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The Factor Content of Bilateral Trade
: An Empirical Test*

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Abstract

The Factor Proportions model of international trade is one of the most influential theories in international economics. Its central standing in this field has appropriately prompted, particularly recently, intense empirical scrutiny. A substantial and growing body of empirical work has tested the predictions of the theory on the net factor content of a country's trade with the rest of the world, usually under the maintained assumptions of factor price equalization and identical homothetic preferences across trading countries (or under quite specific relaxations of these assumptions). In contrast, this paper uses OECD production and trade data to test the restrictions (derived by Helpman (1984)) on the factor content of trade flows which hold even under non-equalization of factor prices and in the *absence* of any assumptions regarding consumer preferences. In a further contrast with most of the existing literature, which has focused on the factor content of country's *multilateral* trade, our tests concern *bilateral* trade flows, thereby enabling the examination of trade flows between only a subset of countries for which quality data (relatively speaking) is available. Our results provide greater support for the theory than have many previous exercises: We are unable to reject the restrictions implied by the theory for the vast majority of country-pairs.

JEL classification codes: F1
Keywords: Trade Theory, Factor Proportions, Factor Content of Trade, Bilateral Trade, Empirical Testing

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I. Introduction

The Factor Proportions model, which predicts that international trade is driven by differences in factor endowments between countries, is one of the most influential theories in international economics. In addition to being used in the study of trade flows between countries, this model has also served as a platform for innumerable academic and policy analyses in international trade. These range from the study of the impact of trade on income inequality within and between countries to the analysis of the implications of foreign direct investment on welfare and the impact of immigration on production patterns, *inter alia*.

This central standing of the Factor Proportions model in international economics has appropriately prompted, particularly recently, intense empirical scrutiny.[3] Researchers testing this framework have largely focused on an elegant prediction of the model relating to net factor content of trade that obtains in even its multicountry, multifactor and multicommodity version: the well-known Heckscher-Ohlin-Vanek (HOV) prediction. This holds that under the assumptions that technologies everywhere are identical, that trade equalizes factor prices worldwide and that consumer preferences everywhere are identical and homothetic, the net exports of factors by a country will equal the abundance of its endowment of these factors relative to the country's world income share. Early tests of the HOV prediction in its strict form, however, proved very disappointing for the theory: In a widely-cited and pioneering study, Bowen, Leamer and Sveikauskas (1987) reported that the direction of net factor content flows among twenty-seven countries were predicted as well (or better) by a coin toss as by the theory − a finding that established a mood of deep pessimism with regard to the empirical validity of the model.[4]

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[3] See Leamer and Levinsohn (1995), Helpman (1998), and Davis and Weinstein (2001) for comprehensive discussions.

[4] Other trade related predictions of the Factor Proportions theory did not fare much better: In a very well-known contribution, Leontief (1953) used data on the factor content of U.S. exportables and importables to find "paradoxically" that the former used more labor relative to capital than the latter in its production, thus rejecting the central prediction of the Factor Proportions model - that countries export goods which

This apparent failure of the theory (in its strict form) to match the data led researchers to amend the theory and to improve on the data used in the empirical exercises.[5] In a series of remarkable contributions, Trefler (1993, 1995) and Davis and Weinstein (2002) variously attempted particular modifications (some systematic and some ad hoc) of the basic HOV assumptions and tested the resulting predictions to find much stronger support for the theory. Thus, Trefler (1995) reported that a variation of the model that postulated Hicks-neutral factor efficiency differences across country groups performed very well against the standard HOV prediction. And Davis and Weinstein (2002) articulated a series of additional departures from the basic HOV framework, including the use of bilateral trade estimates from the so-called "gravity equations" (themselves valid under the further assumptions of perfect specialization in tradables and specific assumptions on preferences) to account for the role of trade costs in restricting trade, to also report much stronger support for the theory.[6]

Our paper contributes to this literature on empirical testing of the Factor Proportions theory. Our methodology contrasts strongly with nearly all earlier work, however. Nearly all of the tests of the factor content predictions of the model (including the ones we have discussed above) have assumed full factor price equalization across countries (FPE) and identical homothetic preferences across countries (i.e., they have tested the HOV prediction) or have attempted very specific relaxation of these joint assumptions – for instance, by allowing for factor price differences to result from Hicks-neutral factor efficiency differences across countries, as in Trefler (1995). In contrast, this paper implements a test of restrictions implied by the theory (derived originally by Helpman (1984)) on the factor content of trade

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use more intensively their abundant factors.

