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ABSTRACT

In this paper we: (1) estimate the effects of international R&D spillovers on total factor productivity growth of the seven largest industrialized countries (G-7); (2) analyze the effect of spillovers on the structure of production, i.e., the effects on factor demand such as labor and investment and output supply; (3) examine the effect of technological transfers on the pattern of trade, i.e., on imports and exports and; (4) calculate the private rates of return on physical capital and R&D investment as well as the social rates of return of foreign R&D spillovers. To achieve the objectives of this study, we have developed a framework that integrates several strands of the available approaches in the literature: the GNP function approach suggested by Burgess (1974) and Kohli (1978), the spillover models proposed by Bernstein and Nadiri (1988), Bernstein and Mohnen (1994), Coe and Helpman (1995) and Park (1995), and the familiar interrelated factor demand and cost models.

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I. Introduction

There are evidence that the gap in labor productivity and total factor productivity has been narrowed among the richest OECD countries in the post-war period, and the technological progress has often been singled out as an important factor behind the convergence. Nadiri and Prucha (1996) report that disembodied technical change has been the most important source of output and labor productivity growth in the major OECD countries during the past three decades. They suggest these large effects of autonomous technical change may be mixed with the spillover effects of R&D across national boundaries. Dowrick and Nguyen (1989) also found a systematic TFP catching-up throughout the postwar period within the richer group of capitalist economies; they indicated the public goods nature of technological progress as one of the underlying forces behind this phenomena.

Coe and Helpman (1995) and Park (1995) recently attempted to quantify the cross-national spillover effects of R&D for the OECD countries known as the "catch-up club". Based on an extended Cobb-Douglas production technology, they found significant effects of international R&D spillovers on TFP and labor productivity growth. However, they were not able to incorporate the effect of foreign R&D spillovers on the production structure of the economy in a formal analytical framework. To understand clearly the effects of foreign R&D spillovers on productivity growth, it is necessary to estimate the response of factors of production and supply of output to foreign R&D spillover. To achieve this objective structural model is necessary to trace the effect of foreign spillover on TFP growth.[1] In this study, the spillover variables do interact with factors of production and thus the spillover effects change not only the production cost through productivity effect, but also the production structure in each country through factor bias effect. Furthermore these available studies do not calculate country-specific spillover elasticities but only provide estimates of

[1] Several studies approach the problem by estimating reduced form models or using auxiliary relationships. For example, in order to capture the effects of import level on TFP, Coe and Helpman (1995) adjust the international R&D spillover variable (in logarithmic form) by multiplying it with the import-GDP ratio in their modified the TFP regression equation. Park (1995) introduces the indirect effects of spillovers through domestic R&D by estimating an auxiliary regression equation for spillover into research.

the 'average' relation between R&D spillovers and productivity growth among a group of countries. However, R&D spillovers are likely to be country specific even for the highly industrialized G-7 economies.[2] Our model allows the effects of own R&D and international R&D spillovers to be country-specific so that they may be different among G-7 countries.

It is often argued that trade and the degree of openness of an economy play a critical role in making the technological transfer from one country to another possible. In our framework imports and exports are decision variables and are endogenously determined. Technological or R&D spillovers affect both exports and imports in different degrees over time and across countries, and consequently technological spillovers affect the balance of trade among the countries under consideration. In order to carry out the analysis in an open economy framework, we utilize the methodologies developed in Burgess (1974), Kohli (1978), Diewert and Morrison (1988), and Lawrence (1990), which are based on the GNP function approach.[3] We examine specifically the effect of R&D spillover on imports demand and export supply and its effect on the balance of trade of the G-7 countries.

The rest of the paper is organized as follows. In section II we briefly survey the findings of recent studies that have attempted to measure the degree of R&D spillovers. In section III the structure of the model and its econometric implementation are described. Section IV is devoted to the description of the data used in the study. The estimation results are discussed in section V with particular emphasis on the effect of R&D spillovers on the structure of production and the total factor productivity growth. Also the effects on the demand for imports and the balance of trade as well as the rates of return to R&D investment and the flow of benefits received from outside R&D capital are presented in this section. Section VI concludes the study.

[2] Mohnen (1994) reviews the empirical aspects of international R&D spillovers among industrialized economies and reports that the results are highly country-dependent.

[3] A translog cost function is used in Burgess (1974), a translog profit function in Kohli (1978), and Diewert and Morrison (1988) and Lawrence (1990) used a biquadratic profit function. A dynamic aspect of production technology is modeled in Lawrence (1990) by having adjustment costs associated with changes in the capital stock.

II. Previous Studies on International R&D Spillover Effects

The majority of the empirical studies on technological spillovers has been confined to spillovers within the border, that is, either inter- or intra-industry spillovers within specific economy. Recently, however, a few empirical studies that apply the concepts and methodologies developed in the spillover literature have been used to measure the effect of R&D spillovers across national borders.[4] Some pertain to cross-national spillovers at various degree of aggregation -- total economy, total manufacturing, and 2-digit level R&D intensive manufacturing industries or aggregated R&D intensive industries within manufacturing sector. Other studies refer to different groupings of spillovers among most advanced countries, between economies of north and south, between two specific countries, etc. Some studies differ on how technological spillovers are formulated such as the technological flow concept of Terleckyj (1980) or the technological proximity concept of Jaffe (1986). Finally, in some studies international R&D spillovers are identified by the source of fund, public and private foreign R&D capital, with implicit assumption that the former is more susceptible to spillover than the latter.

Most of the studies point to significant but varying degrees of R&D spillovers across borders. Coe and Helpman (1995), for example, found a significant contribution of foreign R&D on the total factor productivity in 22 industrialized countries. Interestingly, they found that the effects of foreign R&D capital are as big as those of domestic R&D capital in smaller countries, while in larger countries (G-7 countries), the effects of own R&D exceeds those of foreign R&D. At industry level, Bernstein and Mohnen (1994) estimated the effects of international spillovers between Japanese and US R&D-intensive sectors, using the generalized McFadden restricted cost function, and found that a one percent increase in US R&D capital caused Japanese average variable cost to decrease by 0.63 percent. On the other hand, a one percent increase in Japanese R&D capital generated only a 0.05 percent decrease in US average variable cost. Bernstein (1994) and Bernstein and

[4] There are a few surveys on empirical aspects of technological spillovers. Nadiri (1993) deals with the technological spillovers in general and Mohnen (1994) on R&D externalities including spillovers across the border. Griliches (1991) focuses on the empirical literature on the R&D spillovers in general.

Yan (1995) distinguish the R&D spillovers between domestic and foreign sources. They found that the effects of domestic and international R&D spillovers are not only industry-specific, but also country-specific and that in terms of the effects on variable cost and factor intensities the international spillovers generally exert greater influence than the domestic spillovers.

III. The Model

Suppose that a firm is maximizing its profit subject to the following transformation function,

$$F(Y, V, K, R, S, t) = 1, \tag{1}$$

where Y is a vector of outputs, V is a vector of variable inputs, and K and R are the physical and own R&D capital stocks respectively. K and R are fixed in the short-run but variable in the long-run. S is a vector of exogenously given stock of R&D of other countries from which R&D spillovers are generated. t is the time variable representing autonomous technical change. The technology of the firm depicted by equation (1) can be alternatively represented by a variable cost function,

$$C_v = C_v(w, Y, K, R, S, t) \tag{2}$$

where C_v is a variable cost and w is a vector of variable input prices. By applying Shephard's lemma to (2) we can derive the demand for the variable inputs,

$$V = \nabla_w C_v(w, Y, K, R, S, t) \tag{3}$$

where ∇ is the vector differential operator.

