

Are International R&D Spillovers Trade-related? Analyzing Spillovers among Randomly Matched Trade Partners*

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Abstract

In this paper, I analyze recent findings by Coe and Helpman (1995) of trade-related international R&D spillovers. I show generally that randomly created bilateral trade shares also give rise to large estimated international R&D spillovers; often, in fact, to larger estimated spillover effects which are more precisely estimated than by employing the 'true' bilateral trade shares. This casts some doubt on the earlier results in the literature.

1. Introduction

The recent development of theories of endogenous technological change, in particular by Romer [6] and Aghion/Howitt [1], have triggered new work on the relations of trade, growth, and technological change in open economies. Most important is the monograph by Grossman and Helpman [4]. These authors embed the new theories in

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multi-sector, multi-country general-equilibrium models to analyze the impact of both trade in intermediate as well as final goods on long-run growth. Technology diffuses in this framework through being embodied in intermediate inputs: If R&D expenditures create new intermediate goods which are different (the horizontally differentiated inputs model) or better (the quality ladder model) from those already existing, and if these are (also) exported to other economies, then the importing country's productivity is improved through the R&D efforts of its trade partner.

Even before the advent of the models of endogenous technological change, a vast literature had developed which related domestic R&D expenditures to total factor productivity (TFP) growth. The particular contribution of the new models of trade and growth therefore lies in the testable hypotheses one can derive with regard to trade and openness. Coe and Helpman [3] have recently attempted to test one of these. These authors suggest that the following testable prediction can be derived and tested empirically: *Ceteris paribus*, if one country imports to a large degree from other countries which have accumulated high levels of technological knowledge, it should exhibit higher productivity levels than if it would import less from 'high-tech' countries.

At the center of the analysis by Coe-Helpman is what the authors call the "foreign stock of knowledge". This variable is constructed as a weighted sum of the cumulative R&D expenditures of a country's trading partners. The weights are given by the bilateral import shares.¹ According to Coe-Helpman, their analysis

"underlines the importance of the interaction between international trade and foreign R&D" (p.860).

Coe and Helpman conclude their analysis by stating that

"not only does a country's total factor productivity depend on its own R&D capital stock, but, as suggested by the theory, it also depends on the R&D capital stocks of its trade partners." (p.875).

Hence, Coe and Helpman argue that their analysis supports the view that international R&D spillovers are trade-related. The present paper investigates this claim.

¹This is in analogy to the R&D-total factor productivity literature; since Terleckyj [7], several authors have related R&D expenditures in industry $i \neq j$ to the TFP growth of industry j , where for instance input-output coefficients serve as weights.

2. Theory and Empirical Implementation by Coe-Helpman

Coe and Helpman's [3] empirical specification is derived from models which have endogenized the process of technological change. I will give here only a sketch of one type of model (the horizontally differentiated-inputs specification). Assume that final output y is produced according to

$$y = Ak^\alpha d^{1-\alpha}, \text{ with } 0 < \alpha < 1, \quad (2.1)$$

where A is a constant, k are capital services, and d is a composite input consisting of horizontally differentiated varieties $x(s)$

$$d = \left(\int_0^n x(s)^{1-\alpha} ds \right)^{\frac{1}{1-\alpha}}.$$

Here, $n = n(t)$ is the range of intermediate inputs existing in this economy at time t (ignoring integer constraints). Because intermediates enter symmetrically, if only one unit of labor is needed to create a unit of any $x(s)$, it will be the case that l , the total labor employed in the production of intermediate goods, will be given by

$$l = n\bar{x},$$

where \bar{x} is the equilibrium quantity of intermediates employed. Substituting in (2.1) gives

$$y = Ak^\alpha n^\alpha l^{1-\alpha}.$$

Hence, if one defines $\log F = \log y - \alpha \log k - (1 - \alpha) \log l$ as the log TFP level, one obtains that

$$\log F = \log A + \alpha \log n. \quad (2.2)$$

This says that the log TFP level should be positively related to the range of intermediate inputs existing at that time.

We assume that entrepreneurs invest in R&D ($r(t)$), which expands the available range of designs for new intermediate inputs: $\dot{n}(t) = ar(t)$, where a is a constant. If designs never become obsolescent, the stock of intermediate inputs available at time T is

$$n(T) = \int_{-\infty}^T \dot{n}(t) dt = a \int_{-\infty}^T r(t) dt \equiv aS^d(T), \quad (2.3)$$

that is, it is proportional to the cumulative R&D expenditures, $S^d(T)$. Hence, for a single country, by substituting (2.3) into (2.2), we arrive at the prediction that the log TFP level is positively related to the country's cumulative R&D expenditures

$$\log F = \mu + \alpha \log S^d,$$

where $\mu \equiv \log A + \alpha \log a$. International trade among several countries allows to import newly developed intermediates from abroad. If all intermediates worldwide would be tradable to the same degree, then any country's TFP level would depend solely on the world's cumulative R&D expenditures. Because the tradability of intermediates differs, though, Coe and Helpman [3] suggest that a foreign knowledge stock variable for any country i , S_i^f , be constructed as follows:

$$S_i^f = \sum_{h \neq i} \left(\frac{m_{hi}}{m_i} S_h^d \right), \forall i. \quad (2.4)$$

