Trade and the Transmission of Technology

Wolfgang Keller
Department of Economics
University of Wisconsin-Madison*

This version: September 1996

Abstract

This paper studies the role of trade, both domestically as well as internationally, as a channel of technology transmission. A model is presented in which R&D investments towards product innovations trigger total factor productivity growth at the industry level. If the new products are exported to other industries, the return to the R&D investments does in part spill over to these industries. The model predicts that total factor productivity levels are positively related to both own-, and the domestic and foreign industry R&D investments of the trade partners. Using data on trade relations between OECD country sectors, effective R&D stocks are constructed which should pick up technology flows that are trade-related. The empirical results, which are comparative to a benchmark model where trade relations play no role, find generally only weak support for the notion that the transmission of technology is trade-related; more specifically, they point more towards domestic than to international trade. At the same time, the results suggest that the adopted approach might not be powerful enough to identify trade-related technology flows, which has implications for other areas of research which have used analogous approaches before.

1. Introduction

The question of whether goods trade at arm's length contributes to the transmission of new technologies is both old and new: it is an old question in a closed-economy context, because there exist many studies which examine whether research and development (R&D) investments–creating technology–in one industry affect productivity also in other industries. These other industries are often, at least in part, identified through input-output relations–trade as channel of transmission–between industries (see e.g., Griliches 1984). In the open-economy context, however, the idea that trade might be contributing to the international transmission of technology has been emphasized particularly recently.

There has been no consensus for a long time on the question why, on average, outward-oriented economies grow more rapidly (see, e.g., World Bank 1987, Rodrik 1995). Two important issues were the following: First, if the trade models were static, and markets were competitively (as was the case

*1180 Observatory Drive, Madison WI 53706. Email: wkeller@facstaff.wisc.edu. An earlier version of this paper circulated under the title: "International R&D Spillover and Intersectoral Trade Flows: Do they Match?". I thank seminar audiences at Colorado-Boulder, UW-Madison, the NBER Summer Institute, Purdue, and Yale, especially R.Evenson, Z.Griliches, J.Harrigan, K.Maskus, T.N.Srinivasan, and M.Thursby. I also thank C.Langer for providing data on trade flows, and M.Craw for the US import input-output data.

in most of them), then they predicted static gains from trade which were very small compared to the real-world differences in productivity growth between the average open and protectionist countries. However, once models predicting positive productivity growth rates even in the long-run (e.g., Romer 1990) were placed into an open-economy context, changes in the trade regime could have both long-run and large growth effects.

Another issue was: how is trade contributing to productivity growth? According to one view, trade is affecting a country's growth rate through its effects on domestic resource allocation. One problem with this view is that trade is predicted to generate the same growth effects as other influences which alter the domestic resource allocation. Specifically, a purely domestic tax-and-subsidy policy can achieve exactly what trade achieves. An alternative view, therefore, holds that international trade directly affects productivity growth because it is transmitting technological knowledge from country to country (Rivera-Batiz/Romer 1991, Grossman/Helpman 1991). In those models, if R&D investment creates new technology in form of a construction design for a new intermediate product, and this product is traded internationally, the receiving country can benefit from employing the new, imported intermediate good without having first to invent the construction design by itself. In this sense, importing a foreign intermediate good allows to capture its R&D-, or 'technology-content'.[1] For given primary resources, in this model, productivity is increasing in the range of different intermediate goods which are employed, because these are assumed to be imperfect substitutes for each other. The model's predictions is that TFP is positively affected by the country's own, as well as R&D investments made by trade partners.

It is clear from this, however, that the framework is open to another interpretation: that it captures the process of technology transmission between different sectors within one economy. This model could well serve as a theoretical underpinning of the empirical analyses in the closed-economy studies referred to earlier. Indeed, as an empirical matter, this model might even be a better description of technology diffusion within an economy than across economies. This paper, therefore, attempts to provide a unified and balanced approach in analyzing the importance of trade for the transmission of technology along these lines both internationally as well as domestically.

Earlier work in an international setting includes Eaton/Kortum (1996), Coe/Helpman (1995), and Coe, Helpman, and Hoffmaister (1995). In the latter two papers, the authors use country-level data to examine whether countries productivity levels (or growth rates) are positively affected by domestic as well as import-share weighted foreign R&D investments. Because Coe/Helpman and Coe et al. find that to be true, they suggest, contrary to the results obtained by Eaton/Kortum (1996) using a different framework, that imports are important vehicles for the international diffusion of technology. The research on input-output related spillover effects closed-economy industry-analysis can be traced back to Terleckyj (1974), and a good overview is provided by the papers in Griliches (1984).