The demands for the capital inputs and the supply of outputs can be derived from the profit maximization problem, that is,

$$\max_{\{Y,K\}} \quad p \cdot Y - C_v(w,Y,K,R,S,t) - q_K \cdot K - q_R \cdot R \tag{4}$$

where p is the output prices and q is the usual cost of capital. The maximization conditions for (4) determine the output supply and the capital input demands. If we assume perfectly competitive conditions in output markets so that the marginal costs equal output prices, the first order conditions for output supply and capital demand will be,

$$p = \nabla_Y C_v(w,Y,K,R,S,t) \tag{5}$$

$$\begin{aligned} -\nabla_K C_v(w,Y,K,R,S,t) - q_K &= 0 \\ -\nabla_R C_v(w,Y,K,R,S,t) - q_R &= 0 \end{aligned} \tag{6}$$

To implement this model empirically, we use a multi-product-translog-cost function to represent the variable cost function with labor, imports, physical and R&D capital considered as inputs to produce two outputs, domestic output and exports. Labor and imports are assumed to be variable inputs while physical and R&D capital are assumed to be quasi-fixed, that is, they are fixed in the short run but at the full equilibrium level in the long run. R&D spillover S, is treated as an exogenous variable. A time variable is also introduced as a shift factor to represent the autonomous technical change. This model includes a very general specification of technological change; it consists of three components: technology changes due to a country's own R&D efforts, R&D spillovers due to R&D efforts of other countries, and autonomous technical change represented by a time variable.

Another feature of the model is that a knowledge stock is represented as a geometric mean of own and foreign R&D capital, that is, $Z = R^{\theta} * S^{1-\theta}$ where $\theta \in [0,1]$. The weight on own R&D capital θ, is parameterized and estimated simultaneously with other model parameters.[5] The parameter θ measures the contribution of own R&D that a country has accumulated itself and (1-θ) measures the importance of foreign R&D spillover received by the country. This specification implies a complementary relation between own and foreign R&D, and has been used in the literature. Jovanovic, Lach and Lary (1992), for instance, assume that each firm's state of technology, A, depends on the stock of knowledge z that the firm has generated, as well as on the stock of knowledge Z that other firms have accumulated. Similarly, Kim and Lau (1993) introduce physical and human capital in their aggregate meta-production function, as a Cobb-Douglas aggregate quantity index of "aggregate" capital, i.e., $Y_t = A_0 * F\,(\,A(t) * K_t^{\lambda} * H_t^{1-\lambda},\ A_L * L_t\,)$.[6]

We employ a multi-product-translog-cost function to represent the variable cost function where the physical and R&D capital stocks are fixed in the short run. The variable cost function representation below is normalized by the price of import goods (w_M) and includes a knowledge capital stock which is defined as a geometric mean of own and foreign R&D capital.

(7)

$$
\begin{aligned}
\ln C_v = {} & \beta_0 + \beta_L \ln w_L + \beta_Y \ln Y_D + \beta_E \ln Y_E + \beta_K \ln K + \beta_Z \ln(R^{\theta} \cdot S^{1-\theta}) + \beta_T \cdot t \\
& + \tfrac{1}{2} \cdot \{ \beta_{LL} \ln w_L{}^2 + \beta_{YY} \ln Y_D{}^2 + \beta_{EE} \ln Y_E{}^2 + \beta_{KK} \ln K^{\,2} + \beta_{ZZ} \ln(R^{\theta} \cdot S^{1-\theta})^2 + \beta_{TT} \cdot t^2 \} \\
& + \beta_{LY} \ln w_L \ln Y_D + \beta_{LE} \ln w_L \ln Y_E + \beta_{LK} \ln w_L \ln K + \beta_{LZ} \ln w_L \ln(R^{\theta} \cdot S^{1-\theta}) \\
& + \beta_{YE} \ln Y_D \cdot \ln Y_E + \beta_{YK} \ln Y_D \cdot \ln K + \beta_{YZ} \ln Y_D \cdot \ln(R^{\theta} \cdot S^{1-\theta}) \\
& + \beta_{EK} \ln Y_E \cdot \ln K + \beta_{EZ} \ln Y_E \cdot \ln(R^{\theta} \cdot S^{1-\theta}) \\
& + \beta_{KZ} \ln K \cdot \ln(R^{\theta} \cdot S^{1-\theta})
\end{aligned}
$$

where Y_D and Y_E are output for domestic and export markets, w_L is the normalized wage rate. The following set of cost share equations are obtained from the first-order conditions of (3), (5), (6) using the cost function (7)

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[5] This is equivalent to assuming a "knowledge production function" which is characterized by the Cobb-Douglas technology with own and foreign R&D as inputs. See Jovanovic, Lach and Lary (1992); they define their production function as $Y_t = A_t * K_t^a * H_t^b * N_t^c$, where $A_t = z_t^{\theta} * Z_t^{1-\theta}$ and $0 < \theta < 1$.

[6] Kim and Lau (1993) use this specification to restrict the technical progress to be both capital-augmenting and human capital-augmenting.

$$
\begin{aligned}
S_D &= \beta_Y + \beta_{LY} \ln w_L + \beta_{YY} \ln Y_D + \beta_{YE} \ln Y_E + \beta_{YK} \ln K + \beta_{YZ} \ln(R^{\theta} \cdot S^{1-\theta}) \\
S_E &= \beta_E + \beta_{EY} \ln w_L + \beta_{YE} \ln Y_D + \beta_{EE} \ln Y_E + \beta_{EK} \ln K + \beta_{EZ} \ln(R^{\theta} \cdot S^{1-\theta}) \\
S_L &= \beta_L + \beta_{LL} \ln w_L + \beta_{LY} \ln Y_D + \beta_{LE} \ln Y_E + \beta_{LK} \ln K + \beta_{LZ} \ln(R^{\theta} \cdot S^{1-\theta}) \\
-S_K &= \beta_K + \beta_{LK} \ln w_L + \beta_{YK} \ln Y_D + \beta_{EK} \ln Y_E + \beta_{KK} \ln K + \beta_{KZ} \ln(R^{\theta} \cdot S^{1-\theta}) \\
-S_R &= \theta * \{\beta_Z + \beta_{LZ} \ln w_L + \beta_{YZ} \ln Y_D + \beta_{EZ} \ln Y_E + \beta_{KZ} \ln K + \beta_{ZZ} \ln(R^{\theta} \cdot S^{1-\theta})\}
\end{aligned} \tag{8}
$$

where S_i denotes the variable cost shares of output revenues and factor costs.

In this paper we adopt as a maintained hypothesis that the technology at this level of aggregation exhibits constant returns to scale. This implies the following parametric restrictions:

$$
\begin{aligned}
&\beta_Y + \beta_E = 1 - \beta_K - \theta\beta_Z, && \beta_{LY} + \beta_{LE} = -\beta_{LK} - \theta\beta_{LZ}, \\
&\beta_{YY} + \beta_{YE} = -\beta_{YK} - \theta\beta_{YZ}, && \beta_{KY} + \beta_{EK} = -\beta_{KK} - \theta\beta_{KZ}, \\
&\beta_{YE} + \beta_{EE} = -\beta_{EK} - \theta\beta_{EZ}, && \beta_{YZ} + \beta_{EZ} = -\beta_{KZ} - \theta\beta_{ZZ}.
\end{aligned} \tag{9}
$$

The equations in (8) are not independent of one another because the sum of revenue shares is equal to the sum of cost shares at each observation under the constant returns to scale technology and competitive market assumption. As a result, the revenue share for export goods equation is dropped from the system of estimating equations. Hicks neutral technical change is also assumed so that the cost and revenue shares are invariant with respect to changes in technology index.

The final equations for estimation consist of equations (7) and (8) with parameter restrictions (9). A disturbance term is added to each estimating equation to reflect possible optimization errors. For estimation purposes, the data of seven countries are pooled with the assumption that the production structures of the seven sectors are similar enough that the second-order term parameters are the same across countries but not quite similar as to share the first-order term parameters.[7] A nonlinear maximum likelihood method is used for the estimation.