[5] Also, a growing literature has examined other aspects and predictions of the neoclassical trade model: Prominent recent contributions include Harrigan (1995, 1997), Hanson and Slaughter (1999), Schott (1999) and Bernstein and Weinstein (1998), among others.

[6] The work of Davis and Weinstein (2002) is additionally remarkable from the standpoint of the data used. While the vast majority of papers in the literature used US "technology" matrices to proxy for technology matrices in the rest of the world, Davis and Weinstein (2002) used data on actual technology matrices for all OECD countries. This is an enormous data compilation and organization effort that has changed forever the standards on data usage in this area.

which rely on neither FPE nor on *any* restrictions on preferences. We consider this to be a significant step because, as Helpman (1998) has noted, even casual evidence suggests that full FPE does not hold (as we know from data on wages) and that preferences are non-homothetic and vary substantially with income level. A further and equally important contrast with the existing literature derives from the fact that while most empirical tests of the theory (and tests of HOV in particular) have focused on the net factor content of a country's *multilateral* trade, our tests concern *bilateral* trade flows, thereby enabling the examination of trade flows between only a subset of countries for which quality data (relatively speaking) is available.

Helpman's (1984) result, itself an intuitive (and general) formalization of some earlier work by Brecher and Choudhri (1982), is both straightforward and powerful: even in the absence of FPE, with identical technologies across countries, it is a simple matter to observe that the more capital rich a country is, the more capital and less labor it uses in all lines of production, while correspondingly achieving a higher wage-rental ratio. Hence, whatever trade exists between two countries, exports of the capital rich country will embody a higher capital-labor ratio than the exports of the relatively labor rich country. This, in turn, describes a clear *bilateral* factor content of trade. Specifically, the theory implies that, *on average*, a country imports those factors that are cheaper in the partner country and is a net exporter of those factors that are more expensive there. It is this description that we test using data on OECD production and trade flows. It is worth noting that the theoretical restrictions that we test here are easily extended to accommodate the possibility of technological differences across countries. We discuss this extension in Appendix A.2. where we also present the corresponding results for a subset of countries for which the necessary data (on industrial productivity) is available.

The rest of the paper is structured as follows: Section II presents the basic Helpman (1984) result regarding restrictions on bilateral trade flows, incorporating additionally the use of intermediates in production into the analysis. We discuss the advantages and disadvantages of testing these restrictions over standard HOV tests. Section III describes the data. Section IV describes our empirical analysis and the results. Section V concludes. Appendix A.1. provides a detailed description of the data. Appendix A.2. discusses extensions to take account of Hicks-neutral *and* Ricardian technological differences across countries.

II. Theory

Our analysis considers a freely trading world with many goods and countries in which production technology is convex, the technology for producing any good is assumed (for now) identical across countries, and perfect competition characterizes both goods and factor markets.

In this framework, as we have noted before, Helpman (1984) derived intuitive restrictions on the factor content of bilateral trade between countries − relating factor content trade to relative factor scarcities in the trading countries. The basic insight behind Helpman's (1984) result can be easily explained using a Lerner diagram. Figure 1 depicts a Lerner diagram for the two factor - six goods - three country case.