This paper departs from earlier work in several respects: First, I will be using industry-level data also on international transactions, as opposed to the country-level data employed by Coe/Helpman (1995), Coe et al. (1995), and Eaton/Kortum (1996). It has been argued that studies employing aggregate data are likely to miss much of the technology flows, because the diversity of sectoral characteristics as well as the very nature of technology diffusion confound any inferences from that data (e.g., Branstetter 1996). Using two- or three-digit industry level data should reduce this problem. Secondly, and related to the first, the usage of industry-level data allows to integrate the recent emphasis on the open-economy relations with earlier work, in particular by Terleckyj (1974) and Scherer (1984), which had stressed

[1] Note that direct technology spillovers (in the sense of the employed intermediate good revealing anything about its construction design to this industry's R&D entrepreneurs) are not necessary for the importing country to experience productivity gains.

domestic intersectoral technology transmission. The advantage of this is that all market transactions predicted by the theoretical model, both domestic as well as international, are considered, as opposed to only focusing on a subset of those.

Third, I compare the empirical performance of the R&D-driven growth and intermediates inputs trade model with estimates from a benchmark model where technology transmission is unrelated to goods trade. This comparison has rarely been made.[2] It is used to assess exactly how important trade is in the relation of R&D investments on the one, and productivity growth on the other hand. Further, this comparative approach encompasses both the domestic as well as the international elements of the technology-transmission-is-trade-related hypothesis. Therefore, it might be possible to find out whether technology transmission is brought about through trade relatively more in the domestic, rather than in the international context (or vice versa).

Lastly, a more general point of this paper is that it is advocating a simple comparison analogous to the one proposed below to evaluate the empirical importance of any specific weighting matrices which have been used in a variety of contexts: apart from the papers mentioned so far, for instance, Jaffe (1986) and Park (1995) have constructed matrices of technological distance between sectors in work on technological diffusion and spillovers,[3] Englander, Evenson, and Hazanaki (1988) construct technology flow matrices which are similar in spirit, and Bartelsman, Caballero, and Lyons (1994) have used input-output matrix weights in search of so-called customer- and supplier driven externalities. In any of these analyses, a test analogous to what is being proposed here might prove useful.

The remainder of the paper is as follows. In the next section, I develop the benchmark model. Section 3 then describes the R&D-driven growth and intermediate inputs model, first for a closed-economy, and then extending it to an international context. In section 4, I describe the data which will be used. Section 5 gives the estimation results and the comparison of the benchmark and trade-relations models, and section 6 concludes.

2. The Benchmark Model

Consider a model with I different countries, $i = 1, ..., I$, and J different goods, indexed by j, $j = 1, ..., J$. Output is being produced according to a Cobb-Douglas production function which includes both domestic as well as foreign R&D capital stocks (time subscripts are dropped for better readability)

$$q_{ij} = A_{ij} \left(b^p_{ij}\right)^{\nu} \left(b^p_{-ij}\right)^{\mu} l^{\alpha}_{ij} k^{1-\alpha}_{ij} \;, \; 0 < \alpha < 1,$$

where q_{ij} is output, A_{ij} is a constant, b^p_{ij} denotes the domestic cumulative R&D stock, b^p_{-ij} is an aggregator of foreign cumulative R&D stocks, l_{ij} are labor services, and k_{ij} denotes physical capital.[4] A priori, one would expect both ν and μ to be positive: higher R&D stocks, irrespective of whether domestically or foreign, increase, ceteris paribus, domestic output. For specificity, assume that b_{-ij} is just the sum of the foreign cumulative R&D stocks in industry j

$$b^p_{-ij} = \sum_{h \neq i} b^p_{hj}, \;\; \forall i, j. \tag{2.1}$$

[2]The approach taken here differs from Keller (1996a), who uses Monte-Carlo techniques to evaluate the claim of Coe/Helpman (1995) that international R&D spillovers are trade-related.

[3]Also Branstetter (1996) builds partly on Jaffe (1986).

[4]The presentation of the theory assumes that $\alpha_{ijt} = \alpha, \forall i, j, t$; however, as described in the appendix, the data is constructed by using labor shares which vary by country, industry, and over time.

