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Executive summary

Global innovation networks (GINs) are essential for the creation, transfer and absorption of new knowledge and ultimately economic growth. They are generally created on top of an already existing global production networks (GPNs), which contains technology embodied in the goods and services provided by numerous up-stream suppliers located in several different industries and countries. These up-stream suppliers not only differ in the nature and extent of their ability to create new technically relevant knowledge, but also in the way they use the technical knowledge already contained in goods produced in other industries and other countries. Input-output analysis describes the interdependencies in the national production system, and its interdependence in the global economy, and it provides a way to measure global technology flows at the industry level.

This research paper considers the measurement of the direct and indirect flows of knowledge between eight OECD countries, of which 5 are members of the European Union, and Brazil, China, India and South Africa. The OECD countries are seen as representative of the global technology frontier, with a mixture of small open (Norway, Sweden, Denmark) and large (relatively) closed economies (US, Japan, Germany, UK). The remaining four countries are considered to to be catching-up economies that are becoming increasingly integrated into both GPNs and GINs. Input-output tables covering the years 1995, 2000 and 2005 were used to measure domestic and international product-embodied knowledge flows, and completed with data on R&D at the industry level and bilateral trade statistics.

The analysis found that seven of the eight countries on the technology frontier appear mainly as net exporters of embodied technology and that the four countries below the frontier to be net importers of embodied technology. Italy was the main exception to the rule, but this was relative to the other countries included in the analysis. There is strong evidence that GPNs are evolving into GINs in China as this country appears to have become less dependent on imported technology and it may have increased their contribution of embodied technology into these networks during the first half of the 2000s. There is some evidence that something similar is happening with Estonia. By contrast, there is also strong evidence that Brazil and South Africa have become more dependent on technology it imports from the eight countries on the frontier.

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1. Introduction

Global innovation networks (GINs) are essential for the creation, transfer and absorption of new knowledge and ultimately economic growth. They are generally created on top of an already existing global production networks (GPNs), which contains technology embodied in the goods and services provided by numerous up-stream suppliers located in several different industries and countries. These up-stream suppliers not only differ in the nature and extent of their ability to create new technically relevant knowledge, but also in the way they use the technical knowledge already contained in goods produced in other industries and other countries. Input-output analysis provides a way to measure global knowledge flows at the industry level, and the theory of production provides a way to understand why these flows are happening. It does this by analyzing the interdependencies in the national production system, and its interdependence in the global economy.

Wassily Leontief (1936, 1937) developed the first large-scale input-output model in the late 1930s as a way to analyze the interdependence of different sectors in the economy. Many of the ideas contained in the methodology can be traced back to the Physiocrats, the classical economists, including more recently Piero Sraffa, and in neoclassical general equilibrium models pioneered by Leon Walras. In the large-scale model, Leontief described this interdependence between sectors as a set of linear equations, of which the empirically derived coefficients of production express the technology of the economic system. The production coefficients are obtained from statistical input-output tables, which are an integral part of a countries national income account, and are measured over a particular period of time (usually one year) and in monetary terms. In the 1940s, Leontief depicted the economic system as a circular flow, where the monetary transactions between sectors represent the sales and purchases of physical goods and services, making it analytically compatible with the classical theory of production (Kurz and Salvadori, 1995). The technical coefficients of production represent the technology of the economy and describe the direct and indirect effects on the structure of production as functions of the characteristics of demand for output of a sector. In other words, each sector in the economy depends either directly or indirectly on all other sectors in the economy. As with the classical theory of production, technical change and technological learning are essentially exogenous events that occur outside the economic system.

Input-Output analysis makes it possible to describe an economy on the basis of domestic and international knowledge and technology flows contained in intermediate goods. Griliches (1998) and others have used a simple input-output model to describe a linear relationship between upstream R&D activity, midstream product and process innovation and downstream commercialization and diffusion. When a distinction is made between R&D performed in an industry and the R&D embodied in inputs purchased from other R&D intensive industries, the relationship between R&D and productivity were non-linear as pointed out by Terleckyj (1974, 1980) and Scherer (1982). Further non-linearity appears when a distinction is made between R&D activity aimed at creating new products and that aimed at creating new processes. By recognizing the embodied knowledge flows, these authors recognized the interaction between producers and users of innovative or R&D intensive goods, and hence the central role of demand in driving innovative activity. Schmookler (1966) had already acknowledged that one of the best ways for an industry to innovate is "to improve the inputs it buys from other industries".

There are some important similarities between Lundvall's (1985, 1988) idea that interactions between users and producers generate potential technological opportunities and embodied knowledge flows in input-output analysis. These interactions are closely related to the ideas of Hirschman (1958) that backward linkages are related to derived demand and forward linkages are related to the utilization of output. Linkages between users and producers describe the flows of physical products and other intangibles from the producer to the user, whether it is for final consumption or intermediate consumption. Lundvall (1985) then proposes to extend the input-output table to include capital as an intermediate good, which might also include R&D activity. While he does not consider knowledge flows between users and producers to be embodied directly in the product flows, but he does consider these flows to overlap with the product flows to a substantial degree. Innovation networks thus symbolize the interactive learning that goes on between the user and producer and production networks symbolize the interdependencies and physical flows in the real economy. Having a substantial overlap implies that there is a close relation between innovation and production.

The paper builds on the ideas of Terleckyj (1974, 1982) and Scherer (1982) that a distinction should be made between R&D performed in an industry and the R&D embodied in inputs purchased from other R&D intensive industries. They show that purchased inputs, whether domestic or imported intermediate and capital goods and services contain technology and knowledge created by another industry. Papaconstantinou et al. (1998) provided a more precise way to measure domestic and international product embodied technology diffusion, diffusion, it does not adequately account for the industry-to-industry interaction within technology flows, which may lead to double accounting. Hauknes and Knell (2009) provided a more general approach that provides a way to estimate and assess the total interaction through technology flows between two sectors. It considered the direct and indirect flows of knowledge between different technology-intensive industries in France, Germany, Norway, Sweden, and the United States. One weakness of this paper is that it assumes that international embodied knowledge flows will have the same R&D intensity contained in them. It also does not consider production and innovation networks that can develop between technological leaders and technological followers over time.

Input-Output analysis can provide important insights into the economic impacts of global production and innovation networks. This requires harmonized input-output tables that contain information about intermediate inputs that are domestically produced and imported, and harmonised international bilateral trade data. However, trade statistics are generally reported in terms of commodities and not in terms of economic activities, as the input-output tables require. Input-output analysis is used in this paper to measure the direct and indirect flows of technology between selected European countries (Denmark, Estonia, Germany, Italy, Norway, Sweden, and the United Kingdom) and the CIBS countries (China, India, Brazil and South Africa). We apply the general framework outlined in Hauknes and Knell (2009) to multiregional input-output data to address the relative strength of spatial interdependence between certain European countries and the CIBS countries. In the previous paper we estimated and assessed the total interaction through knowledge flows between two sectors within a single economy, whereas in this paper we consider the direct and indirect knowledge flows between a pair of countries, one that could be considered on the technological frontier and the other an emerging 'learning' economy. To do this, we introduce an interregional technology multiplier that captures the knowledge flows between two countries and measure the total backward linkage. In the following two sections we describe how to measure the direct and product-embodied flows of R&D activity and sectoral linkages. Sections four and five apply the methodology to five countries. Some concluding remarks follow.

