NBER WORKING PAPER SERIES

INTERNATIONAL R& D SPILLOVERS: A RE-EXAMINATION

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NBER Working Paper 5668

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
July 1996

The opinions expressed in this paper are those of the authors, and not those of Columbia University, Université Libre de Bruxelles or the National Bureau of Economic Research. An earlier version of this paper was presented at the OECD Conference on New S&T Indicators for the Knowledge-Based Economy, Paris, June 1996 under the title "The Channels of International R&D Spillovers." The work on this paper was entirely done when I was Visiting Researcher in the Jerome A. Chazen Institute of International Business at Columbia University. I thank the Columbia Business School for its hospitality. Further, I am grateful to my Ph.D supervisor in Brussels, Professor Henri Capron, who thoroughly encouraged and supported me in this project of international collaboration. Financial assistance from Université Libre de Bruxelles is gratefully acknowledged. This paper is part of NBER's research program in Productivity.

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ABSTRACT

Coe and Helpman (1995) have measured the extent to which technology spills over between industrialized countries through the particular channel of trade flows. This paper re-examines two particular features of their study. First, we suggest that their functional form of how foreign R&D affects domestic productivity via imports is probably incorrect. We provide an alternative model which turns out to be more accurate, both theoretically and empirically. Second, we take into account two new potential channels of technology transfer: inward FDI and technology sourcing, as proxied by outward FDI. The empirical results show that outward FDI flows and imports flows are two simultaneous channels through which technology is internationally diffused. Inward FDI flows are not a significant channel of technology transfer. The hypothesis of technology sourcing associated with MNEs activities abroad is therefore confirmed while the widespread belief that inward FDI is a major channel of technology transfer is rejected.

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1. INTRODUCTION

To what extent do the innovations performed in a particular country spill over and benefit other countries? This question was the central concern of Coe and Helpman (1995) who analyze the extent to which technological activities diffuse between industrialized countries through the particular channel of trade flows. The objective of the present paper is to extend their study towards a wider apprehension of the mechanisms underlying the international diffusion of technology. In this respect, two specific features are re-examined. First, we introduce a new functional form of how foreign R&D affects domestic productivity via import flows. This new model appears to be more accurate, both theoretically and empirically. Second, we put forward that trade is not the only channel through which technology disseminates across countries. We suggest that both inward and outward foreign direct investment (FDI) might be efficient channels for the dissemination of technology across countries. We rely on Coe and Helpman's database to reestimate and extend their model along these two issues. The paper is organized as follows. The next section presents the new methodology and compares it with Coe and Helpman's results. In section 3 inward and outward FDI are included in the empirical analysis as two potential channels for the international diffusion of technology. Section 4 concludes.

2. AN ALTERNATIVE ANALYTICAL FRAMEWORK

Coe and Helpman relate their empirical model to the theoretical models of 'innovation-driven' growth (see Grossman and Helpman (1991)). Their objective is to assess how foreign technical advances contribute to improve domestic productivity. More precisely, the idea is to evaluate the indirect benefits emanating from imports of goods and services that embody the technological knowledge of trade partners. Their simplest equation has the following form:

$$log\, F_{it} = \alpha_i^0 + \alpha^d \, log\, S_{it}^d + \alpha^f \, log\, S_{it}^{fm} + \varepsilon_{it} \, , \qquad (1)$$

where i = 1,.., 22 is a country index, α^0 is a country-specific constant, α^d is the output elasticity of domestic R&D capital stock, α^f is the output elasticity of foreign R&D capital stock, ε_{it} is the error term, log F is the logarithm of total factor productivity, S^d represents the domestic R&D capital stock, and S^{fm} represents the foreign R&D capital stock defined as the import-share-weighted average of the domestic R&D capital stocks of trade partners:

$$S_i^{fm} = \sum_j \frac{m_{ij}}{m_{i.}} \cdot S_j^d \quad , \qquad (2)$$

where m_{ij} is the flow of imports of goods and services of country i from country j ($i \neq j$); $m_{i.}$ is the total imports of country i from its 21 trade partners: $m_{i.} = \sum_j m_{ij}$. As quoted by Coe and Helpman:

> « *The specification of (1) may not capture adequately the role of international trade. Although, the foreign stock of knowledge S^{fm} consits of import weighted foreign R&D capital stocks, these weights are fractions that add up to one and therefore do not properly reflect the level of imports. It might be expected that whenever two countries have the same composition of imports and face the same composition of R&D capital stocks among trade partners, the country that imports more relative to its GDP may benefit more from foreign R&D.* ». [p. 863]