Define an index of TFP, f_{ij}, as $f_{ij} = \frac{q_{ij}}{l_{ij}^{\alpha} k_{ij}^{1-\alpha}}$.Then, substituting and taking logs, one has

$$\ln f_{ij} = \ln A_{ij} + \nu \ln b_{ij}^{p} + \mu \ln b_{-ij}^{p}. \tag{2.2}$$

Adding a random disturbance with mean zero, ε_{ij}, equation (2.2) predicts that in a OLS regression

$$\ln f_{ij} = \alpha_{ij} + \beta^{d} \ln b_{ij}^{p} + \beta^{f} \ln b_{-ij}^{p} + \varepsilon_{ij}, \tag{2.3}$$

the coefficient $\hat{\beta}^{d}$ is an estimate of the domestic elasticity, ν, and the coefficient $\hat{\beta}^{f}$ is an estimate of the structural parameter μ.

3. R&D-Driven Growth and Intermediate Inputs Trade

Alternative to the benchmark model just laid out, I now consider a typical model of the Grossman/Helpman, Romer variety, in which long-run growth is endogenously driven by R&D investments, and technology is being transmitted via trade in intermediate inputs. I develop a closed-economy version first.

3.1. Domestic Intersectoral Trade

Assume that good z_j is produced according to

$$z_j = A_j\, l_j^{\alpha} d_j^{1-\alpha}, \tag{3.1}$$

where A_j is a constant, l_j are labor services used in final output production, and d_j is a composite input consisting of horizontally differentiated goods x of variety s. Specifically, d_j is given by

$$d_j = \left(\int_0^{n_j^{de}(s)} x_j(s)^{1-\alpha}\, ds \right)^{\frac{1}{1-\alpha}}. \tag{3.2}$$

The variable n_j^{de} denotes the range of intermediate inputs which are employed in this sector (ignoring integer constraints). Distinguish n_j^{de} from n_j^{p}, the range of intermediate inputs produced in any sector j; the latter is increased by entrepreneurs devoting resources to R&D. Denote with ϕ_j^{p} the flow of R&D expenditures in sector j. Let the blueprints of new inputs be created simply according to $\dot{n}_j^{p} = \phi_j^{p}$. These resources could be in form of labor services which have an alternative use in the output sector.[5] If designs never become obsolete, the stock of intermediate inputs produced in sector j at time T is equal to $n_j^{p}(T) = \int_{-\infty}^{T} \dot{n}_j^{p}(t)dt = \int_{-\infty}^{T} \phi_j^{p}(t)\, dt$, that is, proportional to the cumulative R&D resources at time T. Define, as in the benchmark case, $n_j^{p}(T) \equiv b_j^{p}(T)$.

Assume that one unit of any intermediate good requires one unit of sectoral output. Then, if capital k_j is defined as cumulative foregone sectoral output, this will be equal to $k_j = \int_0^{n_j^{p}(s)} x_j(s)\, ds$. In a symmetric equilibrium, all intermediates x are produced at the same level, so that $k_j = n_j^{p} x_j$. Rearranging for x, and substituting into (3.2) leads to the following expression for output[6]

$$z_j = A_j' \left(n_j^{de}\right)^{\alpha} l_j^{\alpha}\; k_j^{1-\alpha},$$

[5]This presentation does not fully account for those; see, e.g., Romer (1990) for a complete description.

[6]Here, $A_j' = A_j \left(n_j^{de}/n_j^{p}\right)^{1-\alpha}$. In the following, I will ignore the term $\left(n_j^{de}/n_j^{p}\right)^{1-\alpha}$, expecting that this will not crucially affect the estimation below.

Defining another index of TFP, f_j^*, as $f_j^* = \frac{z_j}{l_j^\alpha k_j^{1-\alpha}}$,and taking logs results in

$$\ln f_j^* = \ln A_j' + \alpha \ln n_j^{de}. \tag{3.3}$$

Note that in equation (3.3), f^* is positively related not to the range of intermediates which have been invented in sector j (n_j^p), but those which are employed there (n_j^{de}). Empirically, I intend to approximate the range of intermediates employed as the weighted average of the ranges of intermediates of all sectors, where the weights are given by the input-output relations of the sectors (see Terleckyj 1974)

$$n_j^{de} = \sum_{v=j}^{J} \omega_{jv} n_v^p, \ \forall j.$$

Let Ω be the matrix of observed input-output coefficients, with a typical element ω_{jv}

$$\Omega = \begin{bmatrix} \omega_{jj} & \omega_{jv} & \omega_{jw} & \cdots \\ \omega_{vj} & \omega_{vv} & \vdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \cdots & \cdots & \cdots & \ddots \end{bmatrix}$$