2. Measuring direct and indirect flows of R&D activity

To measure product-embodied R&D diffusion, we start with the open Leontief model, which considers technology and final demand separately. In the model, N industries are represented as a vector of domestic outputs xD and a vector of domestically produced final demands yD.2 Furthermore there are vectors of imported volumes xI and a vector of imported goods satisfying final demands yI. Total supply and total final demand are then given by

$$x = x^D + x^I \text{ , and } y = y^D + y^I$$

The total IO matrix has the following structure

$$x^D{}_i = \sum_j x^D{}_i^j + y^D{}_i = \sum_j d_i^j x^D{}_j + y^D{}_i, \qquad d_i^j \equiv \frac{x^D{}_i^j}{x^D{}_j}$$

$$x_i = \sum_j x_i^j + y_i = \sum_j a_i^j x_j + y_i,$$

where

$$a_i^j \equiv \frac{x_i^j}{x_j} = \frac{x^D{}_i^j + x^I{}_i^j}{x_j} \equiv a^D{}_i^j + a^I{}_i^j$$

or

$$x^D = \boldsymbol{D}x^D + y^D$$

$$x = \boldsymbol{A}x + y, \qquad \boldsymbol{A} = \boldsymbol{A}^D + \boldsymbol{A}^I$$

[2] Notation is standard: scalar and vector variables are in italics with lower-case variable names, matrix variables in bold, with capitals. Matrix and vector components are given in lower-case italics with the required number of matrix indices.

where $\boldsymbol{A}$ represents the matrix of total (technical) inter-industry coefficients, $\boldsymbol{D}$ is the matrix of domestic coefficients. Multiplied with the vector x, $\boldsymbol{A}$ gives the total intermediate inputs to production. On the assumption that the inverse of the matrices $\mathbf{1} - \boldsymbol{D}$ and $\mathbf{1} - \boldsymbol{A}$ exists, i.e. all eigenvalues of $\boldsymbol{D}$ and $\boldsymbol{A}$ are different from unity, we get the general solution for the two linear equations:

$$x^D = (\mathbf{1} - \boldsymbol{D})^{-1} y^D \equiv \boldsymbol{E} y^D$$

$$x = (\mathbf{1} - \boldsymbol{A})^{-1} y \equiv \boldsymbol{B} y$$

where $\boldsymbol{B}$ and $\boldsymbol{E}$ are the Leontief inverse matrices of $\boldsymbol{A}$ and $\boldsymbol{D}$, respectively. The individual elements b_{ij} of the matrix $\mathbf{B}$ may be interpreted as the direct and indirect requirements of increased output of industry i necessary to produce one additional unit of goods in industry j going to final demand ($i, j = 1, \dots, N$, with N sectors).

The matrices $\boldsymbol{A}^D$ and $\boldsymbol{D}$ are related, as are $\boldsymbol{B}^D$ and $\boldsymbol{E}$. Defining the diagonal $N \times N$-matrices

$$\boldsymbol{X} = \mathbf{diag}(x_1, x_2, \dots, x_N), \text{ and } \boldsymbol{X}^D = \mathbf{diag}(x^D{}_1, x^D{}_2, \dots, x^D{}_N)$$

and it is readily seen that

$$\boldsymbol{A}^D = \boldsymbol{X}^D \boldsymbol{X}^{-1} \boldsymbol{D} = (\mathbf{1} - \boldsymbol{M})\boldsymbol{D}$$

where $\boldsymbol{M}$ is the diagonal matrix of industrial import shares,

$$\boldsymbol{M} = diag(\mu_1, \mu_2, \dots, \mu_N), \text{ where } \mu_i = \frac{x^I{}_i}{x_i} = 1 - \frac{x^D{}_i}{x_i}$$

Then

$$\boldsymbol{B} = (\mathbf{1} - \boldsymbol{A})^{-1} = [\mathbf{1} - (\boldsymbol{A}^D + \boldsymbol{A}^I)]^{-1}$$

$$= [\mathbf{1} - (\mathbf{1} - \boldsymbol{A}^D)^{-1} \boldsymbol{A}^I]^{-1} (\mathbf{1} - \boldsymbol{A}^D)^{-1}$$

$$= [\mathbf{1} - \boldsymbol{B}^D \boldsymbol{A}^I]^{-1} \boldsymbol{B}^D = \boldsymbol{B}^D [\mathbf{1} - \boldsymbol{A}^I \boldsymbol{B}^D]^{-1}$$

or

$$\boldsymbol{B}^D = \boldsymbol{B}[\mathbf{1} + \boldsymbol{A}^I \boldsymbol{B}]^{-1} = [\mathbf{1} + \boldsymbol{B} \boldsymbol{A}^I]^{-1} \boldsymbol{B}$$

Here

$$B^D \equiv \left(1 - A^D\right)^{-1} = [1 - (1 - M)D]^{-1}$$

$$= (1 - D)^{-1}[1 + (1 - D)^{-1}MD]^{-1}$$

$$= E[1 + EMD]^{-1}$$

Thus the domestic Leontieff inverse $\boldsymbol{B}^D$ depends on the import shares.

The total technology content of any industry j, as generated through R&D, would be measured by the direct R&D expenditure of industry j, and by embodied R&D used in industry j, sourced from all other industries $k \neq j$. The latter are embodied in domestic intermediate inputs into production in industry j, in domestically produced investment goods and services, in imported intermediate inputs and lastly, in imported investment goods and services purchased by the industry j. Defining the direct R&D intensity for industry i as R&D expenditures per gross output, or $r_i = R_i/X_i$, an N-vector t of total domestic R&D embodied in intermediate inputs per unit of final demand for industry j is obtained by multiplying the R&D intensities of the source industries i by the elements of the Leontief inverse marix b_i^j:

$$t = r^T\boldsymbol{B}^D \tag{1}$$

or

$$t^j = \sum_i r^i b^D{}_i^j$$

where r is the column vector of components r^i.

Now, we want to measure the technology intensity of total output, and not of final demand. In this case, there is a double-counting the technology flows. Through b_i^j the component t^j sums up all embodied flows from industry i to final use of industry j production, including both the backward (upstream) linkages of the industry j required for the determination of the sectoral R&D embodiment intensities, as well as all further forward (downstream) intermediate linkages from industry j that eventually end up in the exogenous final use categories of sector j. These latter contributions should be excluded from the expression.