Therefore, they put forward a modified specification of (1) that should take into account the interaction between foreign R&D capital stocks and the propensity to import:

$$log\, F_{it} = \alpha_i^0 + \alpha^d\, log\, S_{it}^d + \alpha^f \frac{m_{it}}{y_{it}}\, log\, S_{it}^{fm} + \varepsilon_{it}\,, \qquad (3)$$

where m_i is the total imports of country i and y_i is country i's GDP[1]. Here the elasticity of output with respect to the foreign R&D capital stock equals $\alpha^f\ (m_i/y_i)$. This specification seems to be very convenient since it allows the elasticity to vary across countries in proportion to their import shares[2]. There is however a theoretical drawback associated to the computation of the foreign R&D capital stock: it is highly sensitive to a potential merger between countries. Assume a world with three countries, whit the following GDPs (y) and domestic R&D capital stocks (r) for countries 2 and 3: y2 = 40, y3 = 40, r2 = 10, r3 = 20. Then, if country 1 imports 10 from country 2 and 10 from country 3, its foreign R&D capital stock (f) should be calculated as follows:

$$f1 = \frac{10}{20}\cdot 10 + \frac{10}{20}\cdot 20 = 15$$

If we assume that countries 2 and 3 merge into one single country, the foreign R&D capital stock of country 1 becomes (with the same trade flows as before):

$$f1' = \frac{20}{20}\cdot 30 = 30$$

which is twice as large as the foreign R&D capital stock estimated from two distinct countries. That is, the foreign R&D capital stock estimated as in equation 2 suffers from an aggregation bias. Why should the foreign R&D

[1] The use of total imports on GDP ratio overestimates the real level of imports from industrialized countries. In Japan for instance, the imports from OPEC countries accounted for roughly twice the imports from the United States during the eighties.

[2] At this stage, Coe and Helpman make an analogy with microeconomic studies to put their use of import shares in context (cfr. foot note 3, p. 863). They are right in the sense that the studies of technological spillovers commonly seek a metric, such as technological closeness in order to gauge the intensity of spillovers (see Scherer (1982), and Griliches and Lichtenberg (1984), or Terleckyj (1980) who rely on input-output flows or inter-industry technological flows matrices in order to evaluate the degree of inter-industry R&D spillovers). In the context of international trade, this analogy refers to specification (1), not to specification (3).

capital increase when countries merge? We suggest that what really matters is the real R&D intensity embodied in the import flows of country i. In this case, the foreign R&D capital stock should be computed as in specification (4), the imports of country i from country j being naturally embodied with the R&D intensity of country j:

$$\log F_{it} = \alpha_i^0 + \alpha^d \log S_{it}^d + \alpha^f \log \sum_j \frac{m_{ijt}\, S_{jt}^d}{y_{jt}} + \varepsilon_{it}, \tag{4}$$

where y_{jt} is country j's GDP. Then, the foreign R&D capital stock of country 1 would be:

$$f1 = \frac{10}{40}\cdot 10 + \frac{20}{40}\cdot 10 = 7.5$$

and after the merger between country 2 and country 3, the stock becomes:

$$f1' = \frac{(10+20)}{(40+40)}\cdot 20 = 7.5$$

The ratio is unaffected by the reunification of the two countries[3]. A rational test is to compare the explanatory power of specifications (1) and (3) proposed by Coe and Helpman to the explanatory power of specification (4). However, the methodology used by Coe and Helpman in order to estimate specification (3) may also be improved. The authors have transformed all variables into index numbers (1985=1) because TFP is measured in country specific currencies whereas both R&D capital stocks are in constant 1985 US PPPs. The transformation of the TFP variable in index numbers is legitimate, since it provides comparable series across countries; though the authors could have relied on exchange rates (the same as those used for the R&D variables) to transform the components of the total factor productivity variable in constant 1985 US PPPs. The transformation of the R&D capital stocks into index numbers may also be justifiable, though it is an

[3] The ratio would be affected by the merger if country 2 and country 3 had different GDP levels; however the difference would be marginal as compared to the previous import shares methodology.