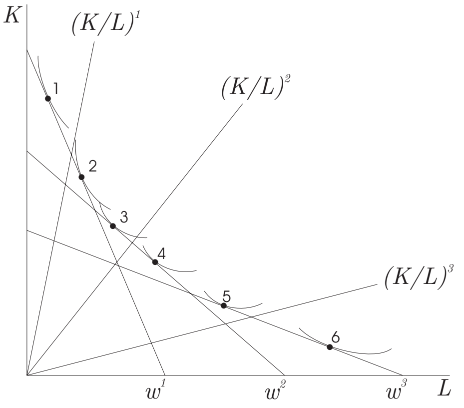

Figure 1: Lerner Diagram

The isoquants in Figure 1, numbered from 1 to 6, describe output levels of goods 1 to 6 respectively, each worth a dollar at free trade prices. The factors used in the production of these goods are capital and labor. The capital-labor ratios of the three countries are represented by the rays $(K/L)^c$, and their free trade wage-rental ratios are represented by the slopes ω^c, $c = 1, 2, 3$. In the equilibrium described above, country 1, which has the highest capital-labor ratio, produces goods 1 and 2; country 2, with an intermediate capital-labor ratio, produces goods 3 and 4; and country 3, with the lowest capital-labor ratio, produces goods 5 and 6. It is a simple matter then to observe that the more capital rich a country is, the more capital and less labor it uses per dollar output in all lines of production. Hence, whatever trade takes place between any two countries, the exports of the relatively capital-rich country will embody a higher capital-labor ratio than the exports of the relatively labor-rich country. This in turn describes a clear bilateral factor content pattern of trade even in the absence of factor price equalization and any assumption regarding preferences.

In what follows, we present Helpman's (1984), result allowing additionally for the presence of intermediate goods in production. It is worth noting that, even under the maintained assumption of identical technologies across countries, non-equalization of factor prices will still result in different techniques of production being used across countries. We denote the direct input matrix, which indicates how much direct input of each factor is required to produce one dollar of gross output within each industry, for any country c, by $\mathbf{A}^c$. The input-output matrix for country c, indicating the amount of output each industry must buy from other industries to produce one dollar of its gross output, Y^c, is denoted by $\mathbf{B}^c$. For any country c, the trade vector $(\mathbf{T}^c)$ is the difference between net production $(\mathbf{Q}^c)$ and consumption $(\mathbf{C}^c)$:

$$\mathbf{T}^c \quad = \quad \mathbf{Q}^c - \mathbf{C}^c. \tag{1}$$

In the presence of intermediates in production, we have,

$$\mathbf{Q}^c = (\mathbf{I} - \mathbf{B}^c)\mathbf{Y}^c. \tag{2}$$

Since $\mathbf{A}^c(\mathbf{I}-\mathbf{B}^c)^{-1}$ is then the matrix of total (direct and indirect) factor inputs required to produce one dollar of net output in each industry (i.e., it is the overall technology matrix in the presence of intermediate goods), the factor content of the trade flow, $\mathbf{T}^c$, on the left hand side of (1) can be determined by pre-multiplying $\mathbf{T}^c$ by $\mathbf{A}^c(\mathbf{I}-\mathbf{B}^c)^{-1}$. Thus, for any *bilateral* trade between two countries, c' and c, we can write

$$\mathbf{T}_V^{c'c} = \mathbf{A}^c(\mathbf{I}-\mathbf{B}^c)^{-1}\mathbf{T}^{c'c}, \tag{3}$$

where $\mathbf{T}^{c'c}$ is the gross *import* vector by country c' from country c and thus $\mathbf{T}_V^{c'c}$ is the gross *import* vector of factor content by country c' from country c.

Now, by the definition of the revenue function, we know that for country c', $\mathbf{\Pi}(\mathbf{p},\mathbf{V}^{c'}) = \mathbf{p}\mathbf{Q}^{c'}$, where $\mathbf{\Pi}$ is a revenue function representing production technology, $\mathbf{V}^{c'}$ is the endowment vector in country c' and $\mathbf{p}$ is the commodity price vector in the free trade equilibrium.[7] Given the assumption of identical technologies across countries, it should be clear that if country c' is given its gross import of factor content ($\mathbf{T}_V^{c'c}$) as an extra amount of factor endowment, it could produce with it at least the value of gross imports ($\mathbf{p}\mathbf{T}^{c'c}$). This and the concavity of $\mathbf{\Pi}$ in $\mathbf{V}$ (used to arrive at the second inequality in what follows) give us that,