In terms of observables, this means that the effective domestic R&D stock which affects TFP in sector j is

$$b_j^{de} = \Omega_j \, b_v^p, \ v = j, ..., J, \ \forall j.$$

Here, Ω_j, of dimension $(1xJ)$, is the jth row of Ω, and b_v^p is of dimension $(Jx1)$. Hence, b_j^{de} is an input-output weighted average of the cumulative R&D stocks of all sectors v. Substituting, this leads to

$$\ln f_j^* = \ln A_j' + \alpha \ln b_j^{de} = \ln A_j' + \alpha \ln \Omega_j \, b_v^p \tag{3.4}$$

3.2. International Trade

By looking at a single country, so far the productivity effects resulting from foreign R&D have been ignored. With the possibility of international trade, however, output producers in country i's sector j can employ intermediates from other countries h in addition to those from other domestic sectors, $v \neq j$.[7] Therefore, let d_{ij}^+ be

$$d_{ij}^+ = \left(\int_0^{n_{ij}^e(s)} x_{ij}(s)^{1-\alpha} \, ds \right)^{\frac{1}{1-\alpha}}. \tag{3.5}$$

Here, n_{ij}^e is the range of intermediates employed in country i's sector j, with $n_{ij}^e \geq n_{ij}^{de} \geq n_{ij}^p$. Intermediates can come from abroad, or from other sectors, or both. In a fully symmetric model where all intermediates are different from one another, and traded to the same extent, any of these types of intermediates will have the same productivity effects for the importing industry.[8] But suppose there is heterogeneity across

[7] This will happen in equilibrium. Analytic results for the symmetric two-country case are derived, e.g., in Keller (1996b).

[8] Define again the sectoral capital stock as foregone consumption of good j. Then $k_{ij} = k_{ij}^{ij} + k_{ij}^{-i-j}$, that is, the domestic capital stock can be split into resources which are used to produce ij intermediates (superscript ij), or into those which are–in form of intermediate inputs–used to exchange for inputs which are not produced in country i, or not in sector j, or neither (superscript $-i-j$). If the country-sector ij intermediate varieties are all produced at the equilibrium level $\tilde{x}_{ij}$, then $k_{ij}^{ij} = n_{ij}^p \tilde{x}_{ij}$, and $k_{ij}^{-i-j} = (I \times J - 1)\, k_{ij}^{ij}$. Therefore, $k_{ij} = (I \times J)\, n_{ij}^p \tilde{x}_{ij}$, or, $k_{ij} = n_w \tilde{x}_{ij}$, where n_w is the world range of available intermediate goods.

i and j. At the same time, we can approximate the domestic capital stock with

$$k_{ij} = n_{ij}^e \bar{x}_{ij},$$

where $\bar{x}_{ij}$ is the new equilibrium level when all varieties s of this intermediate are produced at the same level. Upon substitution, one obtains[9]

$$z_{ij}^+ = A_{ij}^+ \left(n_{ij}^e\right)^\alpha l_{ij}^\alpha \; k_{ij}^{1-\alpha}, \quad \forall i,j.$$

If f_{ij}^+ is defined as $f_{ij}^+ = \frac{z_{ij}^+}{l_{ij}^\alpha \, k_{ij}^{1-\alpha}}$, then one obtains

$$\ln f_{ij}^+ = \ln A_{ij}^+ + \alpha \ln n_{ij}^e, \quad \forall i,j. \tag{3.6}$$

As an empirical matter, it appears that the degree to which intermediates are used in sector ij differs significantly by whether the intermediate is of domestic or foreign origin. This not alone for reasons of transport costs related to distance, but also because of other implicit or explicit trade barriers such as tariffs, exchange rate risk, etc. This leads to a specification which allows for two separate coefficients,

$$\ln f_{ij}^+ = \ln A_{ij}^+ + \alpha_1 \ln n_{ij}^{de} + \alpha_2 \ln n_{ij}^{-de}, \quad \forall i,j.$$

Here, n_{ij}^{-de} denotes the range of intermediate goods which are employed in sector ij and imported from abroad. As argued above, the range of domestic intermediates employed in any sector ij will be related to the cumulative R&D investments of all domestic sectors, with intersectoral input-output relations serving as weights: $n_{ij}^{de} = \Omega_{ij}\, b_{iv}^p, v = j, ..., J, \;\forall i,j$. Then, define n_{Ij}^{de} as the $(Ix1)$ vector of variables n_{ij}^{de} from all I countries.