unnecessary procedure since they have been computed in a comparable currency. In the case of specification (1), even if the dependent variable is expressed in index numbers, it makes no differences to use the R&D variables in index or in levels. Since the indexed variables are equal to the levels variables divided by a constant (i.e. the 1985 value) for each country, the fixed country effects of specification (1) would incorporate the denominators used to index each country's R&D capital stocks. This may be illustrated as follows. Assume that S is the level of the foreign R&D capital stock, then estimating its impact on TFP, as indexed 1985=1, is equivalent to estimate this specification:

$$\log F_{it} = \alpha_i^0 + \alpha^f \log \frac{S_{it}}{S_{i,85}} ,$$

which can be expressed as:

$$\log F_{it} = \alpha_i^0 + \alpha^f \log S_{it} - \alpha^f \log S_{i,85}$$

$$\log F_{it} = (\alpha_i^0 - \alpha^f \log S_{i,85}) + \alpha^f \log S_{it} ,$$

since all the components in parentheses are constant over time, the estimated output elasticity of foreign R&D is not affected. Only the estimated country specific constants will differ. In specification (3), however, the estimated elasticities are not invariant with respect to indexation. The authors multiply the import share to GDP ratio by the log of the foreign R&D capital stock indexed for each country as 1985=1. Here, this procedure would yield different results than with the level variables as shown here under:

$$\log F_{it} = \alpha_i^0 + \alpha^f \frac{m_{it}}{y_{it}} \log \frac{S_{it}}{S_{i,85}} \qquad (5)$$

$$\log F_{it} = \alpha_i^0 + \alpha^f \frac{m_{it}}{y_{it}} \log S_{it} - \alpha^f \frac{m_{it}}{y_{it}} \log S_{i,85} .$$

The third term can not be incorporated into the country specific contants because it is now time varying. Clearly, the estimate of α^f in eq. (5) would not in general be the same as the estimate of α^f in the original equation (6).

$$\log F_{it} = \alpha_i^0 + \alpha^f \frac{m_{it}}{y_{it}} \log S_{it} \tag{6}$$

This means that equation (3) would be misspecified by the transformation of the foreign R&D capital stock variable in indices. The first two rows of table 1 (regressions (i) and (ii)) present the estimated parameters of specifications (1), (3) as presented by Coe and Helpman. In the second part of table 1, regressions (iii) and (iv) replicate the same estimations with our data, the variables being also transformed in indices. Our database comes mainly from Coe and Helpman's appendix except the bilateral import flows from 1971 to 1990, which means that our results may be slightly different. Then the third part of table 1 shows the estimated parameters of specifications (1), (3), and (4); all the R&D variables being expressed in levels. These three regressions (v) to (vii) could be considered as being particular cases of the following more general specification (7), in which the output elasticity of domestic R&D is allowed to differ between G7 and other countries by interacting the domestic R&D stock with a dummy variable that takes the value of 1 for G7 countries:

$$\log F_{it} = \alpha_i^0 + \alpha^d \log S_{it}^d + \alpha_7^d \, G7 \log S_{it}^d + \alpha^f \left[\frac{m_{it}}{y_{it}}\right]^{\theta_1} \log \left[\sum_j \frac{m_{ijt} \cdot S_{jt}^d}{m_{i.t}^{\theta_2} \cdot y_{jt}^{\theta_3}}\right] + \varepsilon_{it} \tag{7}$$

Except for the G7 dummy variable, specification (1) is equivalent to specification (7) with the parameters θ_1 and θ_3 constrained to zero and θ_2 to one. In specification (3), only θ_3 is set equal to zero. Specification (4) corresponds to specification (7) with the paramaters θ_1 and θ_2 constrained to equal zero and θ_3 to equal 1. In the last row of table 2, regression (viii) presents the non linear estimates of specification (7), which aim at comparing specifications (1) and (4). This test should be helpful to choose between total domestic imports and the GDP of the trade partners as the best denominator in the computation of foreign R&D capital stocks.

Regressions (i) and (ii) are two basic specifications reported by Coe and Helpman, where the impact of domestic R&D is allowed to differ between the largest seven economies compared with the other 15 economies[4]. As expected, the parameters of regressions (iii) and (iv) are very close to the parameters estimated by Coe and Helpman presented in (i) and (ii). We attribute the very small variations to the different databases used for bilateral import flows matrices. As observed by Coe and Helpman, the output elasticities of domestic R&D capital stock have a value which correspond to the values usually estimated for single country studies. However, the same output elasticities are much higher for the G7 countries, well above the usual estimates from single country studies. The coefficients of the foreign R&D capital stock are significantly different from zero but vary substantially with the specifications used.

Specification (1) yields an estimated output elasticity of foreign R&D equal to 0,06 in both regressions (i) and (iii). The impact of the foreign R&D capital stock is much stronger when it interacts with the share of imports in GDP. The corresponding estimates of specifications (1) and (3) are provided in regressions (v) and (vi), where the explanatory variables are now expressed in levels instead of indices. As expected from the previous discussion, regression (v) yields exactly the same parameters as regression (iii), which is estimated with the R&D variables expressed in indices.