IV. Data Sources and the R&D Spillover Variables

For estimation of the model we extend the data developed by Nadiri and Prucha (1996) for the six major OECD economies for the period (1964-1991). Canada was added to the sample and thus the sample of countries pertain to the G-7 advanced industrial nations. Value added (GDP) is used for the measure of output. In order to measure value-added from the point view of the producer, all indirect business taxes on the value of output (including all sales and excise taxes) were removed while all subsidies and taxes on factors of production were not. As in Lawrence (1991) and Diewert and Morrison (1986), the current and constant dollar GDP is decomposed by type of purchaser into output for domestic market (Y_D) and for foreign market (Y_E). The rationale for treating imported goods as an intermediate input has been stated in the previous studies: (i) many imports are intermediate goods and (ii) even if imports are for the final consumption, they have to go through distribution and retail channels before getting to the household. The value of output for domestic market in current price is obtained from the accounting identity of $p_D \cdot Y_D = p_Y \cdot Y - p_E \cdot EX + w_M \cdot IM$ where Y and p_Y denote the tax-adjusted GDP and its price deflator respectively.[8] The total compensation is used as the value of labor input and the price of labor input is computed by the ratio of total compensation to the total man-hours worked.

The physical capital stock series pertains to total economy and includes both public sector capital and dwellings.[9] The depreciation rates assumed for calculating total physical capital stocks are 2.09, 2.58, 3.00, 2.09, 2.64,1.59, and 1.92 (all in percentages) for US, Japan, France, Germany, Italy, UK and Canada, respectively. The data for the gross capital

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[7] Boskin and Lau (1990).

[8] From the domestic absorption identity, $C + I + G = GDP - (EX - IM) = Y_D$, the price of domestic output is computed as a chain price index of C, I, and G as in diewert and Morrison (1988).

[9] See the data appendix in Nadiri and Prucha (1996) for detailed account of the sources and construction methods.

stock for Italy is provided by Marzio Galeotti. The value of physical capital services is retrieved as a residual from the zero profit condition.

The R&D capital stock is constructed by the perpetual inventory method, i.e., $R_t = I_t^R + (1-\delta_R)\cdot R_{t-1}$ where I_t^R and R_t are gross investment on R&D and R&D capital stock. The depreciation rate for R&D capital stock δ_R is set at 0.10 and the benchmark value of 1961 R&D capital stock is estimated as $I_{62}^R/(\delta_R + g_R)$ where g_R is average GDP growth rate over the sample period. Total (privately and publicly funded) expenditures on R&D are used for R&D investment and the GDP deflator is used as the price deflator for the R&D expenditures. The rental price of R&D capital stock is calculated as $p_R\cdot(i_r + \delta_R)$ where the real discount rate, i_r, is set at 5 percent as in Nadiri and Prucha (1996). The R&D double-counting problem is corrected by subtracting the value of R&D expenditures from the total compensation of employees. All the data represented in its national currency are converted to US dollars with 1980 value of the purchasing power parity (PPP) exchange rates obtained from Summers and Heston (1991).

International R&D spillover is specified as an import-share weighted sum of the R&D capital stocks in other countries as in Coe and Helpman (1995). This specification implies that the more a country imports from a foreign country, the more R&D spillover benefits are received by the importing country.[10] Since the sample consists of most advanced industrialized economies in the world, the problem that the bilateral trade patterns do not necessarily provide information about technological (R&D in particular) closeness is not serious. Park (1995), for example, using data on the composition of R&D in G-7 countries, reports that the technical distance weights among the G-7 countries are highly correlated, showing a very high degree of similarity in the R&D composition among the G-7 countries.

Some basic statistics of the variables used for the estimation are presented in the tables 1, 2, and 3. From these tables we can compare the levels and growth rates of the

[10] We are sympathetic with the criticism that countries are technologically linked through a number of channels and not only through international trade so that using imports as a criterion provides only a limited measure of spillovers. Recently Keller (1996) examines the role of international trade as a channel of technology transmission in the context of Coe and Helpman (1995) model.

variables for each country and also across countries. The domestic market for output is at least three (Canada) to ten times (US) greater than the foreign market. However, the foreign market has been growing twice faster than domestic market. Labor cost accounts for major share of the total cost in each country ranging 40 to 60 percent followed by the share of physical capital service in total cost which is about 30 percent on average.[11] The share of imports in total cost ranges between 10 to 20 percent in the G-7 countries. The UK shows a very different pattern of cost structure than the other advanced countries: physical capital has a particularly small share of around 25 percent while imports have relatively large share of nearly over 20 percent of total cost. In all the countries, the cost share of R&D capital is rather small, ranging from less than one percent in Italy to about three percent in the US. The R&D capital stock of the US is by far the largest and almost as large as the sum of R&D capital stocks of the other six countries; Canada has the smallest R&D capital stock.

All four European countries have experienced decreases in employment over the sample period while in the other countries the growth of labor has been very small. The physical capital stock has been expanding rapidly during the sample period but not as rapidly as R&D capital stock (except the UK). The growth of international R&D spillovers in each country is determined by two factors: change in import pattern over time and the growth of R&D capital of other countries in the sample. The US has the highest growth rate of R&D spillover due to the rapid expansion of R&D capital of her trade partners. Slow expansion of domestic R&D capital in the US and the UK relative to the rest of the countries attributes to the moderate growth of international R&D spillovers available to other countries.[12] Measured total factor productivity growth was the highest in Japan (2.09 percent) and lowest in Canada (0.73 percent). Whether and by how much the growth of

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[11] The capital shares used in Coe and Helpman (1995) are 0.335 (US), 0.312 (Japan), 0.401 (Germany), 0.354 (France), 0.376 (Italy), 0.311 (UK), and 0.368 (Canada) for 1987-89 period.

[12] Another important reason for moderate growth of international R&D spillovers for the countries other than the US is that the relative share of imports from the US in these economies has been decreasing over time in general. Since the US has dominated other countries in the magnitude of R&D capital, smaller weight on the US R&D capital means smaller R&D spillover available to these countries.

international R&D spillovers account for the possible convergence of TFP among the G-7 countries will be discussed later.[13]

V. Estimation Results

Table 4 presents the parameter estimates of the model and their asymptotic standard errors. The parameter estimates are in general statistically significant and the standard errors of the equation are small. The model fits data very well as can be seen from the reported R-squares. In order to correct for possible serial correlation in the error terms an AR(1) process is assumed. (All required regularity conditions are satisfied at each point of the sample except for the violation of concavity in prices for a few early periods of the sample for the US.) The country dummy variables used to account for intercountry differences in the production structure are quite significant suggesting differences in the cost structure among the G-7 countries.

The estimates of the θ's measure the relative importance of own R&D compared to the foreign R&D spillovers. Three distinctive groups in terms of the relative importance of own R&D to foreign R&D can be identified from the estimation results. The value of θ is the largest for the US (0.862) and it is the only country where own R&D is clearly far more important than foreign sources of R&D. The US is followed by Germany (0.613), UK (0.587), Japan (0.564) and France (0.538) where own R&D is as important as foreign R&D spillovers. The last group consists of Italy and Canada where the estimates of θ are small, 0.220 and 0.218 respectively; these two countries rely much more on foreign sources of R&D than on their own R&D.

The relative importance of own R&D effort compared to foreign R&D spillovers measured by the ratio of $\theta/(1-\theta)$ varies considerably among these three groups of countries: it is about 6.2 for the US, 1.6 to 1.2 for Germany, UK, Japan and France, and 0.3 for Italy and Canada. The corresponding ratios calculated from the estimation results of

[13] Nadiri and Prucha (1996) found that the high rate of technical progress and the high rate of physical capital accumulation were two most important sources of output growth and convergence of productivity among 6 major OECD countries.