Following Miller and Blair (1985, 2009), Papaconstantinou et al. (1998) and Hauknes and Knell (2009) get around this double-counting problem by treating sector *j* as an exogenous sector to calculate a modified Leontief inverse matrix $\boldsymbol{B}^*$. The technology intensity of industry *j* per unit of total output becomes

$$s_D = r^T \boldsymbol{B}^{D*}$$

or

$$s_D{}^j = \sum_i r^i b^{D*}{}_i^j$$

The matrix $\boldsymbol{B}^D*$ omits the double-counting included in equation (1), such that

$$b^{D*}{}_i^j = \frac{b^D{}_i^j}{b^D{}_j^j}$$

Hauknes (2010) provide the derivation of this expression and other inter-sectoral linkage measures. In (4) the intensity of R&D embodied in domestic intermediate inputs flowing into industry *j* from any other industry is:

$$t_D{}^j = \sum_{\substack{i=1 \\ i \neq j}}^{N} r^i \frac{b^D{}_i^j}{b^D{}_j^j} = s_D{}^j - r^j$$

This equation accommodates the embodied technology flows within the domestic economy, as mediated by the inter-industrial trades captured in the top-left quadrant of the input-output matrix. To get an improved measure we have to consider a further channel for embodied technology flows; imports supplementing domestic inter-industrial trade, technology embodied in the exchanges related to production and use of domestic capital goods, and the domestic use of imported capital goods.

3. Measuring international R&D flows

When considering the distribution of technology flows between domestic and imported flows we also have to consider the impact of differences in R&D intensities in any sector between the exporting and importing country. Consider the case of two countries, k = 1, 2. The full two country IO coefficient matrix then has the following $2N \times 2N$ structure

$$\boldsymbol{A}_T = \begin{bmatrix} \boldsymbol{A}_1^1 & \boldsymbol{A}_1^2 \\ \boldsymbol{A}_2^1 & \boldsymbol{A}_2^2 \end{bmatrix}$$

Each entry is an $N \times N$ matrix, with

$$\boldsymbol{A}_k^l = \boldsymbol{A}^D(country\ l)\delta_k^l + \boldsymbol{A}^I(country\ l\ from\ country\ k)\left(1 - \delta_k^l\right)$$

or

$$\boldsymbol{A}_T = \begin{bmatrix} \boldsymbol{A}_1^D & \boldsymbol{A^I}_1^2 \\ \boldsymbol{A^I}_2^1 & \boldsymbol{A}_2^D \end{bmatrix} = \boldsymbol{A}_T^0 + \boldsymbol{A}_T^I, \qquad \boldsymbol{A}_T^0 = \begin{bmatrix} \boldsymbol{A}_1^D & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{A}_2^D \end{bmatrix}$$

Here $\boldsymbol{A}_T$ is the sum of the block-diagonal matrix $\boldsymbol{A}_T^0$ and the off-diagonal matrix $\boldsymbol{A}_T^I$. The full flows of embodied R&D are then described by the Leontief inverse matrix for the total two country economy

$$\boldsymbol{B}_T = [\boldsymbol{1} - \boldsymbol{A}_T]^{-1} = \boldsymbol{B}_T^0 + \boldsymbol{B}_T^I = \begin{bmatrix} \boldsymbol{B}_1^D & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{B}_2^D \end{bmatrix} + \begin{bmatrix} \boldsymbol{B}_1^I & \boldsymbol{B^I}_1^2 \\ \boldsymbol{B^I}_2^1 & \boldsymbol{B}_2^I \end{bmatrix}, \qquad \boldsymbol{B}_T^0 = [\boldsymbol{1} - \boldsymbol{A}_T^0]^{-1}$$

The added term, due to the international trade interactions in $\boldsymbol{B}_T$, is not off-diagonal as was the case with $\boldsymbol{A}_T$. Then the total technology intensity per unit of final output is given by the $2N$ vector t,

$$t = \begin{pmatrix} t_1 \\ t_2 \end{pmatrix} = r^T \boldsymbol{B}_T = (r_1{}^T, r_2{}^T)\boldsymbol{B}_T = (r_1{}^T, r_2{}^T)\begin{bmatrix} \boldsymbol{B}_1^D + \boldsymbol{B}_1^I & \boldsymbol{B^I}_1^2 \\ \boldsymbol{B^I}_2^1 & \boldsymbol{B}_2^D + \boldsymbol{B}_2^I \end{bmatrix}$$

where r is the $2N$ column vector if R&D intensities.

Our task is now to find an expression for these intensities, expressed through the block elements of $\boldsymbol{A}$ and $\boldsymbol{B}$. The two country Leontief inverse $\boldsymbol{B_T}$ may then be expressed as follows. Without international trade, $\boldsymbol{B}_T$ will reduce to the decoupled, block-diagonal form

$$\boldsymbol{B}_T^0 = \boldsymbol{B}_T\left(\boldsymbol{A^I}_k^l = \boldsymbol{0}\right) = \begin{bmatrix} \boldsymbol{B}_1^D & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{B}_2^D \end{bmatrix}$$

as $\boldsymbol{B}_T^I\left(\boldsymbol{A^I}_k^l = \boldsymbol{0}\right) = \boldsymbol{0}$. Then we write

$$B_T = [1 - A_T]^{-1} = \left[1 - \left(A_T^0 + A_T^I\right)\right]^{-1} = \left[\left(1 - A_T^0\right)\left[1 - \left(1 - A_T^0\right)^{-1} A_T^I\right]\right]^{-1} = \left[1 - B_T^0 A_T^I\right]^{-1} B_T^0$$

Since

$$\left[1 - \left(B_T^0 A_T^I\right)^k\right]\left[1 + \left(B_T^0 A_T^I\right)^k\right] = \left[1 - \left(B_T^0 A_T^I\right)^{2k}\right], k \geq 1$$

or

$$\left[1 - \left(B_T^0 A_T^I\right)^k\right]^{-1} = \left[1 + \left(B_T^0 A_T^I\right)^k\right]\left[1 - \left(B_T^0 A_T^I\right)^{2k}\right]^{-1}, k \geq 1$$

it follows that the general solution of the two country IO system is

$$B_T = \left[1 + B_T^0 A_T^I\right]\left[1 - \left(B_T^0 A_T^I\right)^2\right]^{-1} B_T^0 = \cdots = \prod_{\rho=0}^{\infty}\left[1 + \left(B_T^0 A_T^I\right)^{2^\rho}\right] B_T^0$$

when $\left(B_T^0 A_T^I\right)^k \to 0, k \to \infty$. Here we may distinguish between a block-diagonal and an off-diagonal part of B_T

$$B_T(diagonal) = \left[1 - \left(B_T^0 A_T^I\right)^2\right]^{-1} B_T^0 = \prod_{\rho=1}^{\infty}\left[1 + \left(B_T^0 A_T^I\right)^{2^\rho}\right] B_T^0$$