[4] The authors performed different cointegration tests which appeared to yield conflicting results, though the balance seemed to tilt towards the recognition that the equation were cointegrated. However, they recognized that the econometrics of pooled cointegration are not yet fully worked out and placed more emphasis on the a priori plausibility of the estimated parameters than on the tests for cointegration(see Coe and Helpman (1995) p. 870).

The problems lies with specification (3), when it is estimated with the foreign R&D capital stock as an index. Regression (vi) yields different estimates than regression (iv), although the two specifications seem similar. Further, with regression (vi) the estimated coefficient of the foreign R&D capital stock is very small and is no longer significantly different from zero. This confirms our conjecture that the way specification 3 estimates the impact of foreign R&D capital stock on TFP is statistically misspecified. We therefore turn to specification (4), which should characterize more properly the concept of foreign R&D capital stock. Regression (vii) gives credence to our supposition. The output elasticity of foreign R&D capital stock is equal to 11% and is highly significant. The adjusted R2 is much higher than with any of the previous regressions, which means that our R&D spillover variable allows for an improved approximation of the effect of foreign R&D on domestic output.

Regression (viii) aims at comparing specification (1) to specification (4). In other words, we want to test which variable -the GDP of the foreign country j or the total imports of country i- is best suited to 'scale' the domestic R&D capital stocks of the other countries. The parameter θ_2 is not significantly different from zero, while θ_3 is positive and not significantly different from 1. The restrictions imposed in regression (vii) are evidently not rejected by the data. That is, when computing a foreign R&D capital stock for country i, the ratio of imports from country j to the GDP of country j is a more efficient weight than the share of imports from country j in country i's total imports.

3. FDI: CHANNEL(S) OF INTERNATIONAL TECHNOLOGY TRANSFER?

The second issue proposed in this paper is to extend Coe and Helpman's analysis by formaly taking into account other potential channels of technology transfer. The traditional modes of international R&D diffusion - foreign technology payments, foreign R&D investments, R&D joint ventures- are obviously inter-related and typically closely associated to MNE's activities[5]. This underlines the need to take inward FDI into account in any attempt to measure international technological spillovers. Besides, a vast body of empirical research leaves aside the technology sourcing channel, though there is a strong evidence that the sourcing of foreign knowledge is a genuine practice firmly embodied in MNEs' behaviour[6]. The countries which are technological leaders have accumulated substantial scientific and technological capacities. This technological endowments is likely to be accessible to the foreign companies which set up production and research facilities inside the technological leader's boundaries. In this respect, a good indicator of technology sourcing would be outward FDI flows.

[5] Vickery (1986) has analysed the relative importance of foreign technology payments, foreign R&D investments, and FDI. His main conclusions are that both the foreign technology payments and foreign R&D investments are relatively weak in the process of international R&D spillovers, as compared to FDI.

[6] So far, because of the scarcity of information, very few analyses have been able to test the hypothesis of technology sourcing. The pioneer study has been realized by Kogut and Chang (1991) about Japanese FDI in the United States. Their main finding is that Japanese direct investments in the US is drawn to industries intensive in R&D. Furthermore, when the entries are disaggregated by mode (e.g. new plant or acquisition of equity) there is a significant indication that joint ventures are used for the sourcing and the sharing of US technological capabilities. With a similar analytical approach, Yamawaki (1993) finds that japanese firms enter the US and European markets by capturing existing local firms when Japanese parents suffer from a technological and/or comparative disadvantage as compared to their US and European competitors. On the other hand, when Japanese parents possess technological or comparative advantages, they choose to invest in and to establish new plants in the United States or Europe. Focusing on European industries, Neven and Siotis (1992) observe that FDI flows from abroad tend to be higher in those sectors where European technological intensity is higher than that of other industrialized countries.