Coe and Helpman (1995), Park (1995), and Keller (1995) show a great deal of variations from one study to another. Coe and Helpman (1995) estimate an average output elasticity with respect to own R&D of 0.233 for the G-7 countries while the output elasticity with respect to foreign R&D ranged from 0.03 (U.S.) to 0.07 (Germany).[14] In terms of the relative importance, their estimates correspond to a ratio of 3 (U.S.) and 7 (Germany), implying a relatively more important role of own R&D compared to foreign R&D spillovers. Park (1995)'s estimates of output elasticity with respect to own R&D and foreign R&D spillovers of 0.07 and 0.17 respectively, imply an average relative ratio of 0.41 for major OECD countries. Keller (1995) estimates the effects of domestic and foreign R&D on labor productivity growth are 0.045 and 0.217 respectively, which implies a ratio of 0.21. This estimate is close to the lower bound of our estimates of 0.3 for Italy and Canada.[15]

Our results are different from these studies in the basic ways. By allowing for country-specific effects of both own R&D and foreign R&D spillovers, our model allows range of estimates for the relative importance of own R&D vs. foreign R&D among G-7 countries while the ratios implied by the previous studies are deduced as average for a set of countries and do not allow for country-specific effects of own R&D and foreign R&D spillovers. Our results on the relative contribution of own and foreign R&D contains the findings of the three previous studies mentioned above.

A. Production Structure

The short run own price elasticity of variables inputs, labor and imports, are shown in panel A of table 5A. The own price elasticity of labor demand is small in every country and particularly in the US. This suggests that there has been little trade-off between wage increases and unemployment in the short run. The demand for imports, however, are shown

[14] In Coe and Helpman (1995), the output elasticity of own and foreign R&D are assumed to be the same for the G-7 countries but the elasticity for R&D spillovers could be distinguished across countries by the import-GDP ratio. The US, for example, with the lowest import-GDP ratio among the G-7 countries, has the smallest R&D spillover elasticity of all.

[15] Note that the coverage of sample countries is slightly different for Park (1995) and Keller (1995). The sample of Park (1995) consists of 8 OECD countries, G-7 countries and Sweden, while Park (1995) extends his sample to 10 countries by adding Belgium and Netherlands.

to be more sensitive to price changes. The price elasticity of import is more than two or three times larger than the corresponding elasticity of labor. Also the magnitudes of import elasticity are quite similar among all the countries except the US.

As shown in panel B of table 5A, the short run cost elasticities with respect to domestic output and exports vary among the G-7 economies. In US, Japan and Italy costs respond much more strongly to changes in domestic output than in the other European countries and Canada. The cost elasticity with respect to export is small for the US, Japan and Canada ranging between 0.115 to 0.197 while for the other countries it is nearly twice larger. The effects of the two quasi-fixed variables, i.e., physical and R&D capital on variable cost in the short run is negative as expected. The impact of physical capital is more pronounced in Japan and Italy, followed by those in the US, Germany and France; it has a relatively small effect in the UK. The cost elasticity with respect to own R&D capital is higher for the US followed by Japan, France and Germany. In Italy and Canada the variable cost elasticity with respect to own R&D is small in the short-run, -0.015 and -0.016 respectively.

The effect of foreign R&D spillovers on variable cost is very small in the US - on average less than 0.1% - but much more significant in Japan, France, UK and Germany. The magnitudes of these elasticities range in a narrow band between -0.023 to -0.026 while for Italy and Canada these elasticities are more than twice as large, i.e., -0.052 and -0.059 respectively. The time variable picks up the technical progress not explained by own R&D nor by international spillovers. Though small in magnitudes, the effect of autonomous technical change is cost-reducing and productivity-enhancing in all countries.

The short run response of the demand for employment and imports to the increase in domestic output and exports is shown in panel C of this table. The output elasticity with respect to domestic output has a major effect on demand for labor in every country. These elasticities are generally greater than unitary and are about eight to ten times larger than elasticity of employment with respect to exports. Imports also respond strongly in the short run to domestic output than to the exports.

The long run elasticities, shown in table 5B, are calculated after taking into account the responses of the two quasi-fixed factors. The price elasticities of labor and imports are as expected much larger than their short-run elasticities. The employment elasticities are generally smaller than those for the imports. The demand for own R&D capital is most responsive to its own price in the long-run and the magnitudes of the elasticities are similar across countries. Physical capital stock shows a price elasticity of about -0.59 to -0.75.

The long run cost elasticities with respect to domestic output, exports, and R&D spillovers are shown in panel B of table 5B. The cost elasticities with respect to domestic output again dominate, as expected, those with respect to exports. However, both of these long-run cost elasticities are smaller than their short-run counterparts. The reason is that in the short-run because of fixity of R&D and physical capital, variable input demands overshoot their long run equilibrium levels to the increase in both type of outputs.

The comparison of the effects of three variables in the model representing technological change, - own R&D, foreign R&D spillovers, and technical progress proxied by a time variable - shows that the variable cost elasticity with respect to own R&D is the largest (in absolute term) among the three measures while the autonomous technical change has relatively small effect in reducing costs in most countries.[16] The exceptions are Italy and Canada where the foreign R&D spillover elasticities of the variable costs are greater than those of own R&D elasticities. Finally, the long-run input response to changes in domestic output are shown in panel C of table 5B. The labor and import responses are smaller than their short-run elasticities due to the fixity of physical and R&D capital in the short run. The elasticities of physical capital and own R&D with respect to domestic output do not vary much across countries. The elasticities of physical capital exceeds to some extend those of the R&D capital. Again, the effect of an increase in exports on demand for physical and R&D capital seem to be very small in the G-7 countries.

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[16] Park (1995) also allows for all three venues of technological progress, i.e., autonomous change, by-product (externality) of other economic activities, and intentional R&D activities, in his estimation equation for labor productivity growth but the autonomous technical change proxied by a time variable is shown to exert negative productivity effects consistently.

B. International R&D Spillovers Effects

The impact of foreign R&D spillover on the domestic output, exports, costs and derived demand for inputs can be assessed in three steps:

(i) In the short run when the capital inputs are assumed to be fixed, the R&D spillovers will affect the variable cost directly with level of outputs and quasi-fixed factors fixed. The spillovers also affect the production structure through their effects on variable input demand decisions. The direct effects can be computed by differentiating the variable cost function (7) with respect to the spillovers variable, that is,

$$(10) \qquad \varepsilon_{CS} = \left.\frac{\partial \ln C_v}{\partial \ln S}\right|_{\bar{Y},\bar{K}} = (1-\theta)\cdot\{\beta_Z + \beta_{LZ}\cdot \ln w_L + \beta_{YZ}\cdot \ln Y_D + \beta_{EZ}\cdot \ln Y_E + \beta_{KZ}\cdot \ln K + \beta_{ZZ}\cdot \ln(R^{\theta}\cdot S^{1-\theta})\}$$

The short run employment and import elasticity with respect to R&D of spillovers can be derived from the first-order condition for labor demand with respect to spillovers, that is,

$$(11) \qquad \varepsilon_{LS} = \left.\frac{\partial \ln L}{\partial \ln S}\right|_{\bar{Y},\bar{K}} = \frac{(1-\theta)\cdot\beta_{LZ}}{\hat{s}_L} + \varepsilon_{CS}$$

$$\varepsilon_{MS} = \left.\frac{\partial \ln M}{\partial \ln S}\right|_{\bar{Y},\bar{K}} = \frac{-(1-\theta)\cdot\beta_{LZ}}{\hat{s}_M} + \varepsilon_{CS}$$

where $\hat{s}_L$ and $\hat{s}_M$ denotes the fitted variable cost share of labor input and imports.

