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ABSTRACT

A considerable share of R&D investment is due to multinational firms that simultaneously operate R&D bases at home and abroad. The existing empirical literature on R&D investment has however ignored the possibility that domestic and foreign R&D investments are simultaneously decided. In this paper, we draw on the technological opportunity, appropriability, and demand framework suggested by Cohen and Klepper (1996) to develop a simple model of foreign and domestic R&D investment. We test the model's predictions concerning the ratio of foreign to domestic R&D investment on a sample of 146 Japanese multinational firms' R&D investments in Japan and the United States in 1996. The empirical results confirm that the foreign R&D ratio depends on relative technological opportunities, relative demand conditions, and a proxy for firm-level R&D productivity. When differentiating between research and development activities, foreign research is driven by technological opportunity and foreign development by the demand factor, as expected.

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1. Introduction

Over the past three decades, a large body of empirical literature has developed on the determinants of R&D investment.[1] Much attention has been paid to the Schumpeterian hypotheses of the roles of firm size and market structure (concentration) in determining R&D investment (Cohen and Klepper, 1994; Levin, 1984; Pakes and Shankerman, 1984; Acs and Isberg, 1991) and the Schmooklerian hypothesis of a major impact of potential demand and consumers' willingness to pay for innovations (e.g. Goto et al., 1998; Cohen and Klepper, 1996). Other work on firm-level R&D investment has examined the impact on R&D investment of technological opportunity conditions and the extent to which results from innovative activities can be appropriated (Goto et al, 1998; Crépon et al., 1998; Levin and Reiss, 1984). The findings have given broad support for the relevance of demand, appropriability and opportunity conditions in determining R&D. On the role of firm size, Cohen and Klepper (1996) suggest that large firms are less productive in R&D, but are able to sustain larger R&D expenditures because they expect higher, scaleable, returns to innovation.

The empirical studies of R&D investments have limited analysis to domestic R&D investment in the firms' home base, ignoring the role of overseas R&D operations within multinational firms. Evidence suggests, however, that this role has been substantial in the 1990s. US multinationals increased R&D spending abroad from 5.2 billion US dollars in 1987 to 14.1 billion dollars in 1997. The latter figure was 11 percent of total R&D expenditures in the US. (Dalton et al., 1999). For Japanese multinational firms, reported overseas R&D in a survey by Japan's Ministry of Economics, Trade, and Industry stood at 279 billion Yen in 1997 increasing to 411 billion Yen in 2002, with the ratio of overseas to domestic R&D reaching 4.1 percent. At the firm level, Gassman and von Zedtwitz (2002) find much higher foreign R&D ratios for leading multinational firms. Since R&D decisions in both domestic and overseas plants and laboratories are not independently taken, these investment decisions should be analyzed simultaneously, as suggested in an early contribution by Mansfield (1984).

Only few studies have examined (particular aspects of) the interdependence of domestic and foreign R&D. Fors (1996) analyzed the productivity effects of domestic and foreign R&D in Swedish firms. He found that domestic R&D impacts growth in foreign subsidiaries, but found no evidence of a reverse effect of overseas R&D. Hines (1995) is concerned with possible substitution between R&D in overseas affiliates and technology transfer (based on home-based R&D efforts) from the parent to overseas affiliates. He finds evidence that the relative use of licensing and local R&D is sensitive to

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[1] See Cohen and Levinthal (1989), Cohen (1995), and Griliches (1995), for surveys of the literature.

levels of withholding and corporate taxes in different countries. Although a growing management literature on intra-firm knowledge transfer and international R&D has examined the determinants of overseas R&D investments and innovative activities as evidence by patent applications (e.g. Belderbos, 2001; 2003; Kuemmerle, 1997; Frost, 2001; Florida, 1997), this literature has not paid attention to the possible interaction with domestic R&D investment. These studies have suggested that foreign R&D is motivated both by the need to exploit and adapt the investing firms' technology to local demand and manufacturing conditions, as well as the need to get access to local science and technology resources (technology sourcing). Most of these studies have concluded that foreign R&D activities are becoming more important vehicles to access local technological expertise abroad. For instance, findings in Frost (2001) suggests that geographic proximity matters substantially for technology sourcing and spillovers: foreign firms' subsidiaries were found to cite significantly more often research by other institution and firms in the same US state than their own parent firm. Similar findings were obtained by Almeida (1996) for the semiconductor industry. These findings relate to a larger body of literature on the degree of localization of spillovers and know-how (e.g. Audretsch and Feldman, 1996). Jaffe et al. (1993) found that being close to an external information source increases the impact of spillovers from that source on internal technological capabilities and know-how. All this suggests that multinational firms are seeing a presence in foreign markets as a necessary commitment to access and assimilate local know-how where technological opportunity conditions are favorable.