$$\begin{aligned}
\mathbf{p}(\mathbf{Q}^{c'}+\mathbf{T}^{c'c}) &\leq \mathbf{\Pi}(\mathbf{p},\mathbf{V}^{c'}+\mathbf{T}_V^{c'c}) \\
&\leq \mathbf{\Pi}(\mathbf{p},\mathbf{V}^{c'}) + \mathbf{\Pi}_V(\mathbf{p},\mathbf{V}^{c'})\mathbf{T}_V^{c'c} \\
&= \mathbf{p}\mathbf{Q}^{c'} + \mathbf{w}^{c'}\mathbf{T}_V^{c'c},
\end{aligned} \tag{4}$$

where $\mathbf{\Pi}_V$ is the vector of partial derivatives of $\mathbf{\Pi}$ with respect to $\mathbf{V}$ and $\mathbf{w}^{c'}$ is the factor price vector in country c'.

Eliminating $\mathbf{p}\mathbf{Q}^{c'}$ from both sides of (4) in turn gives us

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[7] Note that our assumption of identical production functions across countries implies that the revenue function is also common across countries (and we therefore have no country-superscript for the revenue function).

$$\mathbf{p}\mathbf{T}^{c'c} \leq \mathbf{w}^{c'}\mathbf{T}_V^{c'c}. \tag{5}$$

Further, in country c, since perfect competition implies that every line of production must break even in equilibrium, we have,

$$\mathbf{p}\mathbf{T}^{c'c} = \mathbf{w}^{c}\mathbf{T}_V^{c'c}. \tag{6}$$

Combining (5) and (6) yields the following inequality,

$$(\mathbf{w}^{c'} - \mathbf{w}^{c})\mathbf{T}_V^{c'c} \geq 0. \tag{7}$$

Similarly, for c's imports, we have,

$$(\mathbf{w}^{c'} - \mathbf{w}^{c})\mathbf{T}_V^{cc'} \leq 0. \tag{8}$$

Equations (7) and (8) together yield,

$$(\mathbf{w}^{c'} - \mathbf{w}^{c})(\mathbf{T}_V^{c'c} - \mathbf{T}_V^{cc'}) \geq 0. \tag{9}$$

As Helpman (1994) has pointed out, (9) may be interpreted as implying that, on *average*, country c' is a net importer from country c of the content of those factors of production that are cheaper in c than in c' and vice versa.[8] It should be readily evident that all the variables in (9) relate to the equilibrium *with* trade. (9) may therefore be tested using data from the trade equilibria that we "observe." This is precisely what the rest of our analysis attempts to do. In implementing tests of (9), one needs to take into account the important observation of Staiger (1986) that when intermediates are freely traded, Helpman's measure of the bilateral factor content of trade needs to be modified to exclude the factor content

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[8] It is tempting to interpret (9) as a measure of the savings in production costs in country c' due to the fact that the gross import vector $\mathbf{T}^{c'c}$ is imported rather than domestically produced (measured at equilibrium factor prices in the domestic country. This is however incorrect. The cost savings from importing rather than producing domestically, crudely speaking, require a comparison of autarky equilibria with equilibria with trade. This is not what is being compared in (9).

of traded intermediate goods. Therefore, we perform the tests described above using input-output matrices that include only domestically produced intermediates.[9]

Our discussion so far has assumed identical technologies across countries. It is worth noting here that a relationship quite close to (9) may be easily derived even if technologies are *not* identical across countries. Consider the case when technologies are instead characterized by Hicks-neutral differences across countries, where a country c is uniformly more productive than country c' in the production of every good by a (potentially measurable) factor λ. The logic underlying the derivation of (4) still holds - with the difference that if country c' is given its gross import of factor content ($\mathbf{T}_V^{c'c}$) as an extra amount of factor endowment, it could produce with it at least the value of gross imports ($\mathbf{p}\mathbf{T}^{c'c}$) times the ratio $\frac{1}{\lambda}$. Equations (5) through (9), *mutatis mutandis*, are then easily derived. Alternately, we may allow for Ricardian differences in technology across countries, where technology in industry i in c is more productive than the same industry i in c' by a factor of λ_i. Expressions analogous to (9) (now involving the full set of λ_i's for every industry) may be easily derived. We develop these expressions in detail in Appendix A.2., where we also provide test results for the subset of countries for which we have data on relative industrial productivities (the λ_i's).

