Y^p$, exhibits no significant impact on home TFP growth. These results confirm our presumption on the role of overseas innovative and adaptive R&D.

Next, to test for the presence of complementarity between home and overseas innovative R&D, we include their interaction term as an additional regressor.[17] The results are reported in columns (5)-(8) of Table 7. According to the Hansen and difference Hansen statistics, the preferred specification is again the system GMM. While the result for the effect of home R&D is similar to the previous result, neither overseas innovative R&D nor its interaction term with home R&D has a significant effect, as shown in columns (5)-(8).[18] These results suggest that while overseas innovative R&D has a direct effect on home TFP growth, it is not complementary to home R&D in the sense that overseas innovative R&D

[17] We omit overseas adaptive R&D, since we found that it has no significant impact.

[18] The inclusion of the interaction term eliminates the positive direct effect of overseas innovative R&D previously found, probably due to multicollinearity between the regressors. Therefore, we eliminate $\Sigma R\&D^s/Y^p$ from the regressors for another set of regressions, while keeping the interaction term. However, the results, which are available on request, indicate that the effect of the interaction term is again insignificant.

does not improve the marginal impact of home R&D on home TFP growth. We therefore conclude that parent firms in Japan and their overseas subsidiaries are performing innovative R&D independently, without close interaction with one another.

These results suggest that overseas innovative R&D stimulates knowledge diffusion to production sites of parent firms and raises productivity in home production. However, overseas innovative R&D does not stimulate knowledge diffusion to home R&D units, since it does not raise the productivity of home R&D. In other words, knowledge diffusion does in fact take place through overseas R&D, but its magnitude may not be large.

Since overseas R&D is a form of foreign direct investment (FDI), our results are comparable to previous findings on international knowledge diffusion through FDI. Lichtenberg and de la Potterie (1998), using country-level data, find that domestic TFP is improved by the weighted sum of foreign R&D capital stocks where the volume of FDI is used as a weight. Another study along these lines is that by Branstetter (2000), who uses patent citation data for Japanese MNEs in the United States. He finds that Japanese MNEs cite more US patents when they have a larger number of affiliates or R&D units in the United States. Our results on the diffusion of knowledge through overseas R&D thus confirm the results of these studies on knowledge diffusion through FDI more generally. In addition, our conclusion that home and overseas R&D are not complementary conforms with the study by Iwasa and Odagiri (2004) which finds that overseas innovative R&D has no impact on the level of innovation of parent firms measured by the number of patent applications.

However, our results also exhibit some inconsistencies with previous studies. First, the finding of Branstetter (2000) presented above suggests that knowledge of the United States diffuses to R&D units in Japan through FDI in R&D. This seems to be at odds with the findings of this paper as well as those of Iwasa and Odagiri (2004) suggesting that overseas R&D does not improve the productivity of home R&D. One possible explanation to reconcile these different findings is that although foreign knowledge diffuses through overseas R&D to parent firms' R&D units, the knowledge fails to improve the productivity of the R&D units.

Second, Fors (1997), using Swedish firm level data, finds no evidence of positive effects of overseas R&D on home productivity growth. We suspect that reasons for the inconsistency between this result and our own comes from the fact that Fors does not distinguish between innovative and adaptive R&D; nor does he correct for any endogeneity of the R&D variables.[19]

5.3 The Impact of Overseas R&D on Overseas TFP Growth

We begin the examination of the effect of overseas subsidiaries' R&D on their TFP growth with a simplified version of equation (12) in which the interaction terms are excluded. OLS, fixed-effects, and differenced and system GMM estimations are performed, and the results are shown in columns (1)-(4) of Table 8. Since the system GMM is the preferred specification according to the Hansen and difference Hansen statistics, we will again focus on the results from that method.

The first row indicates that the effect of home R&D, $R\&D^p/Y^s$, on overseas subsidiaries' TFP growth is positive and significant. Quantitatively, the result indicates that the average amount of home R&D expenditure, which is equivalent to 943 percent of subsidiaries' value added, improves overseas TFP by 6 percent per year.