As far as the intermediates originating from abroad, a natural way of modeling these market transactions is to utilize bilateral import shares as weights (e.g., Coe/Helpman 1995); these are conceptually identical to the input-output relations capturing domestic trade transactions. Let m_{ihj} be the bilateral import share of country i from country h for industry j. Then, let $m_{iij} = 0, \forall i$, M_{ji} the $(1xI)$ vector of import relations of country i's sector j, and let M_j be the matrix which collects these bilateral import shares for sector j.

$$M_j = \begin{bmatrix} 0 & m_{hij} & \cdots & \cdots \\ m_{ihj} & 0 & \vdots & \vdots \\ m_{ih'j} & \vdots & 0 & \vdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

Further, let c_{ij} denote sector ij's bilateral import share-weighted sum of foreign R&D ,

$$c_{ij} = M_{ji}\, n_{Ij}^{de}.$$

Denote the $(13x1)$ vector of all these variables c_{ij} in country i by c_{iJ}.

An imported good classified as belonging to sector j, however, will not necessarily also be used in sector j of the importing country.[10] The matrix which captures those market relations is the import

[9] Here, $A_{ij}^+ = A_{ij} \left(n_{ij}^e / n_{ij}^p\right)^{1-\alpha}$.

[10] The Standard International Trade Classification (SITC) is partly product-, partly process-oriented, but certainly not mainly 'use'-oriented.

input-output matrix, which might be significantly different from the input-output matrix describing economy-wide domestic trade relations. Let γ_{ijv} denote the share of country i's imports of the j intermediate which go to the v industry, where $i = 1, ..., I$, and $j, v = 1, ..., J$. Let Γ_{ij} be the (1x13) vector whose elements are the import input shares of industry j from all industries $v, v = 1, ..., J$, and call Γ_i the corresponding matrix of all import input-output relations of country i.

$$\Gamma_i = \begin{bmatrix} \gamma_{ijj} & \gamma_{ijv} & \cdots & \cdots \\ \gamma_{ivj} & \gamma_{ivv} & \vdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

With these definitions, the range of foreign intermediates employed in sector ij, n_{ij}^{-de}, is given by

$$n_{ij}^{-de} = \Gamma_{ij}\, c_{iJ}, \forall i, j, \tag{3.7}$$

With a mean-zero random disturbance ε_{ij}, this leads to the following estimating equation

$$\ln f_{ij}^{+} = \alpha_{ij} + \beta^{\delta} \ln (\Omega_{ij}\, b_{iv}^{p}) + \beta^{\varphi} \ln (\Gamma_{ij}\, c_{iJ}) + \varepsilon_{ij}, \quad \forall i, j, v = 1, .., J. \tag{3.8}$$

It is clear from above that the foreign variable $n_{ij}^{-de} = \Gamma_{ij}\, c_{iJ}$ depends potentially on 7x13 foreign cumulative R&D stocks, and the domestic variable depends potentially on 13 cumulative R&D stocks. However, if $\omega_{hjj} = 1, \forall j$, and $\omega_{hjv} = 0, \forall j \neq v$, then $b_{ij}^{de} = b_{ij}^{p}$ because economy-wide intersectoral relations are non-existing. Denote this particular situation with $\Omega_i = \Omega_i^B$. Further, if international import relations are symmetric, then $m_{ihj} = m, \forall i, h, j$.[11] In that case, the R&D investments in all partner countries are weighted evenly. In this situation of symmetric trade patterns, let $M_j = M_j^B$. Finally, $\gamma_{ijj} = 1, \forall j$, and $\gamma_{ijv} = 0, \forall j \neq v$, then commodities of the j-type are only imported by the j industry, $\forall j$. Let Γ_i^B denote that situation:

$$\Omega_i^B = \Gamma_i^B = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots \\ 0 & 0 & \ddots & 1 \end{bmatrix}; \quad M_j^B = \begin{bmatrix} 0 & m & \cdots & m \\ m & 0 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots \\ m & m & \ddots & 0 \end{bmatrix}, \forall i, j. \tag{3.9}$$

Note that in the case where Ω_i^B, M_j^B, and Γ_i^B hold simultaneously, one has

$$n_{ij}^{de} = b_{ij}^{de} = b_{ij}^{p}, \forall i, j, \qquad \text{and} \qquad n_{ij}^{-de} = \textstyle\sum_{h \neq i}^{I} b_{hj}^{p}, \forall i, j. \tag{3.10}$$

This, however, is the same as in the benchmark model above:[12] Through the domestic channel, productivity is solely affected through own-industry R&D (b_{ij}^{p}), and the effect of foreign R&D on domestic TFP is appropriately captured by summing over all foreign same-industry R&D stocks, because neither economy-wide- (Ω_i) nor imports intersectoral (Γ_i), nor international trade patterns (M_j) play any role. In the following empirical analysis, I will not only compare whether a specification

[11]If the number of countries in the sample is equal to υ, then symmetric import relations imply that the import share m from any country equals $m = 1/\upsilon$.