In this paper we develop and test a simple model within an appropriability, opportunity and demand framework where R&D investment at home and abroad are decided on simultaneously. We adapt a model of Cohen and Klepper (1996) in which R&D investment is evaluated by its effect on the firms' price cost margins. Levels of R&D investment in the two locations are driven by relative demand conditions and relative technological opportunity conditions, which differ across industries and firms. We test the model on a sample of Japanese multinational firms' R&D investments in Japan and the USA in 1996, using census data from Japan's Ministry of Economy, Trade and Industry (METI).

The remainder of this paper is organized as follows. The next section presents the model of domestic and foreign R&D investment, Section 3 describes the data, Section 4 presents the empirical results and section 5 concludes.

2. A model of domestic and foreign R&D investment

We adapt the model of Cohen and Klepper (1996) to derive domestic and foreign R&D investment functions. Firm i in industry j decides on domestic and foreign R&D investment r_i and r_i^* by evaluating the effect on the price-cost margin of its operations in the domestic and foreign market, pc_i

and pc_i^* (an asterisk refers to the foreign market and foreign operations). R&D can be either process oriented and cost reducing, or product oriented and quality improving (increasing the price the firm can obtain for its products). We allow domestic R&D to have an impact on the foreign price cost margin and vice versa, with $pc_i{'}(r_i), pc_i{'}(r_i^*), pc_i^*{'}(r_i), pc_i^*{'}(r_i^*) > 0$. It is assumed that the effect on the price cost margin lasts for one period, after which imitation by rival firms erodes the firm's advantage. A period is defined as the length of time during with R&D earns the firm rents. The return on R&D depends on the output (demand) to which the increase in the price-cost margin applies during this period. Let these volumes be denoted by x_i and x_i^*. The firm maximizes total profits, which is the sum of profits of domestic and foreign operations minus R&D expenditures at home and abroad.

(1) $\Pi_i = x_i\, pc_i(r_i, r_i^*) + x_i^*\, pc_i^*(r_i, r_i^*) - r_i - r_i^*$

Where the price cost margin is defined as:

(2) $pc_i(r_i, r_i^*) = \alpha r_i{}^{\rho} n_i A_j{}^{\gamma} O_j{}^{\delta} + \beta r_i^{*\rho} n_i^* A_j{}^{\gamma} O_j^{*\delta}$

(3) $pc_i^*(r_i, r_i^*) = \alpha^* r_i{}^{\rho} n_i A_j^{*\gamma} O_j{}^{\delta} + \beta^* r_i^{*\rho} n_i^* A_j^{*\gamma} O_j^{*\delta}$

Both R&D expenditures at home and abroad have an impact on the price cost margin, with the parameter pairs α, β and α^*, β^* indicating the relative effectiveness of domestic and foreign technological knowledge in improving the price cost margin. If international technology transfer within the firm is costly and knowledge generated is more effectively used locally (e.g. in case of development efforts for the local market), $\alpha > \alpha^*$ and $\beta^* > \beta$. R&D impacts through local technological opportunity conditions O_j, as well as the appropriability conditions A_j. Opportunity conditions matter in the country where R&D is performed, but appropriability conditions matter in the country where R&D results lead to improved processes and/or products. Equations (2) and (3) have a number of properties of a CES function with $1/(1-\rho) = \sigma$ the elasticity of substitution between foreign and domestic R&D, requiring $0 \le \rho < 1$. This implies that the relationship between R&D and the price cost margin is characterized by decreasing returns to scale.[2] We allow for firm-level differences in the rate of return to R&D by multiplying with productivity indicators n_i, n_i^* as in Cohen

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[2] Evidence for decreasing returns to scale in R&D has among others been found in Acs and Audretsch (1991). The direct relationship between the elasticity of substitution and the scale parameter helps to keep the first order conditions and derived model for estimation tractable.

and Klepper (1996). This productivity is allowed to differ between domestic and foreign R&D. The derivative of the domestic price cost margin with respect to domestic R&D is:

$$(4) \quad pc_i{}'(r_i) = n_i\, A_j{}^{\gamma}\, O_j{}^{\delta}\, \alpha \rho r_i{}^{\rho-1}$$

This derivative is akin to the most general model in Cohen and Klepper (1996) and shows decreasing returns to R&D. Similar expressions can be derived for the derivatives of the domestic price cost margin with respect to foreign R&D and the derivatives of the foreign price cost margin with respect to both domestic and foreign R&D. Substituting (2) and (3) in (1) and differentiating (1) with respect to domestic and foreign R&D using these derivatives gives, after some rearranging and takings natural logarithms:

$$(5) \quad \ln r_i = \sigma \ln \rho + \sigma \ln n_i + \delta\sigma \ln O_j + \gamma\sigma \ln A_j + \sigma \ln\!\left(\alpha\, x_i + \frac{A_j^{*\gamma}}{A_j^{\gamma}} \alpha^* x_i^* \right)$$

$$(6) \quad \ln r_i^* = \sigma \ln \rho + \sigma \ln n_i^* + \delta\sigma \ln O_j^* + \gamma\sigma \ln A_j^* + \sigma \ln\!\left(\beta^* x_i^* + \frac{A_j^{\gamma}}{A_j^{*\gamma}} \beta\, x_i \right)$$