(ii) The next step is to allow output to adjust in response to the short-run cost reduction due to R&D spillovers. The level of the quasi-fixed inputs is held at their previous level. The response of domestic output and exports are determined simultaneously, i.e.,

(12) $$\begin{bmatrix} \eta_{YS} \\ \eta_{ES} \end{bmatrix} = \begin{bmatrix} \hat{s}_Y - \hat{s}_Y{}^2 - \beta_{YY} & -\hat{s}_Y\hat{s}_E - \beta_{YE} \\ -\hat{s}_Y\hat{s}_E - \beta_{YE} & \hat{s}_E - \hat{s}_E{}^2 - \beta_{EE} \end{bmatrix}^{-1} \begin{bmatrix} \hat{s}_Y \cdot \varepsilon_{CS} + (1-\theta)\beta_{ZY} \\ \hat{s}_E \cdot \varepsilon_{CS} + (1-\theta)\beta_{ZE} \end{bmatrix}$$

The indirect effects of R&D spillovers through output expansion on the variable cost and variable input demands are determined as follows:

(13) $$\eta_{CS} = \left. \frac{\partial \ln C_v}{\partial \ln S} \right|_{\bar{K}} = \varepsilon_{CS} + \hat{s}_Y \cdot \eta_{YS} + \hat{s}_E \cdot \eta_{ES} ,$$

(14) $$\eta_{LS} = \left. \frac{\partial \ln L}{\partial \ln S} \right|_{\bar{K}} = \varepsilon_{LS} + \varepsilon_{LY} \cdot \eta_{YS} + \varepsilon_{LE} \cdot \eta_{ES}$$

where ε_{LY} and ε_{LE} denote the elasticity of labor demand with respect to domestic output and exports respectively. The spillover effects on imports can be computed similarly. The physical and R&D capital, which are fixed in the short run, are not affected by definition by international R&D spillovers in the short run.

(iii) To measure the long run effects of spillovers, the two quasi-fixed inputs are allowed to adjust in response to R&D spillovers. The long run spillover elasticities for the capital inputs are given by:

(15) $$\begin{bmatrix} \varepsilon^L_{KS} \\ \varepsilon^L_{RS} \end{bmatrix} = \begin{bmatrix} \hat{s}_K + \hat{s}_K{}^2 + \beta_{KK} & \hat{s}_K\hat{s}_R + \theta \cdot \beta_{KZ} \\ \hat{s}_K\hat{s}_R + \theta \cdot \beta_{KZ} & \hat{s}_R + \hat{s}_R{}^2 + \theta^2 \cdot \beta_{ZZ} \end{bmatrix}^{-1} \begin{bmatrix} \hat{s}_K \cdot \varepsilon_{CS} - (1-\theta)\beta_{KZ} \\ \hat{s}_R \cdot \varepsilon_{CS} - \theta(1-\theta)\beta_{ZZ} \end{bmatrix}$$

The long run spillover effects on the variable cost and the variable input demands with the output levels held constant can be computed as,

(16) $$\varepsilon^L_{CS} = \left. \frac{\partial \ln C^L_v}{\partial \ln S} \right|_{\bar{Y}} = \varepsilon_{CS} + \varepsilon_{CK} \cdot \varepsilon^L_{KS} + \varepsilon_{CR} \cdot \varepsilon^L_{RS} ,$$

(17) $$\varepsilon^L_{LS} = \left. \frac{\partial \ln L^L}{\partial \ln S} \right|_{\bar{Y}} = \varepsilon_{LS} + \varepsilon_{LK} \cdot \varepsilon^L_{KS} + \varepsilon_{LR} \cdot \varepsilon^L_{RS}$$

where ε_{LK} and ε_{LR} denote the elasticity of labor demand with respect to physical and R&D capital respectively.

Table 6 provides the estimates of short- and long run spillover effects. In the short run, a one percentage point increase in the international R&D spillovers will decrease the variable cost directly by as much as 0.059 percent in Canada, 0.052 percent in Italy, about 0.02 percent in Japan, UK, and Germany, and as little as 0.007 percent in the US. The labor demand decreased in all seven countries while the imports demand decreased only in Italy and Canada where the R&D spillover is most effective. This implies that the foreign R&D spillover benefits induce domestic firms to rely more on foreign sources for their intermediate inputs and less on labor. The international R&D spillovers increase the supply of outputs in the short run as expected. The supply of domestic output is slightly more responsive to the foreign R&D capital than the export supply except for Germany and Italy. Though we confine the effects of R&D spillovers to be cost-reducing, the foreign product innovation, as it spills into the domestic economy, may induce the expansion or contraction of domestic output supply.

In the long run, a similar pattern of international R&D spillovers effects across countries can be observed. The foreign R&D complements own R&D and imports but substitutes labor and physical capital.[17] The relation between own R&D and borrowed R&D is important and has received considerable attention.[18] Whether the physical and R&D capitals (or variable factors) are complements or substitutes to the international spillovers can be established from the above formula. If $\varepsilon^{L}_{RS} > 0$, they are complements; if $\varepsilon^{L}_{RS} < 0$, they are substitutes in the long run. Many previous empirical studies on domestic R&D spillovers have reported that the labor input and the R&D spillovers are substitutes, which is confirmed again in the case of international R&D spillovers.[19] Compared with the short

[17] Bernstein (1994) and Mohnen (1992) report a complementary relation between physical capital stock and international R&D spillovers.

[18] The inter-industry spillovers are generally found to be a substitute for own R&D while the international spillovers are found to be a complement.

[19] The substitutional relation between labor input and R&D spillovers is almost a stylized fact. See Mohnen (1992).

run, the decrease in labor demand due to foreign R&D spillovers is smaller in the long run. This is because physical and own R&D capitals which are substitutes with foreign R&D, are fixed in the short run, the short run demand for variable inputs overshoot their long run demand levels. The effect of R&D spillover on demand for imports is positive rather small for UK and Canada. The same complementarity between R&D spillovers and import demand is evident in all other countries. The R&D spillover has its strongest impact on Japanese import demand.

C. Rates of Return to R&D Investment

The increase of own R&D capital in *i*th country causes its variable cost to decrease but at the same time the benefits of own R&D cannot be entirely appropriated by firms for the benefit of the domestic economy. Some benefits will accrue to firms in other countries leading to cost reductions in the recipient economies. If the benefits of R&D capital is measured in terms of cost reduction the spillover-internalized rates of return to R&D investment (total or global return) can be defined as the sum of private return which is accrued domestically (domestic return) and the spillover return from the overseas (foreign return). The total rates of return to R&D investment can be defined as,

$$\gamma_{it} = -\left\{ \frac{\partial C_{it}^{v}}{\partial R_{it}} + \sum_{j \neq i} \frac{\partial C_{jt}^{v}}{\partial S_{jt}} \cdot w_{it}^{j} \right\} / q_{it} \tag{18}$$

where γ_{it} denotes the total rates of return to country i's R&D investment at time t, q_{it} is the purchase price of R&D investment and w_{it}^{i} is a weight coefficient given to country *i*'s R&D capital for the country *j*'s spillovers, which is measured by country *i*'s share in country *j*'s aggregate imports. The first term in (18) is the marginal benefit of own R&D in terms of cost reduction from an incremental increase in own R&D and the second term is the sum of cost reductions in the foreign countries through the increase in spillovers caused by an increase in R&D of country *i*.