$$B_T(off-diagonal) = B_T^0 A_T^I \left[1 - \left(B_T^0 A_T^I\right)^2\right]^{-1} B_T^0 = B_T^0 A_T^I \prod_{\rho=1}^{\infty}\left[1 + \left(B_T^0 A_T^I\right)^{2^\rho}\right] B_T^0$$

or

$$B_T(off-diagonal) = B_T^0 A_T^I B_T(diagonal)$$

The total technology intensity per unit of final output is given by the 2*N* column vector *t*,

$$t^T = \binom{t_1}{t_2}^T = r^T B_T = r^T \prod_{\rho=0}^{\infty}\left[1 + B_T^0 A_T^I\right]^{2^\rho} \; B_T^0$$

where *r* is the 2*N* column vector of R&D intensities,

$$t^T = r^T B_T = \left(r_1{}^T, r_2{}^T\right)\begin{bmatrix} B_1^D & B_1^D A^I{}_1^2 B_2^D \\ B_2^D A^I{}_2^1 B_1^D & B_2^D \end{bmatrix} + \cdots$$

$$= \begin{bmatrix} r_1{}^T B_1^D + r_2{}^T B_2^D A^{I}{}^1_2 B_1^D \\ r_2{}^T B_2^D + r_1{}^T B_1^D A^{I}{}^2_1 B_2^D \end{bmatrix}^T + \cdots$$

Since $r_k{}^T B_k^D$ is the domestically generated technology intensity $t_k^{D\,T}$ per unit of final output of country *k*, this is

The matrix $B_T^0 A_T^I$ is a measure of the openness of the two interacting economies. When $B_T^0 A_T^I = 0$, the two economies are closed. When the economies are «nearly closed», we may express this as $B_T^0 A_T^I$ being in some sense «small». One way to formalize this is as follows. With a matrix norm $\|M\|$, we have

$$\|A_T\| = \|A_T^0 + A_T^I\| \le \|A_T^0\| + \|A_T^I\|,$$

Thus $\|A_T\| \ll 1$, implies that $\|A_T^0\| + \|A_T^I\| \ll 1$

$$\|A_T^I\| \ll 1 - \|A_T^0\| < 1, \text{since these matrices are real} - \text{valued}$$

If $B_T^0 A_T^I$ is «small», i.e. $\varepsilon \equiv \|B_T^0 A_T^I\| \ll 1$,

$$\|B_T^0 A_T^I\| = \|(1 - A_T^0)^{-1} A_T^I\| \le \|(1 - A_T^0)^{-1}\| \, \|A_T^I\| \ll 1$$

Furthermore

$$\|1\| = \|(1 - A_T^0)^{-1}(1 - A_T^0)\| \le \|(1 - A_T^0)^{-1}\| \, \|1 - A_T^0\| \equiv \kappa(1 - A_T^0)$$

where $\kappa(1 - A_T^0)$ is the condition number of the matrix $(1 - A_T^0)$ relative to the norm $\|\ \|$. Combining we get that for $B_T^0 A_T^I$ to be small,

$$\frac{\|A_T^I\|}{\|1 - A_T^0\|} \ll \frac{1}{\kappa(1 - A_T^0)} \le \frac{1}{\|1\|} < 1$$

or

$$\varepsilon \equiv \|B_T^0 A_T^I\| \ll 1 \Rightarrow \|A_T^I\| \ll \|1 - A_T^0\| = \|B_T^{0\,-1}\|$$

Assuming this is the case, we may expand the expression for $B_T = [1 - A_T]^{-1}$,

$$B_T = \left[1 - B_T^0 A_T^I\right]^{-1} B_T^0 = \sum_{k=0}^{\infty} \left(B_T^0 A_T^I\right)^k B_T^0 = B_T^0 + B_T^0 A_T^I B_T^0 + \mathcal{O}\left[\left(B_T^0 A_T^I\right)^2\right]$$

For $\left\| B_T^0 A_T^I \right\| \ll 1$ we then have

$$B_T = \begin{bmatrix} B_1^D & 0 \\ 0 & B_2^D \end{bmatrix} + \begin{bmatrix} B_1^D & 0 \\ 0 & B_2^D \end{bmatrix} \begin{bmatrix} 0 & A^{I\,2}_{\ 1} \\ A^{I\,1}_{\ 2} & 0 \end{bmatrix} \begin{bmatrix} B_1^D & 0 \\ 0 & B_2^D \end{bmatrix} + \mathcal{O}\left[\left(B_T^0 A_T^I \right)^2 \right]$$

$$B_1^D + B_1^D A^{I\,2}_{\ 1} B_2^D A^{I\,1}_{\ 2} B_1^D \,\&\, B_1^D A^{I\,2}_{\ 1} B_2^D + B_1^D A^{I\,2}_{\ 1} B_2^D A^{I\,1}_{\ 2} B_1^D A^{I\,2}_{\ 1} B_2^D \,@\, B_2^D A^{I\,1}_{\ 2} B_1^D + B_1^D A^{I\,2}_{\ 1} B_2^D A^{I\,1}_{\ 2} B_1^D A^{I\,2}_{\ 1}$$

$$+\mathcal{O}\left[\left(B_T^0 A_T^I \right)^4 \right]$$

with the diagonal and off-diagonal part has an even or odd number of the trade matrix A_T^I. Hence we have

$$B_T = \left[1 + B_T^0 A_T^I + \left(B_T^0 A_T^I \right)^2 + \cdots \right] B_T^0 + B_T^0 A_T^I \left[1 + B_T^0 A_T^I + \left(B_T^0 A_T^I \right)^2 + \cdots \right] B_T^0$$

$$= \left[1 + B_T^0 A_T^I \right] \left[1 - \left(B_T^0 A_T^I \right)^2 \right]^{-1} B_T^0$$

Then the total technology intensity per unit of final output is given by the 2N column vector t,

$$t^T = \begin{pmatrix} t_1 \\ t_2 \end{pmatrix}^T = r^T B_T = \left(r_1^{\ T}, r_2^{\ T} \right) B_T$$

where r is the 2N column vector of R&D intensities, when retaining terms to first order in $\left(B_T^0 A_T^I \right)$,

$$r^T B_T = \left(r_1^{\ T}, r_2^{\ T} \right) \begin{bmatrix} B_1^D & B_1^D A^{I\,2}_{\ 1} B_2^D \\ B_2^D A^{I\,1}_{\ 2} B_1^D & B_2^D \end{bmatrix} + \mathcal{O}\left[\left(B_T^0 A_T^I \right)^2 \right]$$

$$= \left[r_1^{\ T} B_1^D + r_2^{\ T} B_2^D A^{I\,1}_{\ 2} B_1^D, \quad r_2^{\ T} B_2^D + r_1^{\ T} B_1^D A^{I\,2}_{\ 1} B_2^D \right] + \mathcal{O}\left[\left(B_T^0 A_T^I \right)^2 \right]$$