Where $\sigma = 1/(1-\rho)$ is the elasticity of substitution between domestic and foreign R&D. Equations (5) and (6) state that foreign (domestic) R&D is a function of firm-level R&D productivity abroad (at home), technological opportunity conditions abroad (at home) in the industry in which the firm is active, and a term combining foreign and domestic demand weighted by relative appropriability conditions in the industry at home and abroad and the effectiveness parameters α, β and α^*, β^*. We can simplify equations (5) and (6) by making a not too restrictive assumption concerning appropriability conditions. Differences in appropriability conditions between countries, to the extent that they are due to national legal and policy institutions, are largely national in character but vary less across industries. For convenience we assume that the difference in appropriability conditions abroad and at home is constant over industries, where c denotes this ratio:

$$(7) \quad \frac{A_j}{A_j^*} = c \quad \text{for any } j.$$

We cannot observe firm level differences in productivity of R&D (n_i, n_i^*) but such differences are likely to be reflected in differences in the firms' past relative growth rates (Cohen and Klepper, 1996), assuming that productivity differences are relatively stable over time. We define the firm level

productivity index as the deviation of the firm's growth rate from the industry average, in the following manner:

(8) $n_i = ae^{b\hat{q}_i}$, with $\hat{q}_i = \dot{q}_i - \dot{Q}_j$

(9) $n_i^* = a^* e^{b\hat{q}_i^*}$, with $\hat{q}_i^* = \dot{q}_i^* - \dot{Q}_j^*$

Where Q indicates industry sales, a dot indicates past growth. Substituting (7)-(9) in (5) and (6) gives:

(10) $\quad \ln r_i = \sigma\Omega + \delta\sigma \ln O_j + \gamma\sigma \ln A_j + b\sigma \hat{q}_i + \sigma \ln(x_i + \frac{\varepsilon}{c} x_i^*)$

(11) $\quad \ln r_i^* = \sigma\Omega^* + \delta\sigma \ln O_j^* + \gamma\sigma \ln A_j^* + b\sigma \hat{q}_i^* + \sigma \ln(x_i^* + c\eta x_i)$

where $\Omega = \ln\rho + \ln a + \ln\alpha$, $\Omega^* = \ln\rho + \ln a^* + \ln\beta^*$, $\varepsilon = \alpha^*/\alpha$, and $\eta = \beta/\beta^*$. The parameter ε ($0 < \varepsilon \le 1$) indicates the relative effectiveness of domestic R&D in affecting the foreign price cost margin relative to the domestic price cost margin. If ε is small then foreign demand does not have a big impact on domestic R&D, since the effectiveness of domestic R&D when the results are transferred abroad is limited. Similarly, η ($0 < \eta \le 1$) indicates the relative effectiveness of foreign R&D for the domestic price cost margin compared to its application to foreign production. From (10) and (11) it is easy to derive the determinants of the ratio of foreign to domestic R&D:[3]

(12) $\quad \ln(r_i^*/r_i) = \Omega' + \delta\sigma \ln(O_j^*/O_j) + b\sigma(\hat{q}_i^* - \hat{q}_i) + \sigma \ln(x_i^* + c\eta x_i) - \sigma \ln(x_i + \frac{\varepsilon}{c} x_i^*)$

where $\Omega' = \sigma(\Omega^* - \Omega) + \gamma\sigma \ln c$ is a composite constant term. The last two terms in (12) are not linear. It is useful to linearize the equations by making use of the following approximation around ln (1):

(13) $\quad \ln(x_i + \frac{\varepsilon}{c} x_i^*) = \ln[x_i + x_i^* + (\frac{\varepsilon}{c} - 1)x_i^*] = \ln(x_i^* + x_i) + \ln[(1 + (\frac{\varepsilon}{c} - 1)\frac{x_i^*}{x_i^* + x_i}] \cong$

$\quad \ln(x_i + x_i^*) + (\frac{\varepsilon}{c} - 1)\frac{x_i^*}{x_i^* + x_i}$

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[3] Note that through (7), appropriability conditions do not affect the ratio between foreign and domestic R&D and A has dropped out of equation (12).