The existing quantitative analysis of the impact of foreign technology on domestic productivity growth may be classified into two broad categories. On the one hand, a substantial amount of studies concentrate on the impact of inward FDI on the productivity growth of host countries. A positive impact is interpreted as being partly the results of technological diffusion but these studies do not take into account any technological indicators and yield conflicting results[7]. Technological spillovers are certainly not automatic consequences of inward FDI. On the other hand, some studies focus on the impact of foreign technology on domestic productivity growth. They consider that the technology is either non-embodied or embodied in traded goods or technology payments. These studies also yield conflicting results, depending on the country and/or the transfer channel considered. Nevertheless, there is more evidence toward the recognition of international R&D spillovers[8]. The main drawback of these studies on R&D spillovers is that they consider only one of the existing channels of R&D spillovers. FDI flows have barely been examined econometrically in a multicountry approach as a specific mean of technology transfer, though it is widely accepted that they should play a substantial role in the international diffusion of technology. The disadvantage of the studies which concentrate on the impact of FDI on the host country productivity is that they fail to

[7] Kokko (1992) provides a comprehensive survey of this literature. Despite the fact that a positive impact may be the result of different influences, most authors argue that if FDI benefit to the host country, it is at least partly due to technological diffusion. However they do not provide any evidence about the relative importance of technology diffusion. Caves (1974) classifies the externalities arising from FDI into three categories: the improvement of (i) allocative efficiency (fewer monopolistic distortions), (ii) higher technical efficiency (a more efficient use of existing resources), and (iii) increasing rates of technology transfer. Therefore, any positive impact of FDI on productivity growth does not necessarily means that technology transfer occurs between foreign affiliates and local firms.

[8] See the survey by Mohnen (1996). So far, the channels that have been used to measure the impact of international R&D spillovers are foreign technology payments (Soete and Patel (1985) and Mohnen and Gallant (1992)), disembedded[8] R&D spillovers (Bernstein and Mohnen (1994)), and trade flows (Coe and Helpman (1995)).

distinguish the technological transfer component of this impact from the other impact such as the increase in competition. In this section, our aim is to take into account several channels of technology transfer, including the technology that may spill over to other countries through FDI flows. In some way, we reconcile the two different approaches by incorporating a technological component into FDI flows.

In the light of the previous discussion, we hypothesize that both inward and outward FDI flows may serve as channels of international technology diffusion. Because FDI flows data are scarce over the period 1971-90, we test this assumption for only 13 out of the original 22 countries covered in the second section. The focus is now on a sample comprised by the USA, Japan, and eleven European countries (Luxembourg being associated to Belgium). We adopt the new specification proposed in this paper to construct three different foreign R&D capital stocks. The first one, the import-embodied foreign R&D capital stock (S_i^{fm}) is contructed as in equation (4), but with 13 countries. The foreign R&D embodied in inward FDI is computed as follows:

$$S_i^{ff} = \sum_j \frac{f_{ij}}{k_j} S_j^d \ , \qquad (8)$$

where f_{ij} are the FDI flows of country j towards country i and k_j is the gross fixed capital formation of country j. In principle, it might be preferable to specify FDI stocks as opposed to flows, but the construction or the use of FDI stocks is rendered difficult by missing data and by the heterogeneous methodologies adopted in different countries. The hypothesis of technology sourcing is tested with the foreign R&D capital stock embodied in country i's outward FDI:

$$S_i^{ft} = \sum_j \frac{t_{ij}}{k_j} S_j^d \text{ ,} \quad (9)$$

where t_{ij} are the FDI flows of country i towards country j. The econometric results are presented in table 2; regressions (i) to (iii) show the estimated output elasticities of each foreign R&D capital stock, depending on the assumed technology transfer channel. Regressions (iv) includes the simultaneous effects of two variables.

The estimated elasticity of the domestic R&D capital stock is still positive, significant and substantially higher for the large countries. Regression (i) includes the foreign R&D capital stock embodied in trade flows. Although the focus is limited to 13 countries, the estimated output elasticity of the foreign R&D variable (.117) is very close to the estimates of regression (vii) in table 1 (.109) performed with the 22 countries' panel. Regarding the impact of the R&D capital stock embodied in inward FDI, regression (ii) shows that there is no significant international R&D spillovers. This suggests that inward FDI does not yield substantial technology transfers from the home country to the host country. This result may be explained by the fact that the MNEs' aim when establishing subsidiaries abroad is certainly not to contribute to international technology diffusion, but rather to exploit more fully their own technological innovations.

In regression (iii), the output elasticity of the foreign R&D capital stock embodied in outward FDI flows is positive and highly significant. That is, the hypothesis of technology sourcing is confirmed by our estimates. Through their investments abroad, MNE's seem to be able to benefit from the foreign scientific base. Regression (iv) includes the foreign R&D capital stock variables embodied in outward FDI and in imports simultaneously. The output elasticities of the foreign R&D variables associated with outward FDI and imports are both significant, their amplitudes are hardly affected and the adjusted R-squared is higher than in the other three regressions, reinforcing the robustness of our results.