In the second row, we find that overseas innovative R&D, $R\&D^{sI}/Y^s$, has no significant effect on overseas TFP growth. From this result, combined with the finding above that overseas innovative R&D has a positive effect on home TFP growth, we may conclude that the fruits of overseas innovative R&D are mostly utilized by parent firms in the home country. This implies that $\delta^s = 0$ in equation (2), which is not intuitively plausible, but is not inconsistent with our view that the primary purpose of overseas innovative R&D is to exploit foreign advanced knowledge.

The third row shows that overseas adaptive R&D, $R\&D^{sA}/Y^s$, has a positive and significant impact. The effect is similar in size to the effect of home R&D on home TFP growth. Therefore, in contrast with overseas innovative R&D, overseas adaptive R&D has an impact on subsidiaries' but not on parent firms'

[19] When we do not correct for endogeneity, we find no significant impact of overseas innovative R&D (columns [1] and [2] in Table 7).

TFP growth, confirming that the primary role of such R&D is adaptation for the local market.

Next, we include the interaction terms between home and overseas R&D as regressors. The results are reported in columns (5)-(8) of Table 8. The results from the system GMM, which is again the preferred method, indicate that the interaction term between home and overseas innovative R&D has no significant effect. This confirms the estimation results above showing that no complementarity between home and overseas innovative R&D seems to be present.

In contrast, the interaction term between home R&D and overseas adaptive R&D is positive and significant. This result suggests that home R&D raises the marginal effect of overseas adaptive R&D, which is consistent with the assumption shown in equation (2). This assumption leads to a positive effect of parent firms' knowledge on the level of overseas adaptive R&D as shown in the last inequality of (7), which is confirmed by our estimation above on the determinants of overseas R&D. Thus, the results on the determinants and the impact of overseas R&D are consistent.

6 Conclusion

This paper investigated the determinants of R&D activities of overseas subsidiaries and the impact of these R&D activities on the productivity growth of parent firms and subsidiaries using firm-level panel data for Japanese MNEs during the period 1996-2001. We distinguished between overseas innovative R&D (basic research, applied research, and development for the world market) and adaptive R&D (R&D for other purposes) and found substantial differences between the two types of R&D. The estimation results suggest that overseas innovative R&D aims at the exploitation of foreign knowledge, and by doing so, it helps to raise the productivity of the parent firm. In contrast, the primary role of overseas adaptive R&D is to enhance the productivity of overseas subsidiaries through the adaptation of existing technologies and products to host country conditions using parent firms' knowledge. In addition, we find no complementarity between home and overseas innovative R&D, i.e., no evidence that overseas innovative R&D raises the marginal effect of home R&D on home productivity.

The estimated impact of overseas innovative R&D activities on productivity is not as large as we expected. The effect of overseas innovative R&D on parent firms' productivity growth is similar in size to the effect of parent firms' own R&D, while the impact on overseas subsidiariesf productivity growth is insignificant. Therefore, the overall impact of overseas innovative R&D on home productivity growth is smaller than that of home R&D. These results may explain why, though it has been increasing in recent years, overseas innovative R&D by Japanese MNEs is substantially smaller in magnitude than that by U.S. or European MNEs. (Belderbos, 2001). Therefore, what Japanese MNEs should do in order to maximize the benefits from overseas R&D is to promote interaction between home and overseas R&D.

Appendix: Data and Variables

This appendix provides supplementary information on the construction of our dataset. First of all, it should be noted that some parent firms have more than one subsidiary in a particular host country. For example, an automobile firm may have a subsidiary for the production of engines, one for assembly, one for sales, and one for R&D. We aggregate all subsidiaries of the same parent firm in the same country and redefine the various subsidiaries as one subsidiary. We use the industry code of each parent firm to define the industry code of its overseas subsidiaries.