If we follow a similar procedure for $\ln(x_i^* + c\eta x_i^*)$ we obtain:

$$(14) \qquad \ln(x_i^* + c\eta x_{}) \cong \ln(x_i^* + x_i) + (c\eta - 1)\frac{x_i}{x_i^* + x_i}$$

Substituting (13) and (14) in (12) making use of $\dfrac{x_i}{x_i^* + x_i} = 1 - \dfrac{x_i^*}{x_i^* + x_i}$, we get:

$$(15) \qquad \ln(r_i^* / r_i) = \Omega'' + \delta\sigma \ln(O_j^* / O_j) + b\sigma(\hat{q}_i^* - \hat{q}_i) + \sigma(2 - \frac{\varepsilon}{c} - c\eta)]\frac{x_i^*}{x_i^* + x_i}$$

where $\Omega'' = \Omega' + \sigma(\eta - 1)$. The last term in equation (15) shows that the relative size of demand in the foreign market affects the ratio of foreign to domestic R&D stronger if near-market R&D activities are more effective (η and ε small). The impact of ε and η depends on relatively appropriability conditions (c). For instance, if domestic appropriability conditions are better (c>1), the impact of foreign R&D applicability in the domestic market (η) is greater, but the impact of domestic R&D applicability in the foreign market (ε) is smaller.

Finally we have to substitute for x_i and x_i^*. We follow earlier work (e.g. Cohen and Klepper, 1996) in approximating the output level over which the increased price cost margin by the existing level of firm output, augmented by expected demand growth in the industry:

$$(16) \qquad x_i = g q_i (1 + d\dot{Q}_j)$$
$$(17) \qquad x_i^* = g q_i^* (1 + d\dot{Q}_j^*)$$

The expected output level depends on the firm's existing sales and the past growth in industry sales $\dot{Q}_j$. Past growth in the industry as proxy for expected demand growth captures the demand pull effect on R&D.[4] Though not essential for the estimation, it is useful to simplify the resulting expression for the demand ratio:[5]

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[4] This relationship is less strong in case substantial returns can be earned by licensing technologies (Cohen and Klepper, 1996; Pakes and Shankerman, 1984). An alternative specification would be to add the ratio of licensing revenues over R&D expenditure per industry as a measure of the potential licensing sales, treating licensing as a new line of business with minimal production cost.

$$(18) \quad \frac{x_i^*}{x_i^* + x_i} = \frac{q'_i \, (1 + d\hat{Q}_j^*)}{(1 - q'_i)(1 + d\hat{Q}_j) + q'_i (1 + d\hat{Q}_j^*)} = q'_i \, \frac{1 + d\hat{Q}_j^*}{1 + (1 - q'_i)d\hat{Q}_j + q'_i \, d\hat{Q}_j^*}$$

$$\cong q'_i + q'_i (1 - q'_i)(\dot{Q}_j^* - \dot{Q}_j)$$

where $q' = q_i^* / (q_i + q_i^*)$.[6] The foreign to domestic ratio is equal to the foreign to domestic firm sales ratio plus the difference in the industry growth rate abroad and at home, with the latter term having the most significant impact if foreign and domestic sales are equal. Substituting (18) in (15), we obtain the following linear equation for estimation:

$$(19) \quad \ln(r_i^* / r_i) = \Omega'' + \delta\sigma \ln(O_j^* / O_j) + b\sigma(\hat{q}_i^* - \hat{q}_i) + \sigma(2 - \frac{\varepsilon}{c} - c\eta)[q'_i + q'_i(1 - q'_i)(\dot{Q}_j^* - \dot{Q}_j)]$$

3. Data and Descriptive Statistics

We apply the model to the R&D investments by Japanese multinational firms in Japan and in the US in 1996. The US is by far the most important location for overseas R&D by Japanese multinational firms, and was in 1996 responsible for more than 60 percent of all Japanese overseas R&D. Our main source of data is the survey of Trends in Business Activities of Foreign Affiliates conducted by the Ministry of Economy, Trade and Industry in fiscal year 1996 (the year ending March 31, 1997). This survey contains information on the overseas affiliates of Japanese firms, including their expenditure on R&D. This official survey is regulated under the Statistics Law of Japan and received a response rate of 78 percent at the affiliate level.[7] The responses are seen as representative and include large numbers of major multinational firms. From this survey we select parent firms active in manufacturing industries and operating at least one affiliate in the US. A further selection had to be made of the response rate for the R&D question is relatively low. Our analysis requires that for parent firms with multiple affiliates, reliable data are available on R&D for all such affiliates, in order to calculate overall R&D expenditures by the parent in the US. Furthermore we need to establish growth in US operations of the parent firm, for which we calculate sales of US affiliates in fiscal years 1994 and 1996. A number of parent firms in the 1996 had not responded to the 1994 survey, further reducing the sample for analysis. Finally we require accurate data on R&D expenditures by the parent

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[5] Making use of the property $(1 + a)/(1 + b) \cong 1 + a - b$ if a and b are close to zero (as will be the case for the industry growth rates).

[6] The coefficient g from (16) and (17) drops out of the foreign to domestic demand equation.

