International R&D spillovers: A comment

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Abstract

Coe and Helpman presented evidence consistent with the hypothesis that technology spills over across countries through the channel of trade flows, and provided estimates of the magnitude of these spillovers. We re-examine two features of their econometric model. First, we argue that the weighting scheme they used to compute foreign R&D capital stocks is subject to an "aggregation bias". We suggest an alternative weighting scheme that is theoretically much less biased and that yields somewhat better empirical results. Second, we correct an "indexation bias" and generalise their empirical framework by analysing how the output elasticity of foreign R&D depends on a country's openness to trade. The empirical results confirm that the more open to trade a country is, the more likely it is to benefit from foreign R&D.

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1. Introduction

In this paper we re-examine two aspects of Coe and Helpman (1995)'s empirical model of the "propagation mechanism" of international R&D spillovers embodied in

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trade flows. First, we suggest that the weighting scheme they used to compute foreign R&D capital stocks is subject to a kind of "aggregation bias." We suggest an alternative weighting scheme that is theoretically much less biased and that yields somewhat better empirical results. Second, we argue that Coe and Helpman may have improperly indexed some variables in their analysis of how a country's openness to trade affects its output elasticity of foreign R&D, and attempt to correct this "indexation bias". In the next section we discuss the issues of aggregation and indexation. Estimates of our revised specification (based essentially on the same data Coe and Helpman constructed and used) are presented in section 3, and conclusions are reported in Section 4.

2. Aggregation and indexation issues

Coe and Helpman (CH) relate their empirical model to the theoretical models of 'innovation-driven' growth. Their objective is to assess how foreign technical advances contribute to 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 basic equation has the following form:

$$\log TFP_{it} = \alpha_i^0 + \alpha^d \log S_{it}^d + \alpha_7^d \, G7 \log S_{it}^d + \alpha^f \log S_{it}^{f-CH} + \varepsilon_{it} \ , \qquad (1)$$

where log *TFP* is the logarithm of total factor productivity; i = 1, ...,22 is a country index; t = 1, ..., 20 is a time index ranging from 1971 to 1990; α^0 is a country-specific constant; α^d is the output elasticity of the domestic R&D capital stock (S^d), which is allowed to differ between the G7 and other countries by interacting the domestic R&D

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capital stock with a dummy variable that takes the value of 1 for G7 countries; α^f is the output elasticity of the foreign R&D capital stock; ε is the error term; and $S^{f\text{-}CH}$ represents the foreign R&D capital stock defined as the import-share-weighted average of the domestic R&D capital stocks of trade partners:

$$S_i^{f-CH} = \sum_{j \neq i} \frac{m_{ij}}{m_{i.}} \cdot S_j^d \quad , \tag{2}$$

where m_{ij} is the flow of imports of goods and services of country i from country j; $m_{i.}$ is the total imports of country i from its 21 trade partners: $m_{i.} = \Sigma_j \; m_{ij}$. This formulation implicitly assumes that a country will reap, *ceteris paribus*, more international R&D spillovers if it imports more from countries with a relatively high domestic R&D capital stock. As noted by Coe and Helpman[1], however, the weighting vector in (2) reflects the "direction" of R&D spillovers but not their "intensity". They therefore proposed a modified version of (1) in which the foreign R&D capital stocks interacts with the propensity to import:

$$\log TFP_{it} = \alpha_i^0 + \alpha^d \log S_{it}^d + \alpha_7^d \; G7 \log S_{it}^d + \alpha^f \frac{m_{it}}{y_{it}} \log S_{it}^{f-CH} + \varepsilon_{it} \quad , \tag{3}$$

where m_i is the total imports of country i and y_i is country i's GDP. Here the elasticity of output with respect to the foreign R&D capital stock equals α^f * (m_i/y_i); this specification allows the elasticity to vary across countries and time in proportion to their import shares. In particular, the higher the total imports relative to GDP, the more a domestic economy will benefit from foreign R&D.

1 « *The specification of (1) may not capture adequately the role of international trade. Although the foreign stock of knowledge $S^{f\text{-}CH}$ consists 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].