The estimates of the rate of return on the R&D investment are provided in table 7. The rate of return on the physical capital investment is also provided for comparison. The estimated rates of return to domestic R&D investment are quite uniform across the G-7 countries, approximately 14 to 16%. The rates of return on the physical capital investment show more variations, ranging between 7.09% (UK) to 12.4% (Japan). The overseas rates of return to R&D investment calculated from the cost reduction in the other countries are smaller than the domestic rates of return and the estimates are much more diverse among the recipient countries, ranging 5.2% (Italy) to 10.5% (Canada). These estimates suggest that about 60 to 70% of total return to R&D investment occurs domestically and 30 to 40% of return occurs to the trade partners in the form of R&D spillovers. For the G-7 countries on average, Coe and Helpman (1995) estimated rates of return on domestic R&D investment as high as 121.9% while worldwide rate of return as 152.1% in 1990, implying that about 30% of the benefits of R&D investment occur overseas trade partners.[20]

D. Spillover Flows

In table 8 the estimates of bilateral spillover benefits flows among the G-7 countries are presented. The benefits received by a country from foreign countries are shown in the rows and those given to other countries by a particular country are indicated in the columns of this table. The US received most of R&D spillovers from Canada and Japan followed by Germany and UK; Italy and France are not major spillover contributors to the US. The R&D spillover benefits from the US to other countries are sizable. Canada is by far the largest beneficiary and the benefits to Japan are also sizable. The US has been an important source of R&D spillovers to Italy and UK as well. France and Germany received the smallest benefit from the US R&D spillover. Among Germany, France, Italy and UK there

[20] The very high domestic rate of return to R&D investment in Coe and Helpman (1995) might be due to the existence of intra-national R&D spillovers. In our model we impose the optimality condition for R&D capital demand equation (6). However, as Coe and Helpman (1995) noted, it is important to be cautious in interpreting their results on the rate of return since the results are sensitive to the estimated benchmark values for the R&D capital stocks.

is a close relation in both receiving and giving of R&D spillover benefits. Germany has been the main source of R&D spillovers for these countries.

The overall balance of technological spillovers in table 8 shows that US, France and Germany are net exporters of spillover benefits while Japan, Italy, UK and Canada are net importers. Furthermore, the US has been a net exporter of R&D spillover benefits to all six countries while Italy has been a net importer from all six countries. On balance Japan is a net exporter of technology spillover to only Italy and UK. In terms of sheer magnitude the US and Germany give approximately twice as much as they receive while Italy receives three times as much as it gives in terms of R&D spillovers. Japan and Canada receive about two times of what they give. Finally, the average total yearly magnitude of the spillover benefits among the G-7 countries over the period 1964-1991 amounted to $ 83 billion in current prices. In 1991 the size of total R&D spillover flows among these countries reached approximately $ 232.2 billion, more than 20 times greater than its level in 1964, $ 9.3 billion.

E. Decomposition of Total Factor Productivity Growth

We decompose the conventional Divisia index of the TFP growth to explicitly consider the contributions of own R&D and international R&D spillovers and autonomous technical change. The total factor productivity growth, is defined conventionally as,

$$(19) \qquad \dot{TFP} = \sum_i \pi_i \cdot \dot{Y}_i - \sum_j \delta_i \cdot \dot{X}_j - \delta_K \cdot \dot{K} \ ,$$

where π_i is the revenue share of output i, δ_j a cost share of input j, and X_j denotes the variable input. δ_k is the cost share of the physical capital stock K. The dot (.) indicate the rate of change of the specific variable.

The variable cost function is defined as,

(20) $$C^v(\ w,\ Y,\ K,\ R,\ S,\ t)\ =\ \sum w_j \cdot X_j\ .$$

Differentiating the variable cost function with respect to *t* and rewriting the above equation in terms of the total cost (C), we can obtain the following expression,

(21) $$\dot{TFP}\ =\ -\eta^{-1}\cdot\frac{\partial \ln C^v}{\partial \ln R}\cdot\dot{R}\ -\eta^{-1}\cdot\frac{\partial \ln C^v}{\partial \ln S}\cdot\dot{S}-\eta^{-1}\cdot\frac{\partial \ln C^v}{\partial t}$$

where η is the ratio of total cost to variable cost. The terms on the right hand side of equation (21) represent the contribution of domestic R&D growth, international R&D spillover growth, and the pure technological change respectively.

The decomposition results of TFP growth for the seven countries are presented in table 9. In all seven countries, the autonomous technical change has been most important in enhancing the total factor productivity level, accounting for at least one third to two thirds of the conventionally measured TFP growth. This result is in line with the findings of Nadiri and Prucha (1996) and Boskin and Lau (1990). The relative contribution of own R&D to TFP growth in the US, Japan, France, and Germany are much larger than those due to R&D spillover from other countries. In the UK, Italy, and Canada this pattern is reversed.[21] The own R&D has made only modest contribution in spite of its rapid growth during the sample period, due to its relatively minor role among the production factors.[22]

It is often argued that R&D spillover is an important source of TFP catch-up between the US and other OECD countries. During the 1965-1991 period the average contribution of international R&D spillovers to TFP growth was estimated as 0.033% in the US and 0.043, 0.057, 0.033, 0.071, 0.054, and 0.136% in Japan, France, Germany, Italy, UK, and Canada respectively. The international R&D spillovers have contributed to

[21] Eaton and Kortum (1995) compare the domestic and foreign sources of productivity growth. They found that in the complete isolation scenario the productivity levels in Germany, France, UK, and Japan are about 3 times less than the baseline (actual) case. Even the US is shown to obtain over 40 percent of its (labor productivity) growth from foreign innovations.

narrowing the productivity gap between the US and other G-7 countries but the evidence indicates that the international R&D spillovers have played a relatively modest role.

F. R&D Spillover and Balance of Trade

The balance of trade (BOP) can be defined as the value of exports minus the value of imports, i.e., $BOP = p_E*Y_E - w_M*M$. With the estimates of the R&D spillover elasticities of exports and imports, the effects of R&D spillovers on the trade balance can be also computed. Table 10 presents the magnitude of the balance of trade gap due to a percentage increase of R&D spillovers for each country. The induced changes in trade balance are very small if we compare them with the size of economy in table 2. In the short run all the countries experience a deterioration in their trade balances due to the increase in R&D spillovers. However, the magnitude of induced trade deficit is quite small in all G-7 countries. What this implies is that the receiving of foreign R&D spillovers causes domestic firms to use more imported intermediate goods and less labor inputs. At the same time the foreign R&D has only limited effects on export expansion in the recipient country, resulting in the deterioration of trade balances.

However, in the long run, the increase in exports outweighs the increase in imports; an increase in R&D spillover results in the improvement of balance of trade in most countries except the US. Again the foreign R&D induces the demand for import to increase but not as much as in the short run. Japan experienced the largest improvement in her trade balance owing to long run substitutional relation between import demand and R&D spillovers. Technological spillovers, by exerting non-neutral effects on export and import, can be a source of trade balance problem, albeit a very minor one.

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[22] Mohnen (1992) found that the scale economies contribute most of the TFP growth, followed by foreign R&D and domestic R&D in all of the five manufacturing sectors of US, Japan, Germany, France, and UK. We could not confirm his findings in the framework of total economy.

VI. Summary and Concluding Remarks

In this paper we have analyzed the effects of international technology spillovers represented by the R&D spillovers on the production structure, output and productivity growth in the G-7 countries. We also attempted to examine the effects of technological transfer on pattern of trade, i.e., on imports and exports and calculate the rate of return to own R&D investment within a given country and the benefits to other members of the G-7 countries. The following are some of the main results of this study:

1. The degree of benefits received from a country's own R&D effort and those from R&D investments of other countries differ considerably. The relative importance of own R&D effort compared to foreign R&D spillovers is highest for the US - about six times, about 1.6 to 1.2 times for Germany, Japan, France and UK and very low, approximately 0.3 for Italy and Canada indicating their heavy reliance on international R&D spillovers.

2. The short- and long-run cost elasticities with respect to domestic output dominate those with respect to exports. These responses vary considerably over time and across countries. There is an evidence that factors of production including imports overshoot their long-run values in the short-run; this is due to the fixity of physical and R&D capital in the short-run. Also the response of costs and productivity growth to three variables - own R&D, foreign R&D spillovers, and autonomous technical change - representing technological change differ among the countries. In most of the G-7 countries the cost elasticities with respect to own R&D is the largest among the three measures while those with respect to autonomous technical change is the smallest. In Italy and Canada, on the other hand, the cost elasticity with respect to foreign R&D spillover dominates those of own R&D elasticities.