The output elasticities of the domestic R&D capital stocks are much smaller in regression (iv) than in regressions (i) to (iii). We may infer that not properly taking into account the different channels of international R&D spillovers leads to upwardly biased estimates of the elasticity of output with respect to domestic R&D capital stock. Average rates of return may be obtained by dividing the estimated elasticities by the appropriate ratios of R&D capital stocks to GDP. Our calculations (based on the estimated elasticities of regression (iv)) show that the average rates of return over the period 1971-90 of domestic R&D capital stocks was 51 percent in the G7 countries and 63 percent in the remaining smaller countries. This means that a \$100 increase in the domestic R&D capital stock in a G7 country raises its GDP by \$51 while in one of the 7 smaller countries the GDP would increase by \$63. This result is contradicting with Coe and Helpman's study who find a much higher rate of return on domestic R&D in the G7 countries than in the other smaller countries. Concerning the rate of return on foreign R&D, the estimates suggest that a \$100 increase in the foreign R&D capital stock of country i would increase its GDP by \$900 through import flows and by \$1470 through outward foreign direct investment. These very high values are due to the way the foreign R&D capital stocks are constructed.

Relying on the elasticities estimated in regression (iv), we are now able to compute two matrices of bilateral output elasticities of the domestic R&D

performed by foreign countries. The country i's output elasticity of country j's domestic R&D capital stock may be expressed as follows:

$$\frac{\partial \log y_i}{\partial \log S_j^d} = \frac{\partial \log y_i}{\partial \log S_i^f} \cdot \frac{\partial \log S_i^f}{\partial \log S_j^d} = \alpha^f \cdot \frac{\partial \log S_i^f}{\partial \log S_j^d} = \alpha^f \cdot \frac{\partial S_i^f}{\partial S_j^d} \cdot \frac{S_j^d}{S_i^f} \quad , \tag{10}$$

and since the foreign R&D capital stock depends on the domestic R&D capital stock of each other country:

$$S_i^f = \sum_j \frac{m_{ij} S_j^d}{y_j} \; ,$$

equation (10) becomes:

$$\frac{\partial \log y_i}{\partial \log S_j^d} = \alpha^f \cdot \frac{m_{ij}}{y_j} \cdot \frac{S_j^d}{S_i^f} \tag{11}$$

The estimated bilateral elasticities, for the two channels of R&D spillovers, are presented in table 3. For instance, a one percent increase in the US R&D capital stock raises the Japanese output by 0.07 percent through trade flows and by 0.03 percent through the Japanese outward FDI in the USA. On the other hand, a 1 percent increase in the Japanese R&D capital stock contributes to raise the US output by 0.04 percent through trade flows and by 0.001 percent through the US outward FDI in the Japanese economy. The mean 'international' impact of each country's R&D capital stock is illustrated in the last rows of table 3. A one percent increase in the US R&D capital stock induces a 0.02 percent increase of foreign output through trade flows and a 0.015 percent through outward FDI in the USA. For some countries, the impact of other countries' domestic R&D capital stock is greater through the technology sourcing channel than through import flows. This is particularly true for the effect of the US domestic R&D capital stock which benefit most of the other industrialized countries (except Japan) more through their outward investments in the US boundaries than through their imports from the USA.

4. CONCLUDING REMARKS

We resorted mainly to Coe and Helpman's database to replicate and extend their analysis of international R&D spillovers. Our empirical findings may be summarized as follows. (i) We provide a superior -both theoretically and empirically- model of how the R&D performed by other countries affects domestic output and productivity via trade flows. (ii) Our re-examination also suggest that some of the estimates presented by Coe and Helpman may have been based on inappropriately-indexed data. (iii) Outward FDI flows and import flows are two simultaneous channels through which technology spills over and benefits other industrialized countries. That is, while we confirm some of the empirical findings of Coe and Helpman about the role of international trade flows in the process of technology transfer, we also give credence to the hypothesis of technology sourcing associated with MNEs' activities abroad. Further, and contrary to the frequent conjectures, inward FDI flows do not contribute to the improvement of the technological base of the host economies.

Appendix: Data sources and definitions

The total factor productivity index F comes from Coe and Helpman (1995, table A.1); it is defined as $F = Y / \left[K^{\beta} L^{(1-\beta)}\right]$, where Y is value-added in the business sector, K is the stock of business sector capital, and L is employment in the business sector. All variables are constructed as indices with 1985=1. The coefficient β is the average share of capital income from 1987-89. See Coe and Helpman for a detailed description of the other data sources.