Since $r_k^{\ T} B_k^D$ is the domestically generated technology intensity ${t_k^D}^T$ per unit of final output of country k, this is

$$t \cong \begin{bmatrix} t_1^D + t_2^D A^{I\,1}_{\ 2} B_1^D \\ t_2^D + t_1^D A^{I\,2}_{\ 1} B_2^D \end{bmatrix}$$

Transforming this to intensities of total, rather than final output, s, becomes

$$s = \begin{bmatrix} s_1^D + t_2^D A^{I\,1}_{\ 2} B^{*D}_{\ 1} \\ s_2^D + t_1^D A^{I\,2}_{\ 1} B^{*D}_{\ 2} \end{bmatrix}$$

where

$$s_k^D = r_k{}^T \boldsymbol{B}^{\bullet}{}_k^D = \left[\sum_{sectors\ i} r_k^i b_k^{\bullet D}{}_i^j\right]_{j=1,\dots N}, k = 1,2$$

and

$$\boldsymbol{B}^{\bullet}{}_k^D = \left[b_k^{\bullet D}{}_i^j\right]_{i,j=1,\dots N} = \left[\frac{b^D{}_i^j}{b^D{}_j^j}\right]_{\substack{\text{country } k=1,2 \\ i,j=1,\dots,N}}$$

Hence we may write

$$s_k = s^D{}_k + t_l^D \boldsymbol{A}^I{}_l^k \boldsymbol{B}^{\bullet}{}_k^D, k, l = 1,2, k \neq l$$

The matrix $\boldsymbol{A}^I{}_l^k$ measures imports from country l to country k, each (i, j) matrix element $a_i^j{}^I{}_l^k$ gives the intermediate inputs into industry j in country k, from industry i in country l. For M countries, indexed $k = 1, \dots M$, generalizing from $M = 2$, it is easy to see that to the first order in $\left(\boldsymbol{B}_T^0 \boldsymbol{A}_T^I\right)$, we may write

$$s_k^i = s^D{}_k^i + \sum_{\substack{l=1 \\ l \neq k}}^{M} t_l^D \boldsymbol{A}^I{}_l^k \boldsymbol{B}^{\bullet}{}_k^D + O\left[\left(\boldsymbol{B}_T^0 \boldsymbol{A}_T^I\right)^2\right], \qquad k = 1, \dots, M$$

with the same linear inter-economic structure as in the two-country case. To higher orders the M-country expansion will involve terms such as $\boldsymbol{A}^I{}_l^m \boldsymbol{B}_m^D \boldsymbol{A}^I{}_m^r \boldsymbol{B}_r^D$ involving complex webs of inter-economic interactions.

To resolve the total imports matrix $\boldsymbol{A}_k{}^I$ from the country k IO tables, we distribute imports among exporting countries l, based on data from the OECD Bilateral trade database and an assumption of constant proportions, i.e.,

$$a_i^j{}^I{}_l^k = \frac{\mu_i{}_l^k}{\sum_m \mu_m{}_l^k} a_i^j{}^k = \frac{\mu_i{}_l^k}{\sum_m \mu_m{}_l^k} \frac{x_i^j{}^k}{x^j{}^k}$$

$$= \left[\frac{\textbf{Imports of } i \textbf{ to } k \textbf{ from } l}{\textbf{Total imports to } k \textbf{ from } l}\right]$$

$$\times \left[\frac{\textbf{Intermediate inputs of imported products } i \textbf{ into industry } j \textbf{ in country } k}{\textbf{Total supply from industry } j \textbf{ of country } k}\right]$$

where the ${\mu_i}_l^k$ are given by the BTD database as imports from country *l* to country *k* of products mainly produced in industry *j*, the denominator is total imports to country *k* from country *l*, while the import IO-coefficient ${a_i^j}^k = \frac{{x_i^j}^k}{{x^j}^k}$ is taken from the IO table. Since the BTD database is activity based, the relevant IO-coefficient may be taken from the industry × industry IO table. Using other trade data such as the UN Comtrade, which generally are SITC based, would require access to product × industry use tables to be consistent. As we do not have access to use and supply tables we are barred from using alternative trade data. Hence we are limited to the data given by the OECD BTD data.

Then the total technology intensity per unit of total output of industry *i* in country *k* is:

$$s_k^i = {s^D}_k^i + \sum_{\substack{countries\ l\\ sectors\ m,j}} {t^D}_l^m \frac{{\mu_m}_l^k}{\sum_n {\mu_n}_l^k} {a_m^j}^k {b^*}_{j\ k}^{i\ D}$$

Note that this derived expression is different from the expression commonly used in the literature to describe imported intermediate inputs, and is also assumed in Hauknes and Knell (2009). With the notation of the present paper this assumption would correspond to

$$s_k^i = {s^D}_k^i + \sum_{\substack{countries\ l\\ sectors\ j}} {s^D}_l^j \frac{{\mu_j}_l^k}{\sum_n {\mu_n}_l^k} {a_j^i}^k$$

There are two major differences between the latter expression and the derived expression. Firstly the imports into country *k* in the former equation is exposed to multiplication through the domestic ***B****-matrix, secondly the input intensities in the expression derived here is not the domestically determined *s*-intensities, but the domestic per unit of final output intensities t_l. These modifications ensure that imported inputs are treated on the same level as domestic inputs, when the assumption $\|\boldsymbol{B}_T^0 \boldsymbol{A}_T^l\| \ll 1$ is valid.

The parameter $\varepsilon \equiv \|\boldsymbol{B}_T^0 \boldsymbol{A}_T^l\|$ measures the openness of the economy, the size of imports relative to domestic trade flows. Similarly the parameter $\delta \equiv 1 - \varepsilon$ is a measure of the «closedness» of the economy. The equations above thus furnish an expansion in powers of the openness parameter ε, around the value $\varepsilon = 0$, the perfectly closed economy. Similarly we may construct an expansion around $\varepsilon = 1$, or $\delta = 0$, the completely open economy in powers of δ.

The total technology intensity per unit of total output of industry *i* in country *k* is:

$$s_k^i = s^D{}_k^i + s^I{}_k^i = \sum_{\text{sectors } j} r_k^j \, b_{\bullet k}{}^{D}{}_j^i + \sum_{\substack{\text{countries } l \\ \text{sectors } m,j}} t^D{}_l^m \frac{\mu_m{}_l^k}{\Sigma_n \mu_n{}_l^k} a_m^j{}^k \, b_{\bullet}{}_j^i{}^D_k$$

$$= \sum_{\text{sectors } j} \left[r_k^j + \sum_{\substack{\text{countries } l \\ \text{sectors } m}} t^D{}_l^m \frac{\mu_m{}_l^k}{\Sigma_{\text{sectors } n} \mu_n{}_l^k} a_m^j{}^k \right] b_{\bullet k}{}^{D}{}_j^i$$