CH's procedure for constructing foreign R&D capital stocks is not invariant to the level of data aggregation. A merger between countries would always increase the stock of foreign R&D calculated according to (2). We propose an alternative measure of foreign R&D that is much less sensitive to the level of data aggregation. Our proposed measure is

$$S_{it}^{f-LP} = \sum_j \frac{m_{ijt}\, S_{jt}^d}{y_{jt}}, \qquad (4)$$

where y_{jt} is country *j*'s GDP. This formulation reflects the intensity as well as the direction of international R&D spillovers. According to (4), the stock of R&D that country *i* "receives" from country *j* is country *j*'s R&D stock times the fraction of country *j*'s output that is exported to country *i*. Measures of "imported" or "embodied" R&D similar to (4) have been used in previous empirical studies of inter-industry technology flows. With this alternative weighting scheme, the stock of foreign R&D becomes approximately equal to the amount of total imports multiplied by the R&D/GDP ratio of the larger ex-country; if the two merging countries were the same size, the foreign R&D capital stock would not be affected at all by the merger. Table 1 presents the values of the foreign R&D capital stocks of the US and Japan in 1990, before and after a hypothetical merger of the eleven EC countries, computed from the CH data under the two alternative methods.

Insert Table 1 about here

The merger substantially increases the US and Japanese foreign R&D capital stocks calculated using the CH formula by more than 100% and 25%, respectively, whereas it reduces only marginally (by 4% and 2%, respectively) the capital stocks calculated using our formula. Since the $S^{f\text{-}LP}$ measure is more robust to arbitrary choices about data aggregation, one might expect it to have greater explanatory power in the *TFP* regression; we will determine whether it does in the next section.

The statistical methodology used by Coe and Helpman to estimate specification (3) may also be improved upon. 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. Due to the presence of fixed country effects in specification (1), it makes no difference in this equation whether the R&D variables are expressed as levels or as indexes (the levels divided by a constant - e.g., the 1985 value for each country): the fixed country effects would incorporate the denominators used to index each country's R&D capital stocks. Only the estimated country specific constants would 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. If *S* represents the level of the foreign R&D capital stock, then estimating its impact on *TFP*, as indexed 1985=1, is equivalent to estimating this specification:

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

The third term cannot be incorporated into the country-specific constants because it is time varying. Clearly, the estimate of α^f in equation (5) would not, in general, be the same as in equation (6) (with no indexation of the variables), implying that equation (3) would be misspecified by the transformation of the foreign R&D capital stock variable into indices.

$$\log TFP_{it} = \alpha_i^0 + \alpha^f \frac{m_{it}}{y_{it}} \log S_{it} \cdot \qquad (6)$$

3. Econometric results

The first two rows of Table 2 show the estimates of specifications (1) and (3), similar to the ones reported by Coe and Helpman (cf. their Table 4, P. 869), in which all the R&D variables are expressed as indexes. Our estimates are slightly different because we compiled our own data on bilateral import flows from 1971 to 1990[2] (these were not reported in Coe and Helpman's appendix, from which the remainder of our data comes). The second part of Table 2 shows the estimated parameters of specifications (1), (3), and (4); all the R&D variables being expressed in levels. The three regressions *(v)* to *(vii)* might be considered as special cases of the following more general specification:

$$\log TFP_{it} = \alpha_i^0 + \alpha^d \log S_{it}^d + \alpha_7^d \; G7 \log S_{it}^d + \alpha^{fm} \left[\frac{m_{it}}{y_{it}}\right]^{\theta_1} \log\left[\sum_j \frac{m_{ijt} \cdot S_{jt}^d}{m_{i.t}^{\theta_2} \cdot y_{jt}^{\theta_3}}\right] + \varepsilon_{it} \cdot \qquad (7)$$

Specification (1) is equivalent to specification (7) with the parameters θ^1 and θ^3 constrained to equal zero and θ^2 constrained to equal one. In specification (3), only θ^3 is set equal to zero. LP's weighting scheme corresponds to specification (7) with the parameters θ^1 and θ^2 constrained to equal zero and θ^3 to equal 1. Regression *(vi)* presents the non-linear estimate of specification (7), which includes (nests) the two alternative weighting schemes as special cases. Estimates of this model should help us to determine whether total domestic imports or the GDP of the trade partner is the more

[2] Bilateral imports flows are from the United Nation's *International Trade Statistics Yearbooks* (Coe and Helpman used data from the IMF's *Direction of Trade*). Data on GDP's are from the OECD's *Main Economic Indicators* for the 21 OECD countries, and from the IMF's *Statistical Yearbook* for Israel.

appropriate denominator (scale factor) in the computation of foreign R&D capital stocks.