We have derived here theoretical restrictions on the factor content of bilateral trade flows that may be tested using "observable" data. These tests offer significant advantages over the HOV-based tests that currently dominate the literature − but also suffer from some disadvantages. The primary advantages are that the restrictions that we have derived do not require that factor prices be equalized across countries and do not require any assumptions on consumer preferences. Both of these are significant relaxations of the theoretical assumptions under which most HOV-based testing of the factor proportions model has been conducted (from both a theoretical and an empirical perspective, as we have previously dis-

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[9] See Appendix A.1. for a detailed discussion and a simple example illustrating the need for the modification of Helpman's measure as suggested by Staiger (1986).

cussed). Further, while most empirical tests of the theory (and tests of HOV in particular) have focused on the net factor content of a country's *multilateral* trade, our tests concern *bilateral* trade flows, thereby enabling the examination of trade flows between only a subset of countries for which quality data (relatively speaking) is available. Finally, extensions of tests to allow for differences in production technologies across countries (including Ricardian, industry specific differences), while infeasible in the HOV context, are straightforward here. The disadvantages of the tests proposed here, on the other hand, are as follows: While HOV-based tests provide *exact* predictions regarding the factor content of trade in each factor, our tests provide only a statement regarding the direction and magnitude of the flow of factors, on *average*. Further, while HOV tests require information on trade and technology from the entire trading world, they permit us to focus on only those factors in which we are interested or on which we have data. In contrast, the tests proposed here require information on all factors of production (so that the value of produced output is split among the factors of production considered). Thus, the tests conducted here offer some significant theoretical and implementation advantages over HOV tests but are also inferior to HOV tests in some respects. The two approaches should largely be seen as complements.

III. Data Sources

The countries we consider in this study are Canada, Denmark, France, Germany, Korea, Netherlands, the UK and the US. In order to test the restrictions (7)-(9) for any pair of these countries, we need data on the factor price vector ($\mathbf{w}$), the direct input matrix ($\mathbf{A}$), and the input-output matrix ($\mathbf{B}$) for each country in the pair, as well as the gross bilateral import vectors ($\mathbf{T}$) that describe trade flows between them.

Most previous work that implemented tests of the factor proportions theory has generally assumed (and used) the same technology matrices (**A** and **B**) across countries (usually U.S. technology matrices) in order to calculate the factor content of trade of any country – mostly due to the general difficulty of obtaining the relevant data for a cross-section of countries at any given time.[10] Under the maintained assumptions of FPE as well as identical technologies across countries, the use of the same technology matrices to represent production in different countries does not create any problems at the theoretical level. In contrast, because we choose to abandon the assumption of FPE, we are forced to confront the fact that, at the theoretical level itself, different technology matrices across countries are implied even under the maintained assumption of identical technologies across countries. To this end, this study has required the collection of technology data on both the direct input matrices as well as the input-output matrices for each country. As noted earlier, taking trade in intermediates into account implies that we need to use input-output matrices that only include the usage of domestically produced intermediates – since Helpman's measure of the bilateral factor content of trade needs to be modified to exclude the factor content of traded intermediate goods (as Staiger (1986) has pointed out). Details on the relevant technology matrices that we used are provided in the Data Appendix A.1. at the end of this paper.

The factor price data that we used in this paper were put together from a variety of sources. Details on the original data sources and our processing of this data in order to arrive at internationally comparable factor price vectors are described below (with some additional details provided in the Data Appendix A.1.).

For the purposes of empirical implementation, production technology was assumed to admit two types of primary input factors: capital and (dis-aggregated) labor. In compiling the data for our analysis, one issue that arose was the lack of availability of internationally comparable

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[10] Some exceptions may be noted: Trefler (1993), while assuming that the U.S. technology matrix was basically valid for all countries, rescaled each by a country-specific productivity parameter. Hakura (1999) used the data of direct input matrices as well as input-output matrices for each of the five European countries. Davis and Weinstein (1998) was the first study which used the same data set as ours: the OECD Input-Output Database.

data on factor prices. A second and equally compelling problem was that the factor price data that was reported was sometimes inconsistent with GDP data (i.e., the inner product of factor prices and the factor endowment vector does not sum to GDP).