The intensity of total technology content of industry *j* thus becomes:

$$s_k^i = s^D{}_k^i + s^I{}_k^i = r_k^i + \sum_{\substack{l=1 \\ l \neq k}}^{K} \left(s^I{}_i^i\right)_l^k + \sum_{\substack{j=1 \\ j \neq i}}^{N} \left[s^D{}_j^i + \sum_{\substack{l=1 \\ l \neq k}}^{K} \left(s^I{}_j^i\right)_l^k \right]$$

where

$$s_k^D = r_k{}^T \boldsymbol{B}_{\bullet}{}_k^D = \left[\sum_{\text{sectors } i} r_k^i \, b_{\bullet k}{}^{D}{}_i^j \right]_{j=1,\dots N}$$

and

$$\left(s^I{}_j^i\right)_l^k = \sum_{m=1}^{N} t^D{}_l^j \frac{\mu_j{}_l^k}{\Sigma_n \mu_n{}_l^k} a_j^m{}^k \, b_{\bullet}{}_{m_K}^{i}{}^{D}, l \neq k$$

4. Balancing the technology flows

In the expression for s_k^i above we have reorganized terms to identify intra-sectorial flows,

$$\left(\sigma_i^i\right)_l^k = r_k^i \delta_l^k + \left(s^I{}_i^i\right)_l^k \left(1 - \delta_l^k\right)$$

and the inter-sectorial flows

$$\left(\sigma_j^i\right)_l^k = s^D{}_k{}^i_j \delta_l^k + \left(s^I{}_j^i\right)_l^k \left(1 - \delta_l^k\right)$$

Then we may write

$$s_k^i = \sum_{l=1}^{K}\left[(\sigma_i^i)_l^k + \sum_{\substack{j=1\\ j\neq i}}^{N}(\sigma_j^i)_l^k\right] = \sum_{l=1}^{K}\sum_{j=1}^{N}(\sigma_j^i)_l^k$$

To the approximation we consider in this paper, we only have to consider the linear influence of country *l* on country *k*, all information is captured in the bilateral linkages of any pair of countries, irrespective of all the others. Organizing the individual components of this in a $(2\times2)^2$ matrix, the following chart describes the structure. The total inflow to a sector *i* in country *k* from any sector *j* in the pair (*k*, *l*) may be read out as the column sum in the table.

$(\sigma_j^i)_l^k$		*k*		*l*	
		i	*j*	*i*	*j*
k	*i*	r_k^i	$s_k D_i^j$	$(s^I{}_j^i)_k^l$	$(s^I{}_j^i)_k^l$
	j	$s_k D_j^i$	r_k^j	$(s^I{}_j^i)_k^l$	$(s^I{}_j^i)_k^l$
l	*i*	$(s^I{}_i^i)_l^k$	$(s^I{}_i^j)_l^k$	r_l^i	$s_l D_i^j$
	j	$(s^I{}_j^i)_l^k$	$(s^I{}_j^j)_l^k$	$s_l D_j^i$	r_l^j

These indices are intensities in units of total sectoral outputs of country *k*. Let X^k be the total production output of country *k*,

$$X^k = \sum_i x_i^k = \sum_{i,j=1}^{N}\left[a^k{}_i^j x_j + \delta_i^j y_j\right]$$

Consider any pair of countries (*k*, *l*). The related components of technology flows may be read out of table 1. Define the two aggregate measures of domestic and imported flows, as respectively the sectorally weighted sum of the diagonal and off-diagonal quadrants of table 1,

$$D_l^k = D^k\delta_l^k \equiv \sum_{i,j}\left(r_k^i\delta_i^j + s_k D_j^i\left(1-\delta_i^j\right)\right)\frac{x_i^k}{X^k}\delta_l^k = \sum_{i,j} D_j^{i\,k}\frac{x_i^k}{X^k}\delta_l^k$$

$$I_l^k \equiv \sum_{i,j}\left(\left(s^I{}_i^i\right)_l^k\delta_i^j + \left(s^I{}_j^i\right)_l^k\left(1-\delta_i^j\right)\right)\frac{x_i^k}{X^k}\left(1-\delta_l^k\right) = \sum_{i,j}\left(I_j^i\right)_l^k\frac{x_i^k}{X^k}\left(1-\delta_l^k\right)$$

Then D^k is the domestically generated technology intensity of economy *k*, while I_l^k is the total technology flows imported from country *l* into *k*, both measured as intensities relative to total production output of country *k*.

$$\Delta^k = D^k + \sum_l I_l^k$$

is then the total technology intensity of country *k*.

Similarly we may form sectoral indices by performing partial sums. Let $\mathfrak{A}$ and $\mathfrak{B}$ be subsets of $\mathfrak{N} = \{1,2,\ldots,N\}$,

$$D_{\mathfrak{A}\,l}^{\mathfrak{B}\,k} = \delta_l^k \sum_{j\in\mathfrak{A},i\in\mathfrak{B}} D_j^{i\,k} \frac{x_i^k}{X^k}$$

$$I_{\mathfrak{A}\,l}^{\mathfrak{B}\,k} = \left(1 - \delta_l^k\right) \sum_{j\in\mathfrak{A},i\in\mathfrak{B}} \left(I_j^i\right)_l^k \frac{x_i^k}{X^k}$$

We may then form the following anti-symmetric indices,

$$\vartheta_l^k \equiv \frac{I_l^k}{D^k} - \frac{I_k^l}{D^l} = -\vartheta_k^l \tag{2}$$

and

$$\varphi_l^k \equiv \frac{I_l^k \tau_l^k - I_k^l \tau_k^l}{I_l^k \tau_l^k + I_k^l \tau_k^l} = -\varphi_k^l \tag{3}$$

where τ_l^k is a measure of the relative sizes of the two economies,

$$\tau_l^k \equiv \frac{X^k}{X^k + X^l}$$

with X^k measured in a common currency. While ϑ_l^k measures the size of imported technology flows relative to domestic generation, and φ_l^k the balance of trans-national exchange of technology flows, both are designed so that the sign tell about the relative technology relation between the two countries. When either of the indices is positive, country *l* is in this bilateral relation a technology exporter, while country *k* is an importer relative to the relevant index. With negative ϑ_l^k and φ_l^k the relation is the opposite. These indices are constructed so that ϑ_l^k distinguishes between bilateral relations that are unbalanced in terms of volume of technology flows and size of the economy, while φ_l^k distinguishes more clearly the intermediate cases of balanced trade relations.

5. R&D expenditures and estimated embodied technology diffusion

The OECD Input–Output database, the OECD Analytical Business Enterprise Research and Development (ANBERD) database, and the OECD STAN Bilateral Trade Database are used to measure domestic and international product-embodied knowledge flows. Being part of the OECD Structural Analysis (STAN) family of databases, these are comparable across industries and countries. Input-output tables exist for virtually all OECD Member States, covering the years 1995, 2000 and 2005 or nearest years, as well as for Estonia and the four CIBS countries. ANBERD data also exists for virtually all OECD Member States for three years that input-output tables exist, but not for Estonia and the four CIBS countries except for one year for each China and South Africa. Additional data were obtained from national sources to have data covering the years 2000 and 2005 or nearest years, for Estonia, Brazil, China, and South Africa. No data exist for these countries in 1995, nor does comparable data exist for India. The Bilateral Trade Database (BTD) is derived from the OECD's International Trade by Commodity Statistics (ITCS) database, where (values and quantities of) imports and exports are compiled according to product classifications and presented by partner country.