The estimates of domestic business sector R&D capital stocks are described in Coe and Helpman (p.878). We have reestimated the value of the domestic R&D capital stocks from the indices provided in table A.3 of Coe and Helpman and the value of the stock in 1990, provided in their table A.7. The domestic R&D capital stocks are in U.S. dollars, based on PPP's and in constant 1985 prices.

The three different foreign R&D capital stocks have been computed from the domestic R&D capital stock of each country. The formulas are presented in the text. The GDP and the Gross Fixed Capital Formation for each country comes from the OECD's *Main Economic Indicators*. For Israel, the GDP data are from the IMF's *Statistical Yearbook*. Bilateral imports flows were used for each year, from 1971 to 1990 based on data from the United Nation's *International Trade Statistics Yearbooks* (Coe and Helpman used data from the IMF's *Direction of Trade*). The ratios of the imports of goods and services to GDP come from Coe and Helpman's table A6 and are from the IMF's *Direction of Trade*. National total inward and outward Foreign Direct Investments flows come from three OECD publications: *Recent*

Trends in International Direct Investment (1981, 1987) and the *International Direct Investment Statistics Yearbook 1993*. In order to avoid sharp yearly fluctuations, the series of inward and outward FDI flows have been computed within a four years moving average framework (the average of the present and the three preceeding years). There are no complete time series of bilateral inward FDI flows over the period 1970-90.

We have computed two bilateral inward FDI shares matrices (representing for each country the distribution of inward FDI over the origin countries), one for the 70's and one for the 80's from the available data provided by the OECD publications during the two decades. We used these shares to estimate the yearly bilateral inward FDI flows from the total inward FDI flows described here above. From 1970 to 1975, the 70's weighting matrix has been used. From 1985 to 1990, the 80's weighting matrix has been used. For each year during the period 1975-1985, we assumed a constant yearly rate of growth of each components from the weighting components of the 70's matrix to the corresponding components of the 80's matrix. Since these weighting components have sometimes negative values, we have set all negative values to zero, because the stock of foreign R&D may be zero but not negative. The bilateral outward FDI flows are the transposed of the bilateral inward FDI flows, for each country and each year.

Table 1.

Total factor productivity estimation results - 22 countries, 1971-90, 440 observations[1]

	reg.	θ_1	θ_2	θ_3	α^d	α^d_7	α^f	R2 adj	St.er.
Coe and Helpman (1995) [2] Explanatory variables as indices, 1985=1	(i)	0	1	0	.089	.134	.060	.600	.046
cfr. table 3, p. 869	(ii)	1	1	0	.078	.156	.294	.630	.044
This study Explanatory variables as indices, 1985=1.	(iii)	0	1	0	.086 (.009)	.126 (.017)	.058 (.016)	.612	.050
	(iv)	1	1	0	.078 (.008)	.145 (.016)	.276 (.044)	.634	.048
Explanatory variables in levels	(v)	0	1	0	.086 (.009)	.126 (.017)	.058 (.016)	.612	.050
	(vi)	1	1	0	.103 (.008)	.144 (.017)	.004 (.004)	.600	.050
	(vii)	0	0	1	.059 (.008)	.086 (.017)	.109 (.012)	.665	.046
	(viii)	0	-1.241 (.937)	1.612 (.523)	.044 (.010)	.086 (.016)	.049 (.022)	.671	.046

1. The dependent variable is log (total factor productivity), indexed as 1985=1. Unreported country specific constants (within estimates). Standard errors in parentheses.
2. The authors do not report standard errors but note that all of them are one fourth (or less) smaller than the estimated coefficients, which means that all parameters are significantly different from zero.

Table 2 .

Total factor productivity estimation results - 13 Triad countries, 1971-90, 260 observations[1].

	(i)	(ii)	(iii)	(iv)
$\log(S_i^d)$	.036 (.009)	.089 (.009)	.049 (.008)	.017 (.008)
$\log(S_i^d) * G7$	.126 (.016)	.192 (.018)	.097 (.017)	.066 (.016)
$\log(\sum_j \frac{m_{ij}}{y_j} \cdot S_j^d)$	.117 (.012)			.090 (.011)
$\log(\sum_j \frac{f_{ij}}{k_j} \cdot S_j^d)$		-.001 (.005)		
$\log(\sum_j \frac{t_{ij}}{k_j} \cdot S_j^d)$			.056 (.005)	.044 (.005)
R2 adjusted	.765	.666	.770	.823
Standard error	.039	.046	.638	.034

1. The dependent variable is log (total factor productivity), indexed as 1985=1. Unreported country specific constants (within estimates). Standard errors between brackets. S^d = domestic R&D capital stock; m_{ij} is the flows of imports of country i from country j. y_j is country j's GDP; f_{ij} is the flows of FDI from country j to country i; t_{ij} is the flows of FDI from country i to country j; k_j is country j's gross fixed capital formation; G7 = dummy variable equal to 1 for the G7 countries and equal to zero for the other countries.