Specification (1) yields an estimated output elasticity of foreign R&D equal to 6% in regression *(i)*. The impact of the (indexed) 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 *(iii)* and *(iv)*, where the explanatory variables are now expressed in levels instead of indices. As expected from the previous discussion, regression *(iii)* yields exactly the same parameters as regression *(i)*, which is estimated with the R&D variables expressed in indices. The problem lies with specification (3), when it is estimated with the foreign R&D capital stock as an index. Regression *(iv)* yields different estimates than regression *(iv)*, although the two specifications seem similar. Further, the estimated coefficient of the foreign R&D capital stock is very small and seems no longer significantly different from zero. This confirms our conjecture that the way specification (3) estimates the impact of the foreign R&D capital stock on *TFP* is statistically misspecified.

Insert Table 2 about here

Regression *(v)* presents the results with LP's measure of the foreign R&D capital stock. The output elasticity of foreign R&D capital stock is equal to 11% and the adjusted R-squared is higher than in any of the previous regressions, which suggests that $S^{f\text{-}LP}$ allows for an improved approximation of the effect of foreign R&D on domestic *TFP*. Regression *(vi)* aims at testing 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 apparently not significantly different from zero, while θ^3 is positive and not significantly different from 1. The restrictions imposed in regression *(v)* 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 appropriate weight than the share of imports from country *j* in country *i*'s total imports.

Coe and Helpman concluded from their econometric results - more particularly from regression *(ii)* - that foreign R&D has stronger beneficial effects on domestic productivity the more open an economy is to foreign trade. This observation does not appear to be supported by regression *(iv)*. Nonetheless, the question may be re-examined by adding among the right-hand side variables the total import share variable, and allowing it to interact with the foreign R&D variable (e.g., θ^l=1). In doing so, regressions *(vii)* and *(viii)* show that the import share has a negative impact on output growth which is compensated by the large amplitude taken by the parameter associated to its interaction with the foreign R&D variable (25% with CH and 31% with LP)[3].

These estimates imply that, unless the foreign R&D capital stock is very large, an increase in openness reduces *TFP*, which is counterintuitive. If one takes the two alternative foreign R&D capital stock averaged over all countries, both regression results would mean that the average effect of import share on *TFP* is zero[4]. This could be interpreted as follows: it is not the intensity of imports *per se* that matters, but rather

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[3] When the import share is included among the RHS variables, with θ^l set to zero (e.g., no interaction is allowed), its impact is insignificant.

[4] Let us compute from regression (*viii*): [d log (*TFP*) / d *m* = -2.8 + .31 log ($S^{f\text{-}LP}$)], or from regression (*vii*): [d log (*TFP*) / d *m* = -3.0 + .25 log ($S^{f\text{-}CH}$)]. The impact of *m* on *TFP* is positive as long as log ($S^{f\text{-}LP}$) is greater than 9 or as long as log ($S^{f\text{-}CH}$) is greater than 12. With the LP weighting scheme, 13 countries have an average foreign R&D capital stock under the required threshold, while with the CH weighting scheme 15 countries are under the required threshold.

the distribution of the countries of origin. The more you import from highly R&D intensive countries, the larger the impact of foreign R&D. This is true with both weighting schemes. With the import share added among the explanatory variables, regression *(ix)* confirms that the LP weighting scheme is probably more appropriate than the one suggested by CH; θ^2 is not significantly different from zero and θ^3 is not significantly different from 1.