As the BTD database is restricted to trade in products from manufacturing industries, the analysis below is limited to these flows as regards international technology flows. India is not covered in this paper because there are no R&D statistics that are comparable to the input-output table for the country. Lastly; we distinguish between categories of trade patterns below, (1) trade between the eight OECD partners, considered as trade between technology leaders, (2) trade between one OECD economy and one CIBS economy, including Estonia. While the first may be described through three data points, 1995, 2000 and 2005, the latter can only be analysed with respect to the two last points in time. In the sense that the countries in the first category have reached a state of balanced growth, these may be seen as providing the benchmark for analysing relative movements and changes in the second category. As the BTD database only covers OECD members with any trade partners, we cannot describe CIBS economies’ trade with CIBS partners.

We interpret the inter-industry linkages, and their evolution, as a problem of growth and catching-up. The eight advanced countries as representative of the global technology frontier, with a mixture of small open (Norway, Sweden, Denmark) and large (relatively) closed economies (US, Japan, Germany, UK) and catching-up economies (China, Brazil, South Africa and Estonia). Let *k* be a catching-up «from far behind» economy and *l* be an technological leader. The expected structural differences in exports from and imports to country *k*, would suggest that $I_k^l \ll I_l^k$ or $\vartheta_l^k \approx \frac{I_l^k}{D^k} > 0$ unless $D^k \gg D^l$, i.e. unless the catching-up partner is much larger than the technological leader, as measured by the intensity of *domestic* technology flows. The strategy of import substitution would imply that I_l^k decreases, while D^l may increase.

Tables 1 through 5 provide the individual data points that described in equations (2) and (3) and represent the bi-lateral embodied technology flows between the advanced technological leaders and from the leaders to the four catching-up economies. The data points between two partner countries will appear symmetrical in the sense that technology flowing into one country will appear as technology flowing out of the other, or the balance of trans-national technology flows. Figures 1 through 5 illustrate the data contained in the tables. The first three figures capture the embodied technology contained in trade between the eight technological leaders in 1995, 2000, and 2005 respectively. Figures 4 and 5 capture the embodied technology contained in trade between the technological leaders and China, Brazil, Estonia and South Africa in 2000, and 2005 respectively. There was not sufficient data for the catching-up economies to include 1995.

All five figures show a clear s-shaped relationship between the technology trade balance described in equation (3) and the importance of imported technology flows relative to domestic technology flows. Each of these data points represents one specific bi-lateral relationship. For either of these two indicators, a positive value implies that embodied technology transfer into the trading country dominant over technology exports to the trading partner in the bilateral relationship and a negative value implies embodied technology transfer into the trading country dominates over technology imports from the trading partner. The two far ends of the s-shaped curve represent the unbalanced trade relations between the two trading partners, and the middle represents the relatively more balanced trade relationships. In general countries that are below the technology frontier should appear in the upper right hand quadrant and far up on the s-shaped curve. As countries catch-up to the technology frontier, they should slide down the s-curve by exporting technology through goods and services.

Domestic flows of technology embodied in goods and services dominate global flows within the eight technological leaders in all three time periods. Within this group of countries, Germany, Japan and the United States mostly appear on the left and side in the first three figures, which suggests that these countries are mainly net exporters of embodied technology in almost all trade relationships. The United Kingdom appears balanced, but with several points at extreme on the left side. By contrast, Italy dominates the upper right end of these figures, indicating that it is a net importer of embodied technology, but by 2005 two points move from the right side of the figure to the left side. The smaller Scandinavian countries have mixed results. Sweden is largely a net exporter and Norway has overall balanced trade relationship, but with several points near the extremes, but what is more surprising is that Denmark consistently lies to the left of centre, meaning it is a net technology exporter. When large net exporters interact with smaller trading partners, they often appear in the lower left-hand end of the diagram.

International flows of technology embodied in goods and services dominate domestic flows in Brazil, China and South Africa. In almost every instance, all of these countries plus Estonia are net importers of embodied technology in trade relationships with the eight technological leaders. One important trend that appears is that China is gradually shifting from the right side to the left side of the diagram from 2000 to 2005, indicating that the country is moving from being a net importer of technology. Estonia appears as an extreme example of a net importer of embodied technology, mainly because of its networks that extend into the Nordic countries, but exports of embodied technology appears to have gained in importance, even to the Nordic countries, in 2005. Brazil and South Africa are also net importers of embodied technology within the group of eight countries, which also appears to have intensified through the 2000s. The only trade relationship where the four catching-up economies are net exporters of embodied technology appear to be with Italy, who also appears as a net importer of embodied technology among the eight advanced economies.

6. Concluding remarks

This paper provides a way to measure the direct and indirect technology flows between any pair of countries. Measurement of the embodied technology flows over time provides a basis for understanding global production networks (GPNs) and how they might evolve into global innovation networks (GINs). The paper analyzed embodied technology flows between eight countries on the technology frontier and the flows between these countries and four emerging market economies. Countries on the technology frontier appear mainly as net exporters of embodied technology, except for Italy, and those below the frontier to be net importers of embodied technology. There is stong evidence that GPNs are evolving into GINs in China and Estonia as these countries have increasingly contributed technology into these networks during the first half of the 2000s.

The main theoretical contribution of this paper was to provide a way to measure embodied technology flows between two pairs of countries. It builds on Hauknes and Knell (2009), which demonstrated how to measure embodied technology flows between any two pairs of industries within a particular country, but assumed that all trading partners were on the technology frontier. Certain limitations would need to be overcome to provide a more balanced picture. Including all of the major trading partners where there is R&D statistics would provide greater comprehensiveness. More complete coverage of R&D activity, especially in the service industries, and coverage of the service industries in the Bi-lateral Trade Database would improve the story. Finally, it would be a great challenge to combine some of the ideas of direct and indirect flows of technology between different technology-intensive industries with trade flows between any two pairs of countries. But this would create greater complexity to an already complicated analysis.

Despite these limitations, we have shown that the wider methodology developed in this paper is workable and provides a way of analysing transnational technology based interactions. With the basis laid out in this paper, the methodology may be generalized to any pair of countries and any industrial interactions, provided the general access of the required National Accounts, R&D and International trade data. In future work we want to expand this to sectorally specific analysis as suggested above, and to generate wider time series than what have been possible in this work.