3. The direction of effects of international R&D spillovers on factor demands and outputs are quite consistent across countries but the magnitudes of the effects vary considerably among the countries and over different periods. An increase in R&D spillovers lead to

reduction in costs and demand for labor while the effect on import demand is positive in the short-run. In the long-run, domestic output, exports, employment and imports all increase in response to an increase in international R&D spillovers. The relation between physical capital and R&D spillovers is substitutional while domestic R&D and international spillovers are complements with each other. The magnitudes of the elasticities with respect to spillovers are generally small in the case of US and comparatively large for UK, Italy and Canada.

4. The rates of return on domestic R&D ranges about 14 to 16% while those on R&D spillovers are smaller and vary among the countries. The total return to R&D (own plus spillovers) is surprising similar - about 23 to 26% but the distribution of the total return between the two types of R&D varies among countries. The return on physical capital is smaller than those on own R&D and also smaller in some countries than the rate of return on foreign R&D spillovers.

5. The bilateral spillover benefits received from and given to other countries vary considerably among countries. The US received most of R&D spillover effects from Canada and Japan followed by Germany and UK; Italy and France are not major spillover contributors to the US. The R&D spillover benefits from the US to other countries are sizable. Canada is by far the largest beneficiary and the benefits to Japan are also sizable. The US has been an important source of R&D spillovers to Italy and UK as well. France and Germany received the smallest benefit from the US R&D spillover. On balance Japan is a net exporter of technology spillover to only Italy and UK. Among Germany, France, Italy and UK there is a close relation in both receiving and giving of R&D spillover benefits. Germany has been the main source of R&D spillovers for these countries. Finally, the average total yearly magnitude of the spillovers among the G-7 over the period 1964-1991 countries amounted to $ 83 billion in 1990 prices. In 1991 the size of total R&D spillover flows among these countries reached approximately $ 232.2 billion, more than 20 times greater than its level in 1964, $ 9.3 billion.

6. During the 1965-1991 period the average contribution of international R&D spillovers to TFP growth was estimated as 0.033% in the US and 0.043, 0.057, 0.033, 0.071, 0.054, and 0.136% in Japan, France, Germany, Italy, UK, and Canada respectively. The international R&D spillovers has contributed to narrowing the productivity gap between the US and other G-7 countries but the evidence indicate that the international R&D spillovers have played only a minor role, with possible exception of Canada.

7. In the short run all the countries experience a deterioration in their trade balances due to the increase in R&D spillovers. However, the magnitude of induced trade deficit is quite small in all G-7 countries. At the same time the foreign R&D have only limited effects on export expansion in the recipient country, resulting in the deterioration of trade balance. However, in the long run, increases in export outweighs increases in import, an increase in and R&D spillover results in improvement of balance of trade in most countries except in the US. Again the foreign R&D induces the demand for import to increase but not as much as in the short run. Japan experienced the largest improvement in her trade balance owing to long run substitutional relation between import demand and R&D spillovers.

There are several issues that require further analysis. Some of the most important research topics are: (1) We have assumed constant returns to scale technology in this analysis. The analysis needs to be extended to non-constant returns to scale technology and carry out formally several hypothesis testing to ensure about the cost and output elasticities with respect to international R&D spillovers; (2) The data for imports need to be disaggregated. Not all imports can be considered as inputs in the production. Imports for consumption purposes should be separated out and the input-output relations need to be revised; (3) A careful analysis of the transfer mechanism for the spillovers needs to be developed. Technological transfers may not be transmitted solely through import or trade channels. Also the absorptive capacity of a country to utilize the benefits of international R&D effort is very critical.

Table 1. Size comparison of outputs and inputs for the 7 OECD countries, mean values of 1964-1991 (in billion 1980 constant $ US)[a]

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
Variable cost	1706.7	474.7	345.2	393.1	330.2	337.4	196.6
Domestic output	2562.4	790.4	397.9	459.9	376.2	387.2	210.2
Exports	234.2	108.7	88.9	142.6	87.7	112.5	71.6
Labor	1519.7	474.2	265.0	327.9	203.1	272.5	130.2
Imports	309.4	118.6	96.3	130.9	98.9	113.7	65.6
Physical capital[b]	13388.8	3096.7	1558.9	3039.1	3421.4	2490.0	1044.8
R&D capital	513.4	120.8	65.4	90.6	24.6	84.4	21.1
R&D spillovers	41.89	249.9	133.0	149.9	110.2	187.9	342.2

a/ The base year (1980) purchasing power parity (PPP) exchange rates were used to convert the national currency to US dollars.
b/ Since different base years have been used in constructing the physical capital stocks, they are not directly comparable with other variables nor across sectors.

Table 2. Average revenue and cost shares of outputs and inputs in the 7 OECD countries, mean values of 1964-1991.

	U.S.	**Japan**	**France**	**Germany**	**Italy**	**U.K.**	**Canada**
Revenue Shares of Outputs							
Domestic output	0.924	0.887	0.821	0.771	0.826	0.781	0.784
Exports	0.076	0.113	0.179	0.229	0.174	0.219	0.216
Cost Shares of Production Factors							
Labor	0.571	0.468	0.473	0.472	0.407	0.499	0.481
Imports	0.083	0.100	0.178	0.203	0.173	0.223	0.208
Physical capital	0.314	0.410	0.326	0.305	0.413	0.254	0.300
R&D capital	0.031	0.023	0.024	0.020	0.007	0.024	0.012

Table 3. Average annual growth rates of main variables in 7 OECD countries, 1964-1991[a] (in percentage).

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
GDP	2.85	5.83	3.29	3.04	3.47	2.26	3.82
Domestic output	2.93	5.62	3.33	2.95	3.59	2.33	3.99
Exports	6.16	9.85	6.51	6.17	6.30	4.11	6.18
Labor	1.48	0.54	-0.22	-0.23	-0.13	-0.12	1.75
Imports	5.90	7.64	6.01	5.94	6.07	4.24	7.06
Physical capital	2.81	6.95	4.24	3.71	2.77	3.01	4.58
R&D capital	3.37	8.69	5.51	5.77	6.33	1.80	6.29
R&D spillovers[b]	7.32	2.98	3.79	3.18	4.01	3.48	4.10
Total factor productivity[c]	0.88	2.09	1.46	1.38	1.92	1.00	0.73

a/ Growth rates are computed by a difference in log.
b/ 1965-1991 average.
c/ Total factor productivity growth is approximated by Tornqvist index.

Table 4. Nonlinear Maximum Likelihood Estimates for 7 OECD Countries, 1964-1991.

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
θ	0.8618	0.2033	β_{Y7}	-0.0206	0.0501
θ_2	-0.2978	0.1069	β_K	-0.2768	0.0509
θ_3	-0.3235	0.1238	β_{K2}	-0.2446	0.0307
θ_4	-0.2490	0.1032	β_{K3}	-0.0971	0.0332
θ_5	-0.6420	0.1683	β_{K4}	-0.0698	0.0336
θ_6	-0.2746	0.1081	β_{K5}	-0.3098	0.0320
θ_7	-0.6441	0.1730	β_{K6}	0.0242	0.0331
β_0	0.9826	0.1278	β_{K7}	-0.0650	0.0237
β_{02}	0.6259	0.0942	β_Z	-0.0597	0.0076
β_{03}	0.4035	0.0943	β_T	-0.0122	0.0039
β_{04}	0.5116	0.0967	β_{T2}	-0.0160	0.0026
β_{05}	1.3801	0.0968	β_{T3}	-0.0105	0.0024
β_{06}	0.1563	0.0988	β_{T4}	-0.0091	0.0025
β_{07}	0.4361	0.1291	β_{T5}	-0.0175	0.0025
β_L	0.6626	0.0369	β_{T6}	-0.0007	0.0024
β_{L2}	0.0213	0.0173	β_{T7}	-0.0032	0.0026
β_{L3}	-0.0415	0.0173	β_{LL}	0.0898	0.0083
β_{L4}	-0.0547	0.0165	β_{YY}	0.3019	0.0211
β_{L5}	-0.0531	0.0165	β_{KK}	-0.0027	0.0107
β_{L6}	-0.0657	0.0166	β_{ZZ}	-0.0063	0.0029
β_{L7}	-0.0123	0.0180	β_{TT}	0.0005	0.0002
β_Y	0.9702	0.0233	β_{YL}	0.0658	0.0131
β_{Y2}	0.1693	0.0266	β_{LK}	0.0094	0.0145
β_{Y3}	0.0251	0.0261	β_{LZ}	-0.0162	0.0036
β_{Y4}	0.0268	0.0271	β_{YK}	-0.0771	0.0136
β_{Y5}	0.2479	0.0273	β_{KZ}	0.0030	0.0024
β_{Y6}	-0.0327	0.0268	β_{YZ}	0.0040	0.0017
Log of likelihood				3424.33	
Estimating Equation		R-squares		Standard Error of the Regression	
C-equation		0.998		0.021	
S_Y - equation		0.987		0.023	
S_L - equation		0.973		0.012	
S_K - equation		0.976		0.026	
S_R - equation		0.993		0.001	

Table 5A. Estimates of Short-Run Elasticities in 7 OECD Countries, Mean Values of 1964-1991.