Our strategy in dealing with these problems was to collect factor price data from various sources which were perhaps not directly comparable in the first instance, and then to process it so as to get comparability across nations *and* a match with GDP data. This was achieved as follows: the Annual National Account (ANA) Database of the OECD provides data on cost components of GDP where GDP is decomposed into the following terms: compensation of employees (CE), operating surplus (OS) and an aggregate of other components (OC) such as indirect taxes and subsidies. To achieve consistency of the factor price data with national income accounts, we started first with returns to aggregates (of labor and capital) and then moved on to dis-aggregated returns. Thus, to begin with, we require that the total return to labor in any country be equal to its CE, i.e., we *set* $\mathrm{CE} = \sum_i w_i L_i$, where the summation is across dis-aggregated labor categories.

To determine the total return to capital we have two options: the first (henceforth referred to as the Capital I method) is to let the operating surplus equal the ex-post return to capital in the economy (i.e., to set $\mathrm{OS} = rK$).[11] A second option (henceforth referred to as the Capital II method) is to let

$$\mathrm{GDP} - \sum_{i=1}^{n} w_i L_i = rK$$

that is, to let the return to capital equal the residual when employee compensation is taken out of GDP. We perform our tests using both methods for calculation of the total return to capital.

Given the overall compensation to labor ($\sum_i w_i L_i$) and the overall return to capital, we need next the returns to dis-aggregated labor. This was accomplished in the following manner.

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[11] To set operating surplus equal to rK requires a strong zero-profit assumption because, in general, the operating surplus contains other components, such as profit, as well.

Endowments of labor in various occupations (L_i) and the occupational wage rates (w_i) were directly obtained from various national statistical publications for three non-European countries and from Eurostat's Structure of Earnings for the five European countries in our data set. There are two problems with using this data directly. First, there is the issue of overall consistency with the national income accounts because the value of $\sum_i w_i L_i$ rarely equals the CE data reported in the national income accounts. In order to achieve this consistency, we *construct* a modified series of wage rate data as follows. Given the observed data on occupational wage rate (w_i), occupational employments (L_i) and compensation of employees (CE), we calculated the modified wage rate ($\hat{w}_i$) for each occupation by solving

$$\sum_{i=1}^{n} \hat{w}_i L_i = CE \quad \text{and} \quad \frac{w_i}{w_j} = \frac{\hat{w}_i}{\hat{w}_j}, \ \ \forall i, j \in n$$

That is, we took the information about the wage ratios between occupations from the reported wage series w_i and made the sum of constructed wage rates multiplied by occupational employment levels consistent with the measure of compensation of employees in the national accounts database.

A second issue had to do with comparability of labor classes across countries. Publications for different countries use different occupational classification systems.[12] Thus, some re-categorization of occupational classifications was inevitable. Data for each of the three non-European countries (Korea, Canada, and the United States) were reported in a manner conforming closely to what is referred to as the ISCO (Industrial Standard Classification of Occupation) 1968 system. However, the occupational classifications of European countries in their structure of earnings data (as reported in Eurostat) were quite different from those of the non-European countries and could not have been recategorized easily into the ISCO 1968 system. Also, these were at a substantially higher level of aggregation than the data for the non-European countries. We considered two types of re-categorization. The first was simply to divide the labor force for all countries into production workers and non-

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[12] For details on publication sources, see the Data Appendix

production workers (henceforth Euro I categorization). The other one was to disaggregate the non-production workers into three categories; managerial, clerical and others (henceforth Euro II categorization).