[12]This is despite the fact that above, the foreign R&D variable is obtained by summing over all foreign sector j's cumulative R&D stocks, whereas in (3.8), one sums over $m = 1/\upsilon$ times these same R&D stocks; this will affect only the intercepts α_{ij}, but not the coefficients of interest β^{δ} and β^{φ}.

based on actual input-output and international trade relations performs better than the benchmark, $(\Omega_i^B, M_j^B, \Gamma_i^B)$-model, but also ask whether the transmission of technology is more closely related to domestic, as opposed to international trade, by imposing the structure of intersectoral and international trade (i.e., Ω_i, M_j,and Γ_i) step-by-step.

Before turning to this, I will outline the basic characteristics of the data.

4. Data

This paper uses data for eight OECD countries and the years 1970-1991 (for more details, see the appendix). The countries are Canada, France, Germany, Italy, Japan, Sweden, the United Kingdom, and the United States; hence, the G-7 group plus Sweden. I use industry classification with thirteen two- to three-digit manufacturing industries according to the UN International Standard Industrial Classification (ISIC).[13] A TFP (index) is constructed using the Structural Analysis industrial (STAN) database of the OECD (1994) by first calculating the growth of TFP as the difference between output and factor-cost share weighted input growth. Then, the level of TFP is normalized to 100 in 1970 for each of the 8*x*13 time series. In Table A.1, I show summary statistics on the TFP data.

As defined above, the unobservable technology stock variable *n* is identified with the sectoral cumulative R&D stocks, derived from OECD (1991) data on private R&D expenditures. This data covers all intramural business enterprise expenditures. Summary statistics on this data are given in Table A.2. The R&D stocks are derived from the R&D expenditure series using the perpetual inventory method.

Constructing the import-weighted foreign R&D capital stocks as described above requires data on bilateral import flows. These are obtained from the World Trade Data Base of the Hamburg Institute of Economic Research (HWWA). It is clear from the construction of the *n* variable that the origin of a given country's imports (together with the R&D efforts there) determines the size of the productivity effect in the domestic economy. In Tables A.3-1 and A.3-2, I show a subset of these bilateral import shares by sector (for sectors ISIC 31 and ISIC 384).

The input-output matrix Ω_i of the U.S. economy is employed for all countries in the sample; it is derived from the benchmark input-output Table 2 ('use of commodities by industry') published in U.S. Department of Commerce (1991). The 13x13 matrix of input-output coefficients can be found in Table A.4. The input-output matrix for imports, Γ_i, is also derived from US data, and assumed to be the same for all countries. It is based on unpublished material of the U.S. Department of Commerce (1996) on the use of commodities by industry in the import sector.[14] I have aggregated the 525 x 505 matrix up to the 13 x 13 industry classification used in this paper;[15] the result is shown in Table A.5.

[13] These are: (1) ISIC (adjusted revision 2) 31 Food, beverages, and tobacco; (2) ISIC 32 Textiles, apparel, and leather; (3) ISIC 33 Wood products and furniture; (4) ISIC 34 Paper, paper products and printing; (5) ISIC 351+352 Chemicals and drugs; (6) ISIC 353+354 Petroleum refineries and products; (7) ISIC 355+356 Rubber and plastic products; (8) ISIC 36 Non-metallic mineral products; (9) ISIC 37 Basic metal industries; (10) ISIC 381 Metal products; (11) ISIC 382+385 Non-electrical machinery, office and computing equipment, and professional goods; (12) ISIC 383 Electrical machines and communication equipment; and (13) ISIC 384 Transportation equipment.

[14] This data was collected for the 1987 benchmark survey. I thank Michael Craw at the BEA for providing it to me.

[15] The bilateral trade shares matrices M_j are averaged over time (1972-91); the input-output matrix Ω_i reflects the relations in the U.S. economy in the benchmark year of 1980, and the import input-output matrix Γ_i is for the benchmark year of 1987.