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
Panel A Short-Run Own Price Elasticity							
Labor	-0.024	-0.066	-0.148	-0.172	-0.168	-0.181	-0.173
Imports	-0.115	-0.298	-0.395	-0.399	-0.397	-0.399	-0.400
Panel B Short-Run Variable Cost Elasticity w.r.t.							
Domestic output	1.404	1.533	1.251	1.128	1.405	1.081	1.101
Exports	0.107	0.186	0.278	0.351	0.311	0.306	0.338
Physical capital	-0.468	-0.687	-0.499	-0.447	-0.702	-0.354	-0.423
R&D capital	-0.043	-0.033	-0.030	-0.033	-0.015	-0.033	-0.016
R&D spillovers	-0.007	-0.025	-0.026	-0.021	-0.052	-0.023	-0.059
Technical change	-0.004	-0.020	-0.014	-0.013	-0.021	-0.005	-0.007
Panel C Short-Run Domestic Output Elasticity							
Labor	1.480	1.613	1.341	1.223	1.499	1.177	1.196
Imports	0.849	1.147	1.006	0.907	1.180	0.868	0.883
Short-Run Export Elasticity							
Labor	0.037	0.106	0.187	0.258	0.209	0.210	0.235
Imports	0.624	0.574	0.525	0.571	0.556	0.519	0.576

Table 5B. Estimates of Long-Run Elasticities in 7 OECD Countries, Mean Values of 1964-1991.

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
Panel A Long-Run Own Price Elasticity							
Labor	-0.330	-0.413	-0.397	-0.398	-0.452	-0.371	-0.375
Imports	-0.196	-0.391	-0.507	-0.514	-0.537	-0.502	-0.509
Physical Capital	-0.697	-0.604	-0.678	-0.704	-0.593	-0.752	-0.710
R&D Capital	-1.086	-1.048	-1.045	-1.1059	-1.015	-1.042	-1.008
Panel B Long-Run Variable Cost Elasticity w.r.t.							
Domestic output	0.880	0.849	0.769	0.711	0.774	0.723	0.713
Exports	0.120	0.151	0.231	0.289	0.226	0.277	0.287
R&D spillovers	-0.005	-0.015	-0.017	-0.014	-0.029	-0.017	-0.040
Technical change	-0.003	-0.011	-0.009	-0.012	-0.003	-0.005	-0.005
Panel C Long-Run Domestic Output Elasticity[a]							
Labor	0.954	0.932	0.868	0.809	0.876	0.823	0.816
Imports	0.340	0.452	0.514	0.483	0.529	0.502	0.474
Physical Capital	1.042	0.959	0.925	0.887	0.886	0.949	0.895
R&D Capital	0.829	0.776	0.689	0.628	0.679	0.648	0.632

a/ The long run export elasticity can be calculated from the condition that the sum of domestic output and export elasticity of any input in the long run should be equal to one under the constant return to scale technology assumption.

Table 6. International R&D Spillover Elasticities in 7 OECD Countries, Mean Values of 1964-1991.

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
				Short - Run			
ε_{CS}	-0.007	-0.025	-0.026	-0.021	-0.052	-0.023	-0.059
ε_{LS}	-0.009	-0.034	-0.036	-0.030	-0.070	-0.033	-0.077
ε_{MS}	0.012	0.016	0.002	0.0004	-0.008	0.051	-0.017
				Long - Run			
ε^L_{KS}	-0.006	-0.017	-0.020	-0.017	-0.033	-0.021	-0.046
ε^L_{RS}	0.014	0.037	0.038	0.037	0.055	0.030	0.030
ε^L_{CS}	-0.005	-0.015	-0.017	-0.014	-0.029	-0.017	-0.040
ε^L_{LS}	-0.008	-0.024	-0.028	-0.024	-0.048	-0.027	-0.059
ε^L_{MS}	0.016	0.029	0.013	0.009	0.015	0.006	0.004

Table 7. Gross Rates of Return to Physical & R&D Capital Investment in 7 OECD Countries, Mean Values of 1964-1991.

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
Physical capital	0.079	0.124	0.104	0.085	0.107	0.070	0.093
R&D capital (domestic)	0.144	0.149	0.149	0.152	0.161	0.140	0.154
(overseas)	0.091	0.081	0.065	0.101	0.052	0.061	0.105
R&D capital (total)	0.235	0.231	0.214	0.253	0.213	0.201	0.260

Table 8. Balance of International R&D Spillover Benefit Flows in 7 OECD Countries, Mean Values of 1964-1991, (billions of US dollars, current price)

to from	U.S.	Japan	France	Germany	Italy	U.K.	Canada	Total
U.S.		4.03	0.60	1.35	0.60	1.02	4.52	12.12
Japan	8.69		0.63	1.25	0.47	0.65	1.58	13.27
France	1.62	0.62		3.79	2.23	1.36	0.16	9.78
Germany	1.64	0.93	2.57		1.95	1.37	0.20	8.66
Italy	2.44	0.76	5.55	7.65		1.90	0.31	18.61
U.K.	2.06	0.86	1.49	2.52	0.90		0.48	8.31
Canada	10.20	0.89	0.22	0.39	0.19	0.51		12.40
Total	26.65	8.09	11.06	16.95	6.34	6.81	7.25	83.15

Table 9. Decomposition of the Total Factor Productivity Growth in 7 Major OECD Countries, Mean Values of 1965-1991 (percentage).

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
TFP Growth	0.760	1.860	1.466	1.352	1.916	0.973	0.733
R&D Capital	0.095	0.161	0.104	0.124	0.054	0.045	0.069
Int'l Spillovers	0.033	0.043	0.057	0.033	0.071	0.054	0.136
Technical Change	0.238	1.124	0.924	0.871	1.233	0.322	0.472
Residual	0.394	0.532	0.381	0.324	0.558	0.551	0.056

Table 10. Effects of International R&D Spillovers on the Balance of Trade in 7 OECD Countries, Mean Values of 1964-1991 (billions of US dollars, current price).

	U.S.	Japan	France	Germany	Italy	U.K.	Canada
				Short Run			
ΔEXP[a]	0.020	0.030	0.038	0.058	0.104	0.036	0.047
ΔIMP[a]	0.060	0.058	0.068	0.068	0.115	0.067	0.084
ΔBOP[b]	-0.040	-0.028	-0.030	-0.010	-0.011	-0.031	-0.037
				Long Run			
ΔEXP	0.101	0.173	0.190	0.205	0.375	0.172	0.260
ΔIMP	0.342	-0.532	0.041	0.095	0.129	0.055	0.095
ΔBOP	-0.240	0.706	0.149	0.110	0.247	0.117	0.166

a/ Measured by the change in the value of exports and imports due to one percentage point increase in international R&D spillovers.
b/ ΔBOP = ΔEXP - ΔIMP.

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