[7] Affiliates are included in the survey if the Japanese firm owns at least 10 percent of equity.

firm in Japan, which are (not in all cases) available from the Basic Survey of Business Enterprises. In total this left us with 146 parent firm observations. Total R&D expenditure in the US by these firms was 75.3 billion (about 700 million US dollars in 1996 exchange rates) our of a total reported R&D expenditure by Japanese firms in the US of 214 billion Yen. Among the 146 firms, 64 had zero R&D expenditures in the US. The firms are distributed over industries and regions in a roughly similar manner as the total population of Japanese firm active in the US. Table 1 shows the distribution over industries defined at the two-digit ISIC level (third revision). Industries with the largest numbers of firms are non-electric machinery, electrical machinery, motor vehicles, Radio/TV & telecommunication equipment, and chemicals, while no firms are active in wood & furniture and aircraft.

Variable definitions

The variables in equation (19) are defined as follows:

r_i^* = total R&D investment of US affiliates of the firm in 1996;

r_i = R&D investment of the Japanese parent firm in Japan 1996;

q_i = (unconsolidated) sales of the Japanese parent firm in 1996;

q_i^* = total sales of US affiliates of the firm in 1996;

$\dot{q}_i$ = percentage growth in Japanese sales of the parent firm between 1994 and 1996;

$\dot{q}_i$ = percentage growth in total sales of US affiliates of the firm between 1994 and 1996;

O_j = average growth ratio in the number of US patent grants on innovations in Japan in the 2-digit ISIC industry of the parent firm, 1994-1995, 1995-1996, 1996-1997;

O_j^* = average growth ratio in the number of US patent grants on innovations in the 2-digit ISIC industry of the parent firm, 1994-1995, 1995-1996, 1996-1997;

$\dot{Q}_j$ = percentage growth 1994-1996 in production of the 2-digit ISIC industry in Japan;

$\dot{Q}_j^*$ = percentage growth 1994-1996 in production of the 2-digit ISIC industry in the US.

Unconsolidated sales data of the Japanese parent firms are drawn from the METI survey in 1994 and 1996, as are the figures on total sales by the firms' US affiliates in 1994 and 1996. As proxy for technological opportunity we take the average growth in patent grants (1994-1997) to inventors in the US and Japan, respectively, in the ISIC industry in which the firm is active. [8] The growth in

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[8] Industries were assigned to the parent firm by aggregating the more detailed industry classification for the parent used by METI to 2-digit ISIC revision three level. All parent firms in the sample had affiliates in the US operating in the same ISIC industry as the parent firm in Japan, although a number operated additional affiliates in other manufacturing industries, usually in closely related sectors (e.g. electrical machinery vs. communication

patenting active is likely to be a suitable proxy for technological opportunity as fast growth in patented technologies indicates rapid technological developments that are likely to lead to appropriable benefits.[9] A three year period, 1994-1997, appears a suitable horizon to measure growth in innovative activities relevant to 1996 R&D investment decisions. Since patents are granted with a 1-3 year lag, grants in 1997 will reflect innovation activity in 1994-1996. The patent grants are assigned to US or Japanese residents on the basis of the address of the inventor listed in the patent information. Patents are assigned to ISIC industries based on the MERIT patent to industry concordance, adapted to third revision ISIC classifications. This concordance attaches to each international patent classification code (IPC, describing the technological domain of the patent) a probability that it is originating in a specific ISIC industry, based on the industries of applicant firms. Data on production growth in the ISIC manufacturing industries in the US and Japan were drawn from the OECD STAN Database for Industrial Analysis. Production figures for the US were converted into Yen. All 1994 nominal values (firm-level R&D in the US and Japan and industry production figures) were converted into 1996 prices using the GDP deflator.

The indicators of technological opportunity and industry demand growth for the ISIC industries in the US and Japan are shown in Table 2. In the US, average patent growth in 1994-1997 reached 20-25 percent in the food & drinks industry (including parts of biotechnology sector) and drugs & medicines, followed by office and computing equipment (14 percent). In Japan the patent growth rate has been smaller overall, with the largest growth rates for electrical machinery (7 percent), professional & optical goods (6 percent). In these and a number of other industries featuring positive patent growth (e.g. motor vehicles, publishing) Japanese patent growth rates exceed those in the US. US production growth rates in the period (expressed in Yen in 1996 prices) are positive for all industries.[10] The highest production growth rates are reported for computing equipment and radio, TV and communication equipment, and marginal growth rates for the textiles industry. Japanese growth rate differ more markedly across industries, with shipbuilding as well as textiles & clothing declining, but computing equipment and radio TV and communication equipment showing rapid growth.

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equipment), and some performed R&D in distribution affiliates or separately incorporated research laboratories. Separating R&D performed in those 'diversified' affiliates from R&D performed in affiliates operating in the same ISIC industry did not affect the results markedly.