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Figure 1: *Technology trade flow indices, OECD countries with OECD trade partners, 1995.*

Figure 2: *Technology trade flow indices, OECD countries with OECD trade partners, 2000.*

Figure 3: *Technology trade flow indices, OECD countries with OECD trade partners, 2005.*

Figure 4: *Technology trade flow indices, Brazil, China, South Africa and Estonia with OECD trade partners, 2000.*

Figure 5: *Technology trade flow indices, Brazil, China, South Africa and Estonia with OECD trade partners, 2005.*

Table 1. *Technology trade flow indices OECD countries with OECD trade partners, 1995 (percent)*

	Denmark		*Germany*		*Italy*		*Japan*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark	0.27	0.38	-0.39	0.03	-0.38	-0.04	-0.28	0.32
Germany	0.50	0.02	1.10	0.12	0.57	0.04	-0.92	0.09
Italy	0.01	-0.31	-0.62	-0.78	-1.64	-0.70	-1.78	-0.66
Japan	0.27	0.17	0.36	-0.28	0.57	0.35	0.18	0.49
Norway			-0.70	0.04	-0.36	0.08	-0.46	-0.02
Sweden	0.70	-0.04			-0.28	0.11	-0.36	0.43
UK	0.36	-0.08	0.28	-0.11			-1.37	-0.11
US	0.46	0.02	0.36	-0.43	1.37	0.11		

	Norway		*Sweden*		*UK*		*US*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark	0.18	0.25	-0.66	-0.11	-0.34	0.05	-0.34	0.05
Germany	0.70	0.11	1.59	0.28	1.15	0.27	-0.89	-0.31
Italy	0.00	-0.63	-0.31	-0.74	-1.04	-0.61	-1.50	-0.71
Japan	0.32	0.06	0.33	-0.37	0.69	0.39	-0.13	-0.10
Norway			-0.81	-0.06	-0.41	-0.02	-0.56	-0.29
Sweden	0.81	0.06			-0.32	0.06	-0.82	-0.13
UK	0.41	0.02	0.32	-0.06			-1.46	-0.33
US	0.56	0.29	0.82	0.13	1.46	0.33		

Table 2. *Technology trade flow indices OECD countries with OECD trade partners, 2000 (percent)*

	Denmark		*Germany*		*Italy*		*Japan*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark			-0.71	0.19	0.18	0.84	-0.08	0.75
Germany	0.71	-0.19			4.75	0.73	-0.73	-0.36
Italy	-0.18	-0.84	-4.75	-0.73			-0.94	-0.80
Japan	0.08	-0.75	0.73	0.36	0.94	0.80		
Norway	-0.27	-0.38	-0.50	-0.02	-0.01	0.31	-0.27	-0.17
Sweden	0.39	-0.03	-1.10	-0.12	0.62	0.78	-0.36	0.28
UK	0.38	0.04	-0.57	-0.04	1.64	0.70	-0.57	-0.35
US	0.28	-0.32	0.92	-0.09	1.78	0.66	-0.18	-0.49

	Norway		*Sweden*		*UK*		*US*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark	0.27	0.38	-0.39	0.03	-0.38	-0.04	-0.28	0.32
Germany	0.50	0.02	1.10	0.12	0.57	0.04	-0.92	0.09
Italy	0.01	-0.31	-0.62	-0.78	-1.64	-0.70	-1.78	-0.66
Japan	0.27	0.17	0.36	-0.28	0.57	0.35	0.18	0.49
Norway			-0.70	0.04	-0.36	0.08	-0.46	-0.02
Sweden	0.70	-0.04			-0.28	0.11	-0.36	0.43
UK	0.36	-0.08	0.28	-0.11			-1.37	-0.11
US	0.46	0.02	0.36	-0.43	1.37	0.11		

Table 3. *Technology trade flow indices OECD countries with OECD trade partners, 2005 (percent)*

	Denmark		*Germany*		*Italy*		*Japan*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark			-0.54	0.24	0.23	0.88	-0.04	0.78
Germany	0.54	-0.24			3.02	0.62	-0.84	-0.44
Italy	-0.23	-0.88	-3.02	-0.62			0.00	-0.74
Japan	0.04	-0.78	0.84	0.44	0.62	0.74		
Norway	-0.42	-0.55	-0.54	-0.23	-0.03	0.15	-0.32	-0.51
Sweden	0.24	-0.09	-1.20	-0.21	0.21	0.68	-0.31	-0.19
UK	0.21	-0.35	-0.65	-0.03	1.11	0.67	-0.45	-0.26
US	0.20	-0.66	0.67	-0.05	1.48	0.71	-0.49	-0.56

	Norway		*Sweden*		*UK*		*US*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark			-0.54	0.24	0.23	0.88	-0.04	0.78
Germany	0.54	-0.24			3.02	0.62	-0.84	-0.44
Italy	-0.23	-0.88	-3.02	-0.62			-0.62	-0.74
Japan	0.04	-0.78	0.84	0.44	0.62	0.74		
Norway	-0.42	-0.55	-0.54	-0.23	-0.03	0.15	-0.32	-0.51
Sweden	0.24	-0.09	-1.20	-0.21	0.21	0.68	-0.31	-0.19
UK	0.21	-0.35	-0.65	-0.03	1.11	0.67	-0.45	-0.26
US	0.20	-0.66	0.67	-0.05	1.48	0.71	-0.49	-0.56

Table 4. *Technology trade flow indices, Brazil, China, South Africa and Estonia with OECD trade partners, 2000.*

	Brazil		*China*		*Estonia*		*South Africa*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark	0.03	0.89	0.00	0.57	3.16	0.92	0.03	0.89
Germany	0.91	0.81	0.49	0.65	8.99	0.91	0.91	0.81
Italy	0.09	0.22	-0.05	-0.14	0.53	0.85	0.09	0.22
Japan	0.58	0.72	3.08	0.79	9.36	0.97	0.58	0.72
Norway	0.00	0.06	-0.01	0.46	2.45	0.96	0.00	0.06
Sweden	0.15	0.71	0.22	0.91	32.09	0.93	0.15	0.71
UK	0.32	0.67	0.09	0.36	3.22	0.80	0.32	0.67
US	3.38	0.73	0.88	0.32	1.42	0.18	3.38	0.73

Table 5. *Technology trade flow indices, Brazil, China, South Africa and Estonia with OECD trade partners, 2005.*

	Brazil		*China*		*Estonia*		*South Africa*	
	ϑ	φ	ϑ	φ	ϑ	φ	ϑ	φ
Denmark	0.03	0.82	0.03	0.82	0.03	0.82	0.04	0.91
Germany	1.88	0.78	1.88	0.78	1.88	0.78	3.43	0.91
Italy	0.07	-0.09	0.07	-0.09	0.07	-0.09	0.11	0.23
Japan	1.54	0.74	1.54	0.74	1.54	0.74	2.85	0.83
Norway	0.00	0.51	0.00	0.51	0.00	0.51	0.01	0.68
Sweden	0.18	0.90	0.18	0.90	0.18	0.90	0.14	0.86
UK	0.66	0.80	0.66	0.80	0.66	0.80	0.84	0.86
US	1.03	0.69	1.03	0.69	1.03	0.69	1.30	0.75