The real value of each firm's capital stock in equation (13) is computed according to the perpetual inventory method. Since our original dataset starts from 1995 and book values of fixed capital for subsidiaries are available only for 1995, 1998, and 2001, we use as the initial capital stock in 1995 the book value of fixed capital in 1995 divided by the price level for investment goods in country j where the firm is located (Japan or a host country), P_t^j, which is taken from the PWT 6.1. Capital stocks in subsequent years are computed from $K_{it}^k = (1 - \tilde{\delta})K_{i,t-1}^k + I_{it}^k / P_t^j$ for $k = p$, s, where the depreciation rate, $\tilde{\delta}$, is 0.0792 taken from Masuda (2000). I_{it}^p is the reported value of parent firm i's purchases of fixed capital in year t less the reported value of its sales. However, data for overseas subsidiaries do not include sales of fixed capital; we therefore estimate them using fixed capital stocks and the average ratio of sales to the stock of fixed capital for Japanese firms.

The aggregate capital stock for each country is also computed according to the perpetual inventory method, following Hall and Jones (1999) and Caselli (2005). Initial capital stocks in 1970 are calculated according to $K_{j,1970}^{host} = I_{j,1970}^{host}/(\delta^{host} + g_j)$ where δ^{host}, the depreciation rate, is 0.06, I_{jt}^{host} is the real value of investment in country j in year t, and g_j is the average growth rate of investment between the first year with available data and 1970 for country j. Capital stocks in subsequent years are computed using $K_{jt}^{host} = (1 - \delta^{host})K_{i,t-1}^{host} + I_{jt}^{host}$.

We eliminate from our sample firms with non-positive value added or capital stocks. Then, to alleviate biases due to outliers, we drop firms of which either the growth rate of TFP or the ratio of the estimated value of capital stock to its deflated book value is among the top or bottom 1 percent. Additionally, we eliminate firms whose ratio of R&D expenditures to value added is among the top 1 percent.

The sample of parent firms is created by aggregating data for overseas subsidiaries. The number of parent firms used in the estimations is substantially smaller than the number of firms included in the original surveys, because we only selected firms that provided information on their own and subsidiariesf R&D expenditure in each year during the period 1996-2001.

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Table 1: Characteristics of the Three Types of R&D

Type of R&D	Knowledge used	Impact on the quality improvement in	
		the parent firm	the overseas subsidiary
Innovative R&D of the parent firm	Firm-specific knowledge of the parent firm	Yes	Yes
Innovative R&D of the overseas subsidiary	Public knowledge of the host country	Yes	Yes
Adaptive R&D of the overseas subsidiary	Firm-specific knowledge of the parent firm	No	Yes

Table 2: Description of Variables and Summary Statistics: Data for Overseas Subsidiaries in the Regressions for the Determinants of Overseas R&D

Variable	Description	Mean (Standard Deviation)
$\frac{R\&D^s}{Y^s}$	R&D expenditure of each overseas subsidiary (as a percentage of its value added)	1.163 (3.549)
$\frac{R\&D^{sI}}{Y^s}$	Innovative R&D expenditure of each overseas subsidiary (as a percentage of its value added)	0.703 (2.787)
$\frac{R\&D^{sA}}{Y^s}$	Adaptive R&D expenditure of each overseas subsidiary (as a percentage of its value added)	0.460 (2.273)
$\ln A^p$	Log of the TFP level of each parent firm	2.430 (0.884)
$\ln A^s$	Log of the TFP level of each subsidiary firm	2.420 (0.417)
$\ln A^{host}$	Log of the aggregate TFP level of the host country	6.162 (0.441)
$\ln Y^{host}$	Log of the aggregate GDP of the host country	13.725 (1.461)

Table 3: Description of Variables and Summary Statistics: Data for Parent Firms

Variable	Description	Mean (Standard Deviation)
$\Delta \ln A^p$	Growth rate of TFP of the parent firm (%)	2.588 (56.891)
$\frac{R\&D^p}{Y^p}$	R&D expenditure of the parent firm (as a percentage of its own value added)	10.278 (6.821)
$\frac{\sum R\&D^s}{Y^p}$	Total R&D expenditure of overseas subsidiaries (as a percentage of value added of the parent firm)	0.386 (1.239)
$\frac{\sum R\&D^{sI}}{Y^p}$	Total innovative R&D expenditure of overseas subsidiaries (as a percentage of value added of the parent firm)	0.274 (1.123)
$\frac{\sum R\&D^{sA}}{Y^p}$	Total adaptive R&D expenditure of overseas subsidiaries (as a percentage of value added of the parent firm)	0.112 (0.512)