An additional method for testing the stability of the estimated elasticities of foreign R&D is to interact the foreign R&D variable with a dummy variable (*M8L)* that takes the value of one for the eight countries characterised by the lowest values of openness to trade[5]. In regression *(x)* the output elasticity of foreign R&D computed with CH's weighting scheme is equal to 8.9% for highly open economies, but is negative (-4.4% = 8.9% - 13.3%) for the countries with a low propensity to import. This result is somewhat puzzling since it means that foreign R&D would actually decrease domestic productivity growth in countries that are relatively weakly open to trade. Regression *(xi),* which is based on the alternative weighting scheme, provides more plausible results. For relatively closed economies, the estimated output elasticity of foreign R&D is positive (5.4%) but it is lower than that of relatively open economies (13.2%).

4. Concluding remarks

Coe and Helpman presented evidence consistent with the hypothesis that technology spills over across countries through the channel of trade flows, and provided

[5] The eight countries are the US (with a ratio of total imports on GDP equal to 9%), Japan (10%), France, Italy, Canada, Australia, Spain (24%), and Germany (24%).

estimates of the magnitude of these spillovers. We have re-examined two features of their econometric model. First, we argued that the weighting scheme they used to compute foreign R&D capital stocks is subject to an "aggregation bias". We suggested an alternative weighting scheme that is theoretically much less biased and that yields somewhat better empirical results. Second, we corrected an "indexation" bias and generalised their empirical framework by analysing how the output elasticity of foreign R&D depends on a country's openness to trade. The empirical results confirm that the more open to trade a country is, the more likely it is to benefit from foreign R&D.

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Reference

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Table 1.
Stylised facts: The sensitivity of the US and Japanese foreign R&D capital stock to a potential merger of the eleven EC countries[1].

	USA		Japan	
weighting scheme:	CH	LP	CH	LP
Before the merger	124.6	27.8	514.7	16.4
After the merger	259.6	26.8	644.2	16.1
Difference	+108%	-4%	+25%	-2%

1. These figures represent the value, in billion of US$, of the US and Japanese f oreign R&D capital stocks computed over 21 industrialised countries, before and after the merger of eleven EC countries. CH is Coe and Helpman's weighting scheme of equation (2), LP is the alternative weighting scheme of equation (4).

Table 2.
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	α^m	α^f_{M8L}	R^2-adj (Std. err.)
Explanatory variables as indices, 1985=1.	*(i)*	0	1	0	.086 (.009)	.126 (.017)	.058 (.016)	-	-	.612 (.050)
	(ii)	1	1	0	.078 (.008)	.145 (.016)	.276 (.044)	-	-	.634 (.048)
Explanatory variables in levels	*(iii)*	0	1	0	.086 (.009)	.126 (.017)	.058 (.016)	-	-	.612 (.050)
	(iv)	1	1	0	.103 (.008)	.144 (.017)	.004 (.004)	-	-	.600 (.050)
	(v)	0	0	1	.059 (.008)	.086 (.017)	.109 (.012)	-	-	.665 (.046)
	(vi)	0	-1.241 (.937)	1.612 (.523)	.044 (.010)	.086 (.016)	.049 (.022)	-	-	.671 (.046)
Import share introduced	*(vii)*	1	1	0	.082 (.008)	.145 (.016)	.249 (.043)	-3.014 (.529)	-	.628 (.048)
	(viii)	1	0	1	.082 (.007)	.112 (.015)	.310 (.026)	-2.768 (.239)	-	.700 (.044)
	(ix)	1	-.581 (.674)	.955 (.262)	.063 (.008)	.123 (.015)	.165 (.077)	-2.643 (.532)	-	.709 (.043)
Differentiation of α^f for low openness[2]	*(x)*	0	1	0	.083 (.009)	.191 (.019)	.089 (.016)	-	-.133 (.029)	.630 (.048)
	(xi)	0	0	1	.057 (.008)	.137 (.021)	.132 (.013)	-	-.078 (.020)	.677 (.045)

1. The dependent variable is log (total factor productivity), indexed as 1985=1. All equations include country specific fixed effects (within estimates). Standard errors in parentheses. The θ's are the exponents in specification (7); θ_1 is the exponent on the ratio of imports to GDP; θ_2 is the exponent on country *i*'s total imports and θ_3 is the exponent on country *j*'s GDP.
2. The estimated elasticity of foreign R&D capital stock is differentiated for the countries with the lowest degree of openness to trade, cf. foot note 5.