Here, m_{hi} are the bilateral imports of country i from country h , and m_i are total imports of country i . Hence, the construction of the variable S_i^f weights the cumulative R&D expenditures of country i 's trading partners by their bilateral import share with country i . Coe and Helpman [3] mention several effects trade can have, ranging from learning about new technologies and production processes to learning about new organizational methods to the direct import of goods and services developed by trade partners. In this way the specification captures the notion that the domestic economy will reap, *ceteris paribus*, more international spillovers if it trades relatively more with countries which have invested heavily in R&D, and hence have large domestic knowledge stocks, S^d .²

Coe and Helpman's first specification is therefore given by

$$\log F_i = \beta_{0i} + \beta_1 \log S_i^d + \beta_2 \log S_i^f + \varepsilon_i, \forall i, \quad (2.5)$$

where ε_i is an error term. Taking this a step further, these authors argue that for a given composition of a country's trade partners, it should be the case that the domestic economy benefits more from R&D activities abroad the higher are overall imports relative to GDP; let s_i denote the import share of country i . This argument presupposes that there are some productivity effects which are tied to the volume of trade (especially

²Clearly, some of these effects are not unique to trade in goods. Foreign direct investment, for instance, can result in the same. Similarly, not all of these effects are related to the volume of trade; see below.

some of the learning effects mentioned above).³ Hence, Coe and Helpman's second specification is therefore

$$\log F_i = \beta_{0i} + \beta_1 \log S_i^d + \beta_2 (s_i \log S_i^f) + \varepsilon_i, \forall i. \quad (2.6)$$

In the Coe-Helpman sample, there are 21 OECD countries plus Israel, for the years 1971-90, making a total of 440 observations. The authors present three regressions in the paper: The one given in (2.5), a second one augmenting (2.5) with an additional effect for the G 7 countries, and the equation (2.6). In Table 1, I reproduce the Coe-Helpman results (their Table 3) as a first step. Each of the following regressions includes unreported country-specific intercepts.

TABLE 1			
TFP estimation results (pooled data; 440 observations)			
	(i)	(ii)	(iii)
$\log S^d$	0.097 [0.097]	0.090 [0.089]	0.078 [0.078]
$G7 * \log S^d$		0.135 [0.134]	0.157 [0.156]
$\log S^f$	0.092 [0.092]	0.060 [0.060]	
$s * \log S^f$			0.289 [0.294]
R^2	0.630 [0.558]	0.683 [0.621]	0.706 [0.651]

For comparison, I have given Coe-Helpman's results in hard brackets.⁴ Note that there are differences in the R^2 of the regressions; the R^2 of the regressions presented here is higher than in Coe-Helpman. There are also very small differences in the point estimates of the coefficients; the largest on the variable $s * \log S^f$, which is 0.294 in Coe-Helpman, whereas it is 0.289 in regression (iii) presented here. These discrepancies are most likely due to data revisions immediately preceding the publication of Coe and

³These effects are not captured by the model as sketched above; see Grossman/Helpman [4], Ch.6.5, for more on this.

⁴In this table, I follow Coe-Helpman who do not give standard errors, because they think of their regressions as cointegrating equations. In that case the conventional standard errors are biased and not asymptotically normal. Solely for the record: All coefficients are significantly different from zero at a 5% level if the conventional standard errors are used.

Helpman's paper, which I could not incorporate so far. However, the point estimate differences are, in any case, very small.⁵

3. The Monte-Carlo Approach: Simulating Bilateral Trade Shares

In evaluating the hypothesis that international R&D spillovers are trade-related, the foreign knowledge stock variable S^f constructed by Coe-Helpman is of central interest. A country's R&D benefit from abroad is taken to be a weighted average of these foreign countries' R&D efforts, where the weights are given by the bilateral import shares. I call this matrix BTS ; the values for 1990 are reproduced from Coe-Helpman in Table 2. For instance, 29.94% of the US imports came from Canada, as opposed to only 1.07% of Germany's. In consequence, the level of the Canadian cumulative R&D expenditure should be much more relevant to the US than it is for Germany. Further, international R&D spillovers are expected to be large if a country imports primarily from 'high-knowledge' economies within this sample of developed countries.