Table 3

International output elasticities of domestic R&D capital stocks, 1971-90

Import flows	GER	FRA	ITA	UK	BEL	DK	GRC	IE	NTH	PT	SP	USA	JAP
GER		.0172	.0058	.0178	.0080	.0009	.0000	.0002	.0188	.0001	.0004	.0168	.0048
FRA	.0278		.0066	.0172	.0093	.0004	.0000	.0002	.0087	.0001	.0007	.0172	.0030
ITA	.0292	.0203		.0124	.0044	.0005	.0000	.0001	.0080	.0001	.0004	.0145	.0019
UK	.0230	.0127	.0034		.0052	.0012	.0000	.0012	.0128	.0002	.0005	.0271	.0053
BEL	.0250	.0163	.0019	.0154		.0002	.0000	.0001	.0197	.0000	.0002	.0095	.0016
DK	.0288	.0059	.0020	.0226	.0032		.0000	.0001	.0080	.0001	.0002	.0116	.0033
GRC	.0278	.0101	.0070	.0130	.0032	.0005		.0001	.0084	.0000	.0003	.0097	.0077
IE	.0060	.0033	.0009	.0604	.0011	.0002	.0000		.0028	.0000	.0001	.0149	.0019
NTH	.0315	.0087	.0019	.0160	.0116	.0004	.0000	.0002		.0001	.0002	.0161	.0021
PT	.0195	.0134	.0045	.0218	.0033	.0004	.0000	.0001	.0063		.0019	.0176	.0032
SP	.0197	.0159	.0046	.0169	.0025	.0003	.0000	.0002	.0045	.0002		.0252	.0040
USA	.0158	.0071	.0032	.0224	.0021	.0004	.0000	.0002	.0032	.0001	.0003		.0358
JAP	.0070	.0034	.0011	.0065	.0007	.0004	.0000	.0001	.0010	.0000	.0001	.0719	
Outward FDI flows													
GER		.0046	.0009	.0067	.0027	.0002	.0000	.0001	.0025	.0000	.0003	.0249	.0002
FRA	.0040		.0014	.0138	.0029	.0001	.0000	.0000	.0010	.0000	.0004	.0188	.0001
ITA	.0061	.0150		.0056	.0024	.0000	.0000	.0000	.0002	.0000	.0007	.0114	.0000
UK	.0011	.0020	.0002		.0006	.0000	.0000	.0000	.0019	.0000	.0001	.0357	.0000
BEL	.0053	.0068	.0010	.0130		.0001	.0001	.0000	.0052	.0000	.0002	.0130	.0000
DK	.0049	.0034	.0002	.0224	.0007		.0000	.0000	.0003	.0000	.0002	.0116	.0000
GRC	.0048	.0026	.0012	.0066	.0000	.0000		.0000	.0003	.0000	.0000	.0276	.0000
IE	.0001	.0008	.0003	.0223	.0007	.0000	.0000		.0002	.0000	.0001	.0188	.0000
NTH	.0016	.0025	.0003	.0079	.0015	.0001	.0000	.0000		.0000	.0002	.0286	.0001
PT	.0032	.0163	.0016	.0147	.0034	.0000	.0000	.0000	.0000		.0028	.0022	.0000
SP	.0048	.0045	.0018	.0124	.0029	.0000	.0000	.0000	.0001	.0006		.0151	.0001
USA	.0031	.0026	.0006	.0337	.0014	.0001	.0000	.0001	.0028	.0000	.0002		.0007
JAP	.0012	.0006	.0001	.0045	.0004	.0000	.0000	.0000	.0004	.0000	.0000	.0344	
Average elasticity of foreign output													
Imports	.0156	.0084	.0032	.0163	.0035	.0005	.0000	.0002	.0060	.0001	.0003	.0200	.0170
Outward FDI	.0026	.0031	.0006	.0186	.0015	.0001	.0000	.0001	.0018	.0000	.0002	.0146	.0003
Average elasticity of domestic output													
	.083	.083	.083	.083	.017	.017	.017	.017	.017	.017	.017	.083	.083

Estimated elasticity of output in the row country with respect to the R&D capital stock in the column country. Based on regression (iv) of table 2 and on equation (11). Averages are calculated using GDP weights.

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