[9] Underlying such rapid growth rates are more basic scientific research efforts. A number of other studies of domestic R&D investments have been able to use the importance firms attach to various sources of scientific information for the firms' innovation process as an alternative measure of technological opportunity (e.g. Crepon et al., 1998; Goto et al., 1998). Such data on technological opportunity which could be drawn from Japanese and US innovation surveys are however not publicly available at the industry level. Since our model contains the log of the ratio in growth rates, we can not use percentage growth rates (as these can take negative values). Instead we calculate the average of the growth rates in each period 1994-1995, 1995-1996, 1996-1997, by taking the percentage growth rate +1).

[10] This in part reflects an appreciation of the dollar between 1994 and 1996 (from 102 to 108 Yen per dollar).

Table 3 contains the means and standard deviations of the variables to be included in the empirical model. One problem in estimating equation (19) is that we have a substantial number of firms reporting zero R&D in the US, while the logarithmic form for the dependent variable rules out zero values for the US to Japan R&D ratio. One solution to this problem is to assume that all Japanese firms with US affiliates will engage in some kind of limited adaptation of products, which remains unreported as R&D. Kleinknecht (1987) and Roper (1999) find that small and medium sized enterprise engage in process and product development efforts but do not report this in official surveys. In overseas affiliates of Japanese firms likewise no accounting system may be in place to record developments efforts that are taking place, if such efforts are very limited. We assume that all firms with US affiliates underreport R&D expenditures by a very small amount, leading to a small ratio of US to Japanese R&D expenditures: we add a ratio of 0.1 percent for all firms.[11] An alternative solution to the zero R&D problem is to omit these cases and estimate the model for firms with strictly positive US R&D expenditures. This limits the number of observations and variation in the sample, but allows for a consistency check of the results.

Overall (including the firms with zero US R&D investment), the US to Japan R&D ratio reached 3.6 percent for the 146 firms. A number of firms reported R&D expenditures in the US amounting to more than half of R&D performed in Japan, with a maximum of 80 percent. The opportunity and demand variables are greater than zero, reflecting that for most firms, US demand prospects and US technological opportunities exceeded demand prospects and technological opportunities in Japan.

4. Empirical Results

The results of the estimation of equation (19) are presented in table 4. The first column presents results with all 146 firms included. The second column presents results with only firms included that reported non-zero US R&D investment. Overall, the empirical results confirm the validity of the theoretical model, although the model explains only a modest share of variation in the US to Japan R&D ratio (an adjusted R-square of 0.149 in the full sample model). The full sample model shows significant positive impacts for our measure of technological opportunity and the demand factor. In addition, the firm-level R&D productivity measure is positive and significant at the 10 percent level. If the analysis is limited to firms with non-zero R&D expenditures in the US, the estimated coefficients remain positive but are reduced in magnitude. Only the demand term remains significant and the model as a whole is barely significant (at the 10 percent level).

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[11] Choosing a different value of unreported R&D (e.g. 0.01 percent) does not alter the sign and significance of results markedly, neither does using Tobit analysis taking into account left censoring.

Given that the estimated coefficients from (19) are composite terms it is not possible to infer values of the parameters of the model unambiguously. Moreover, the magnitude of the estimated coefficients is sensitive to the value chosen for 'unreported' R&D, requiring further caution in the interpretation of the results. This choice does not affect the (smaller) estimated coefficients for the positive US R&D sample, such that those estimates may be considered more conservative. If we take the coefficients from the positive R&D sample, the demand coefficient of 3.8 requires an underlying value of the elasticity of substitution between foreign and domestic R&D ($\sigma = 1/(1-\rho)$) close to 2. In combination with a opportunity coefficient of 2.4, this may suggest either increasing returns to opportunity ($\delta > 1$) and relatively low costs of transfer of technology from the US to Japan and vice versa (α, β close to 1), or a higher value for σ closer to 3. These values for σ imply decreasing returns to scale in R&D with ρ in the range of 0.5-0.7.

Extension: Research vs. Development Activities

Empirical studies on international R&D have shown that tasks of foreign R&D laboratories and factory level R&D activities can often be separated between research on the one hand and (local) development on the other (e.g. Florida, 1997, Kuemmerle, 1997). Research activities are seen to me motivated by access to foreign science and technology while development activities are conducted to adapt products and processes to local markets and manufacturing circumstances. Kuemmerle (1997) coins the former home base augmenting R&D and the latter home base exploiting R&D. Research activities are drawn abroad by foreign technological opportunities but development activities to a much lesser extent. Furthermore, development activities tend to be geared to the specificities of the foreign market and the resulting knowledge is likely to be less applicable at home, while the fruits of research activities are more likely to be transferable to other markets. Hence, it is useful to refine the model by making a distinction between overseas research activities on the one hand, and overseas development activities on the other. The METI survey asks affiliates for the (multiple) purpose(s) of R&D, distinguishing between basic or applied research or development and design of products and processes for local or international markets. Given that affiliates often mention multiple purpose we cannot assign R&D expenditures to research or development uniquely, but the data allow us to make a rough decomposition over the different types of R&D activities in the US. We treat the R&D expenditures of affiliates answering that they engaged in research activities (either in combination or without development expenditures) to the parent expenditures in the US as 'research'. Affiliates that do not report to be engaged in research are treated as being engaged in development activities only.[12]

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[12] This method was chosen because in practice, affiliates only engaging in research are very rare, while it is more common that affiliates only engage in development activities. In principle we would also wish to separate research from development activities in Japan, as part of R&D will be more specific to the Japanese market, but here we lack suitable data.