In the following, I will compare the estimation results of Coe and Helpman with those obtained from assigning bilateral trade partners randomly.⁶ That is, rather than constructing the foreign knowledge stock variable S^f using the observed bilateral trade share matrix BTS , I use random trade share matrices (denoted RTS) and re-do the Coe-Helpman regressions (i)-(iii). For each Monte Carlo experiment I obtain one matrix RTS of 22×22 random elements constructed in the following way: 440 (22×22) elements of a matrix Γ are drawn from a uniform distribution using the (pseudo) random number generator of the GAUSS package.⁷ I then set the diagonal elements of Γ , $\gamma_{ii}, \forall i$, equal to zero. In the next step the sum of each column is calculated, $\gamma_{\bullet i} = \sum_{h \neq i} \gamma_{hi}$. Finally, shares σ_{hi} are formed by

$$\sigma_{hi} = \frac{\gamma_{hi}}{\gamma_{\bullet i}}, \quad \forall h, i, \quad (3.1)$$

with $\sum_h \sigma_{hi} = 1, \forall i$. The 22×22 matrix containing the random shares σ_{hi} is denoted RTS , the random trade share matrix.⁸

⁵I am using data which was provided by David Coe to Chihwa Kao; I thank the latter for transferring the data electronically to me.

⁶See also Ben-David (1995), who has used a random-country-grouping-method to the question of trade and income convergence. He shows that there is more income convergence in groups formed on the basis of trade interaction than in random groupings of countries.

⁷I use a seed value which is updated during the process; the initial seed value is 26875.

⁸Coe-Helpman ([3]) use bilateral trade shares which are varying from year to year from 1971 to 1991. Therefore I will also present results below for the case where the RTS matrix is re-build every year.

With the RTS matrix (and the variable S^d) in hand, I calculate the variable S^f , and then run the Coe-Helpman regressions (i)-(iii). For each of the regressions, I conduct 1000 experiments; the following Table 3 reports the average estimated coefficient and the average estimated standard error (in brackets).

TFP estimation results (pooled data; 440 observations)						
	(i)		(ii)		(iii)	
	<i>BTS</i>	<i>RTS</i>	<i>BTS</i>	<i>RTS</i>	<i>BTS</i>	<i>RTS</i>
$\log S^d$	0.097 (0.009)	0.028 (0.011)	0.090 (0.008)	0.034 (0.010)	0.078 (0.008)	0.048 (0.008)
$G7 * \log S^d$			0.135 (0.016)	0.097 (0.016)	0.157 (0.015)	0.158 (0.014)
$\log S^f$	0.092 (0.016)	0.157 (0.013)	0.060 (0.015)	0.126 (0.014)		
$s * \log S^f$					0.289 (0.041)	0.337 (0.030)
R^2	0.630	0.703	0.683	0.728	0.706	0.749

The estimates of central interest are the coefficients on $\log S^f$ and $s * \log S^f$. From Table 3 it is clear that the regressions based on simulated data generate (on average) larger estimated foreign R&D spillovers, as well as a better fit in terms of R^2 . This does not support the argument that the actually observed trade patterns are behind the estimated international R&D spillovers. Figure 1 shows a histogram of the experiment (i), RTS , in Table 3.

Further inspection of Table 3 shows that in the regressions based on simulated data the elasticity of the cumulative domestic R&D expenditures (S^d) is estimated to be smaller than in the Coe-Helpman regressions. One wonders, therefore, whether the larger estimated coefficients on S^f using random shares is just a mirror image of that effect. Therefore, I conduct the following two-step simulations: In step one, I regress the log TFP on country-specific effects and the (log) S^d variable.⁹ I then subtract the

⁹When the G 7 dummy is part of the specification, also this variable is included in the first-step

fitted value of that regression from $\log TFP$, and employ the result as dependent variable in the step two-regression on the $\log S^f$ variable, either created using the 'true' trade shares (BTS) or random shares (RTS). The results of this can be seen in Table 4.

Two-step TFP estimation results; second step shown (pooled data; 440 observations)						
	(i)		(ii)		(iii)	
	<i>BTS</i>	<i>RTS</i>	<i>BTS</i>	<i>RTS</i>	<i>BTS</i>	<i>RTS</i>
$\log S^f$	0.037 (0.010)	0.043 (0.007)	0.023 (0.009)	0.029 (0.007)		
$s * \log S^f$					0.118 (0.026)	0.132 (0.020)
R^2	0.031	0.070	0.014	0.040	0.044	0.093

As one sees from Table 4, (1) the average point estimate using random bilateral shares in this two-step analysis is always larger than in the corresponding regression using the observed trade shares; (2) the average estimated standard error is smaller, and (3) the random share variable accounts for more of the variation left in the (purged) $\log TFP$ levels. This result does not depend on the fact that the random share regressions reported in Table 4 use time-invariant random shares for each experiment, corresponding to using the same bilateral trade shares for all years 1971-90.¹⁰

In Figure 2, I show a frequency distribution of the 1000 experiments underlying regression (i), RTS . The plot underlines the point which is already clear from the mean estimate given in the table, that the random share-constructed variable results generally in a higher estimated foreign spillovers effect. However, looking at Figure 3, which shows the 99% confidence region of the experiment, the estimate resulting from the 'true' trade shares can also be thought of being a draw in the random share experiment.