Table 4: Means of Home and Overseas R&D Activities by Year

	$\frac{R\&D^p}{Y^p}$	$\frac{\sum R\&D^s}{Y^p}$	$\frac{\sum R\&D^{sI}}{Y^p}$	$\frac{\sum R\&D^{sA}}{Y^p}$
1996	9.24	0.18	0.14	0.04
1997	9.88	0.35	0.21	0.13
1998	11.06	0.46	0.26	0.20
1999	10.41	0.39	0.34	0.05
2000	10.81	0.55	0.42	0.13
2001	11.49	0.63	0.43	0.20

Note: See Table 2 for a description of the variables used in this table.

Table 5: Description of Variables and Summary Statistics: Data for Overseas Subsidiaries in the Regressions for the Impact of Overseas R&D

Variable	Description	Mean (Standard Deviation)
$\Delta \ln A^s$	Growth rate of TFP of the overseas subsidiary (%)	4.199 (50.178)
$\frac{R\&D^p}{Y^s}$	R&D expenditure of the parent firm (as a percentage of value added of each subsidiary)	934.446 (2329.244)
$\frac{R\&D^s}{Y^s}$	R&D expenditure of the overseas subsidiary (as a percentage of its own value added)	1.946 (4.476)
$\frac{R\&D^{sI}}{Y^s}$	Innovative R&D expenditure of the overseas subsidiary (as a percentage of its own value added)	1.210 (3.635)
$\frac{R\&D^{sA}}{Y^s}$	Adaptive R&D expenditure of the overseas subsidiary (as a percentage of its own value added)	0.736 (2.785)

Table 6: Determinants of Overseas R&D Activities

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	$\frac{R\&D^{sI}}{Y^s}$	$\frac{R\&D^{sI}}{Y^s}$	$\frac{R\&D^{sA}}{Y^s}$	$\frac{R\&D^{sA}}{Y^s}$	$\frac{R\&D^{s}}{Y^s}$	$\frac{R\&D^{s}}{Y^s}$
Estimation method	Tobit	AGLS	Tobit	AGLS	Tobit	AGLS
$\ln A^p$	-0.535	-0.201	3.534	4.619	1.629	2.431
	(0.826)	(1.077)	(0.669)**	(1.334)**	(0.584)**	(1.027)*
$\ln A^s$	-1.958	-2.483	-1.003	-1.063	-1.710	-1.949
	(0.395)**	(0.561)**	(0.291)**	(0.635)	(0.269)**	(0.504)**
$\ln A^{host}$	4.276	4.541	1.262	1.437	3.056	3.220
	(0.777)**	(0.836)**	(0.558)*	(0.942)	(0.514)**	(0.744)**
$\ln Y^{host}$	1.111	1.124	0.692	0.676	1.038	1.030
	(0.212)**	(0.220)**	(0.169)**	(0.265)*	(0.150)**	(0.206)**
No. of observations	2017	2017	2017	2017	2017	2017
Log likelihood	-1683.90		-1614.40		-2736.39	

Note: Standard errors are in parentheses. * and ** denote statistical significance at the 5 and 1 percent levels, respectively. In all specifications, year dummies are included, but the results are not reported. AGLS denotes the Amemiya Generalized Least Squares estimation. See Table 1 for a description of the variables used in this table.