We can expect the results of development expenditures to be less transferable to domestic operations, implying a parameter η close to zero and a strong demand effect. Development activities are neither expected to substitute for domestic R&D efforts, implying a low σ. In contrast, σ is expected to be high and η closer to 1 for research activities, leading to a weaker demand effect and a stronger opportunity effect.

Results of regression analysis distinguishing research expenditures and development expenditures in the US are reported in Table 5, in columns 1-2 (all firms) and 3-4 (firms with non-zero R&D in the US).[13] The estimation results broadly confirm our expectations. For research expenditures, the opportunity factor is significant (though not greater in magnitude than in the R&D model) while the demand coefficient is strongly reduced in magnitude (but still significant at the 10 percent level). For the sub-sample of firms with non-zero US R&D, opportunity remains significant (at the 10 percent level). The results for development expenditures, in contrast, show no effect for technological opportunity, while the demand effect is significant. The value of the demand coefficient is almost double the value in the research model, though the value is not higher than in the total R&D expenditure model. The firm-level productivity variable also is significant (at the 10 percent level) in the full-sample model. This could indicate that our proxy for R&D productivity is more appropriate for development activities than for basic and applied research, perhaps because development efforts are more directly associated with relative firm growth in the short time span over which we measure it (1994-1996). The result for the development equation also holds for the sub-sample of non-zero US R&D firms, though with higher estimated standard errors.

6. Conclusions

We developed a simple model of simultaneous R&D investments at home and abroad in an opportunity, appropriability and demand framework due to Cohen and Klepper (1996). This model yielded an equation in which the foreign to domestic R&D ratio depended on relative technological opportunities, relative demand, and a measure of firm-level R&D productivity. Estimation of this model on a sample of 146 Japanese multinational firms' R&D expenditures in 1996 in the US and Japan, confirmed the role of technological opportunity and demand as determining factors of the R&D ratio. Further analysis distinguishing between research activities and development activities of these firms in the US, showed that research expenditures respond to relative technological opportunity, but

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[13] The decisions by firms to conduct development and research activities in the US are not independent, hence use of a Seemingly Unrelated Regression (SUR) model, which allows for correlation between the error terms of the equations, appears most appropriate. However, given that our right hand side variable are identical, it has been shown that SUR results identical to those of linear regression (Greene, 1999, p. 676).

development expenditures not. In contrast, the demand factor and a proxy for firm-level R&D productivity determine US development efforts. The results are largely in line with Iwasa and Odagiri (2004). Using comparable data, they find that research activities in the US increase the patent to R&D ratio in Japan, indicating technology sourcing and technology transfer, while this was not the case for development expenditures. The estimated coefficients are consistent with a relatively high elasticity of substitution between foreign and domestic research activities (in the range of 3-4) and mildly decreasing economies of scale in R&D.

The analysis had a number of limitations, which should be addressed in future work. Since our model structure implied a direct relationship between the elasticity of substitution of foreign and domestic R&D on the one hand, and returns to scale in R&D on the other, this put restrictions on the estimated parameters. Future work should develop more general structural models of foreign and domestic R&D, for instance in a full CES specification, to allow for unrestricted estimation of the R&D parameters. In such a model, taking into account the different roles of research and development activities would be an interesting contribution, as indicated by our empirical results. Second, we could not extend the empirical model to include appropriability conditions. To the extent that differences in appropriability conditions between Japan and the US are industry-specific, our results may be affected by the omission of an appropriability variable. If appropriability data at the industry level become available (for instance those collected in innovations surveys by Levin et al., 2002), this situation can be remedied. At a more general level, future empirical work should expand the scope of analysis to R&D expenditures at the global level, where the geographic distribution of R&D will depend both appropriability conditions (e.g. Branstetter et al. 2003) and technological opportunity conditions in the various locations in which firms are active.