This is the interpretation underlying Table 5, which presents the bilateral trade shares for one particular of the 1000 runs of regression (i), RTS , in Table 4: The shares

regression.

¹⁰The corresponding point estimates (standard errors) are for the regressions (i)-(iii) when the shares are newly drawn every year: (i) $\log S^f$: 0.043 (0.007), $R^2 = 0.070$; (ii) $\log S^f$: 0.029 (0.007), $R^2 = 0.040$; (iii) $s * \log S^f$: 0.132 (0.020), $R^2 = 0.093$. Beyond the 3-digit level which is reported here, the standard errors of the estimates using time-varying random shares are slightly smaller.

presented in Table 5 result in an estimated coefficient on the variable $\log S^f$ of 0.037, which is the same estimate as is obtained on $\log S^f$ in a regression which builds on the observed bilateral trade shares; see Table 4, regression (i), column *BTS*. The upshot of this is that we can compare the observed trade shares m_{hi} in Table 2 with the random shares σ_{hi} given in Table 5. For instance, given the importance of the United States as a technological leader in most fields throughout the period of observations, one would certainly expect that the fact that Japan has imported most of its goods from the USA (45.77% in 1990) is important for assessing the importance of trade for Japanese TFP growth - if the hypothesis of technological knowledge embodied in imported goods is correct. However, we see from Table 5 that the same elasticity with respect to S^f , the foreign knowledge stock, is estimated in a different world where Japan imports only 4.2% of its goods from the US. Or take Canada as another example: It has been importing most of its goods from the US (in 1990: 75.93%). But Table 5 shows that in another world where Canada imports more from Portugal than from the US (8.7% versus 7.5%), we estimate the same effect on the foreign knowledge spillover term $\log S^f$. This analysis clearly suggests that it is problematic to infer from the Coe-Helpman findings that it is indeed trade in goods which transmits international R&D spillovers.¹¹

4. Conclusion

In this paper, I showed that the finding of international R&D spillovers is not unique to an analysis which builds on observed bilateral trade shares; the same qualitative results, and usually quantitatively more important, are found in a systematic study where trade partners are matched at random. The answer to the question posed in the title is therefore clear: We do not know yet whether international R&D spillovers are trade-related; the available evidence, at any rate, does not provide strong support for the hypothesis.

No attempt has been made in this paper to address the original question: What is (is there?) a relation of trade and international technology diffusion? In order to make future progress on that question in the framework of recent models of trade and growth, two questions need to be addressed. First, if the estimation equation correctly corresponds to a (recent trade-and-growth) structural model, would the empirical implementation of Coe-Helpman allow to find conclusive evidence? Chances are that

¹¹Note that Table 2 given only the shares for 1990, not for all years between 1971 and 1990, as does Table 5. Any distorting effect resulting from that, however, is unlikely to be the major reason of why the matrices are as dissimilar as in fact they are: Ireland, for instance, did not only import most of its goods by far (44.55%) from the UK in 1990, but also between 1971 and 1990. The corresponding value for σ_{hi} , though, is only 5.2%.

it would not. For one, the constructed foreign knowledge stock, has, in the light of the considerable uncertainty involved in calculating the domestic R&D stocks (leading to measurement errors), only a small chance of fully and appropriately capturing the trade-relatedness of international R&D spillovers. It is conceivable that any signal which might be in the bilateral trade shares is perfectly confounded through the noise in the domestic R&D stock variables. For another, it is the flows of total merchandise trade which are used in this approach, not intermediate input trade flows. Even though the countries in the sample are a rather homogenous group (OECD plus Israel), this will introduce an error, the effects of which are difficult to judge.

The second question which needs to be addressed: Is the estimation equation indeed corresponding to the recent model(s) of trade and growth? It appears that the link from structural model to the estimation equations so far is not as tight as one would hope. For instance, already the construction of the variable S^f implies that spillovers are tied to the volume of imports. The basic structural model underlying this analysis, however, would predict that spillover effects are forthcoming whenever any quantity, however small, of a new intermediate input is imported.¹²

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¹²See Keller [5] for more on this.

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