Table 7: The Impact of Home and Overseas R&D Activities on Home TFP Growth

	(1) OLS	(2) Fixed-effects	(3) Differenced GMM	(4) System GMM
$\frac{R\&D^p}{Y^p}$	0.506	1.812	1.304	1.292
	(0.137)**	(0.289)**	(0.718)	(0.315)**
$\frac{\sum R\&D^{sI}}{Y^p}$	0.812	1.533	2.688	1.450
	(0.825)	(1.436)	(1.390)	(0.627)*
$\frac{\sum R\&D^{sA}}{Y^p}$	1.073	2.515	1.264	-0.405
	(1.814)	(2.281)	(1.309)	(1.461)
No. of observations	665	665	532	665
R^2	0.05	0.10		
Hansen J statistic			0.71	0.88
Difference between Hansen statistics				0.88

	(5) OLS	(6) Fixed-effects	(7) Differenced GMM	(8) System GMM
$\frac{R\&D^p}{Y^p}$	0.542	1.913	0.775	1.236
	(0.142)**	(0.297)**	(0.750)	(0.342)**
$\frac{\sum R\&D^{sI}}{Y^p}$	2.416	4.912	0.517	3.278
	(2.614)	(4.067)	(5.059)	(2.173)
$\frac{R\&D^p}{Y^p} \times \frac{\sum R\&D^{sI}}{Y^p}$	-0.107	-0.217	0.022	-0.136
	(0.164)	(0.238)	(0.250)	(0.130)
No. of observations	665	665	532	665
R^2	0.05	0.10		
Hansen J statistic			0.74	0.78
Difference between Hansen statistics				0.60

Note: The dependent variable is parent firms' TFP growth rate. Standard errors are in parentheses. * and ** denote statistical significance at the 5 and 1 percent levels, respectively. In all specifications, year dummies are included, but the results are not reported. *P* values are reported for the Hansen J statistic and the difference between the two Hansen statistics. See Table 2 for a description of the variables used in this table.

Table 8: The Impact of Home and Overseas R&D Activities on Overseas TFP Growth

	(1) OLS	(2) Fixed-effects	(3) Differenced GMM	(4) System GMM
$\frac{R\&D^p}{Y^s}$	0.0022	0.0203	0.0182	0.0066
	(0.0011)*	(0.0028)**	(0.0029)**	(0.0022)**
$\frac{R\&D^{sI}}{Y^s}$	0.0733	0.8602	-1.0223	0.5490
	(0.6815)	(1.2364)	(0.9107)	(0.9609)
$\frac{R\&D^{sA}}{Y^s}$	0.9242	2.3405	2.2092	1.6918
	(0.8875)	(1.2442)	(1.6566)	(0.6959)*
No. of observations	410	410	328	410
R^2	0.04	0.17		
Hansen			0.85	0.67
Differenced Hansen				0.22

	(5) OLS	(6) Fixed-effects	(7) Differenced GMM	(8) System GMM
$\frac{R\&D^p}{Y^s}$	0.0020	0.0201	0.0182	0.0058
	(0.0011)	(0.0028)**	(0.0025)**	(0.0017)**
$\frac{R\&D^{sI}}{Y^s}$	-0.5479	-2.3711	1.7149	-0.2186
	(1.0044)	(2.2595)	(3.1646)	(2.5799)
$\frac{R\&D^{sA}}{Y^s}$	-2.2370	-2.4728	-1.9395	-2.1994
	(1.6238)	(2.3625)	(1.6613)	(1.7293)
$\frac{R\&D^p}{Y^s} \times \frac{R\&D^{sI}}{Y^s}$	0.0009	0.0033	-0.0008	0.0008
	(0.0013)	(0.0022)	(0.0025)	(0.0021)
$\frac{R\&D^p}{Y^s} \times \frac{R\&D^{sA}}{Y^s}$	0.0037	0.0044	0.0042	0.0039
	(0.0016)*	(0.0019)*	(0.0012)**	(0.0012)**
No. of observations	410	410	328	410
R^2	0.05	0.19		
Hansen J statistic			0.89	0.70
Difference between Hansen statistics				0.20

Note: The dependent variable is overseas subsidiaries' TFP growth rate. Standard errors are in parentheses. * and ** denote statistical significance at the 5 and 1 percent levels, respectively. In all specifications, year dummies are included, but the results are not reported. *P* values are reported for the Hansen J statistic and the difference between the two Hansen statistics. See Table 4 for a description of the variables used in this table.