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Table 1: distribution of firms over industries

Industry	ISIC #	# firms	%
Food, Beverages and Tobacco	1	7	4,8
Textiles,Clothing,Leather and Footwear	2	4	2,7
Wood & Furniture	3	0	0,0
Paper, Printing and Publishing	4	3	2,1
Chemicals	5	15	10,3
Drugs & Medici	6	6	4,1
Petroleum and Coal Products and Refinery	7	3	2,1
Rubber and Plastic	8	4	2,7
Non Metallic Mineral Products	9	2	1,4
Iron & Steel	10	6	4,1
Non-Ferrous Metals	11	3	2,1
Metal Products	12	2	1,4
Non-Electrical Machinery	13	19	13,0
Office, Computing and Accounting Machinery	14	4	2,7
Electrical Machinery	15	19	13,0
Radio, TV and Communication Equipment	16	15	10,3
Shipbuilding and Repairing	17	3	2,1
Motor Vehicles	18	20	13,7
Aerospace & Aircraft	19	0	0,0
Other Transport Equipment	20	2	1,4
Professional Goods/Medical & optical & precision eq	21	4	2,7
Other Manufacturing	22	5	3,4
Total		146	100.0

Table 2: Industry Technological Opportunity and Industry Demand Growth

Industry	patent growth index		Production growth (%)	
	US	Japan	US	Japan
Food, Beverages and Tobacco	1,25	1,01	0,10	-0,01
Textiles,Clothing,Leather and Footwear	1,10	0,93	0,03	-0,09
Wood & Furniture	1,04	1,03	0,05	-0,02
Paper, Printing and Publishing	0,97	1,04	0,14	0,08
Chemicals	0,99	0,91	0,11	0,06
Drugs & Medicines	1,20	1,03	0,17	0,09
Petroleum and Coal Products and Refinery	0,86	1,05	0,23	0,11
Rubber and Plastic	1,11	0,98	0,13	-0,02
Non Metallic Mineral Products	1,00	1,04	0,19	0,00
Iron & Steel	0,92	0,82	0,10	0,00
Non-Ferrous Metals	0,95	0,98	0,17	0,13
Metal Products	0,98	0,98	0,15	0,03
Non-Electrical Machinery	0,99	1,01	0,19	0,15
Office, Computing and Accounting Machinery	1,14	1,02	0,34	0,22
Electrical Machinery	1,04	1,07	0,14	0,05
Radio, TV and Communication Equipment	1,05	0,99	0,30	0,18
Shipbuilding and Repairing	0,98	0,97	0,08	-0,13
Motor Vehicles	0,99	1,04	0,07	0,01
Aerospace & Aircraft	0,92	0,88	0,03	-0,01
Other Transport Equipment	1,07	0,91	0,13	-0,07
Professional Goods/Medical & optical & precision eq	1,02	1,06	0,12	-0,01
Other Manufacturing	1,01	0,97	0,13	0,01

Table 3: Descriptive Statistics

	Mean	St dev	Minimum	Maximum
R&D ratio	3,788	9,960	0,100	80,10
Log R&D ratio $= \ln(r_i^* / r_i)$	-0,514	1,931	-2,302	4,383
Opportunity $= \ln(O_j^* / O_j)$	0,028	0,086	-0,199	0,217
Productivity $= (\hat{q}_i^* - \hat{q}_i)$	0,093	0,572	-0,954	4,341
Demand$= q_i^{'} + q_i^{'}(1 - q_i^{'})(\dot{Q}_j^* - \dot{Q}_j)$	0,118	0,104	0,0001	0,428

Table 4: Regression Results for Equation (19)

	all firms		firms with positive US R&D	
opportunity	4,48		2,38	
	(2,45)	**	(1,28)	
productivity	0,37		0,16	
	(1,91)	*	(0,64)	
Demand	6,46		3,82	
	(4,31)	***	(2,50)	**
Constant	-1,44		0,22	
	(-7,03)	***	(0,77)	
Adjusted R^2	0,149		0,076	
Chi square	14,9	***	2,3	*
# observations	146		82	

Notes: t-ratios between brackets. *= significant at 10 percent level, **+ 5 percent,
***= 1 percent.

Table 5: Regression Results for Equation (19): Research vs. Development Expenditures

	All firms				firms with positive US R&D			
	Research Expenditures		*Development Expenditures*		*Research Expenditures*		*Development Expenditures*	
Opportunity	4,28		0,15		4,20		-2,07	
	(2,74)	***	(0,10)		(1,74)	*	(-0,90)	
Productivity	-0,07		0,43		-0,41		0,54	
	(-0,28)		(1,97)	**	(-1,12)		(1,58)	
Demand	2,29		4,92		-0,08		4,83	
	(1,77)	*	(4,07)	***	(-0,04)		(2,52)	**
Constant	-1,71		-2,03		-0,67		-1,38	
	(-7,99)	***	(-10,15)	***	(-1,70)	*	(-3,70)	***
# Observations	146		146		82		82	
Adjusted R^2	0,065		0,113		0,054		0,105	
Chi square	10,1	***	18,6	***	4,7	**	9,6	***

Notes: t-ratios between brackets. *= significant at 10 percent level, **+ 5 percent, ***= 1 percent.