The factor prices used in our empirical exercises are reported Table I. Wages for both labor classifications − the Euro I and Euro II classifications described above − are presented in the upper panel. As can be seen from a comparison, say, of US and German wages, there is a reasonable degree of divergence between even the OECD countries used in our analysis. Indeed, the wage gap between Korea and the rest of the OECD is extremely large, as the figures presented in Table 1 indicate. As we have discussed before, we have used primarily two measures of return to capital. Our first measure of the rental price of capital (Capital I method), as we previously discussed, was obtained by dividing the operating surplus by net capital stock. The lower panel in Table I reports rental price of capital calculated in this way for each country. Denmark has the lowest rental price of capital (5.3 percent), while the U.S. is a bit higher (8 percent) and Korea is the highest (15.5 percent). Our second measure of the return to capital (Capital II method) was obtained by taking the net return to capital to be the difference between GDP and CE and dividing this number by the net capital stock. This measure of return to capital, consistent with an overall division of GDP into rewards to labor and capital, is also reported in the second panel of Table I. By the Capital II method, return to U.S. capital, for instance, is 16.5 percent and the return to capital in Korea is 23.37 percent. Since the Capital I measure is net of taxes on production (following the definition of "Operating Surplus") and the Capital II measure is gross of indirect taxes, the Capital I measure can be expected to be lower than the Capital II measure of return to capital. This can be seen from our calculations as well.

IV. Results

Tests of our basic restriction on the factor content of bilateral trade flows, Equation (9), can be conducted using the factor price data and the country specific technology matrices whose construction we have described in the previous section. Since entering technology and factor price data into the left hand side of (9) would simply gives us an un-normalized numerical sum, whose extent of conformance or departure from the theory cannot be easily ascertained,[13] we first re-write (9) in the following manner:

$$\frac{\mathbf{w}^{c'}\mathbf{T}_V^{c'c} + \mathbf{w}^{c}\mathbf{T}_V^{cc'}}{\mathbf{w}^{c}\mathbf{T}_V^{c'c} + \mathbf{w}^{c'}\mathbf{T}_V^{cc'}} = \theta \geq 1 \tag{10}$$

(10) has a convenient interpretation. For any country pair, c and c', with gross bilateral import flows, $\mathbf{T}^{c'c}$ and $\mathbf{T}^{cc'}$, the ratio in (10) is the ratio of the sum of the importers' (hypothetical) cost of production (using domestic factor prices and imported factor content) to the total ("actual") cost of production in the exporting countries. Thus, the first term in the numerator of the ratio in (10), $\mathbf{w}^{c'}\mathbf{T}_V^{c'c}$, is the hypothetical cost of production of the gross import vector of c' from c, $\mathbf{T}^{c'c}$, using the factor prices in c', $\mathbf{w}^{c'}$, and the factor content actually employed in production of this import vector in the exporting country c, $\mathbf{T}_V^{c'c}$. The cost of producing these goods in the exporting country, c, is given by the first term in the denominator of the ratio in (10), $\mathbf{w}^{c}\mathbf{T}_V^{c'c}$. The second terms in the numerator and the denominator relate to the trade flow $\mathbf{T}^{cc'}$, the gross import vector of c from c', and are equal to the hypothetical cost of production in the importer of that flow c and the "actual" cost of production in the exporter c' respectively. We denote this ratio of costs as θ. Clearly, from (9) and (10), the theory predicts that $\theta \geq 1$. Importantly (and this is what has motivated

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[13] For instance, if for a given country pair, we were to obtain that the left hand side of (9) added up to -90,000, we would be able to conclude that the theoretical restriction that the left hand side be greater than zero had not been met, but would be unable to tell how significant a departure this is from the theory.

our transition from (9) to (10)), given the relative cost interpretation for θ that we have provided above, actual measures of θ for any country pair will give us an intuitive sense of the extent of conformance or departure of the data from the theory for those countries.

We describe first the values of θ obtained using the raw factor price measures reported in Table I. Results from additional simulation-based analyses that were conducted to take into account the fact that our factor price measures may be subject to measurement error are described subsequently. The values of θ calculated using the Euro I and Euro II labor classifications and the Capital I measure of return to capital are presented in Tables 2 and 3 respectively. Values calculated using the Capital II measure of return to capital instead are presented in Tables 4 and 5.

Consider the results presented in Tables 2 with the Euro I and Capital I factor price measures. Keeping in mind the theoretical prediction that $\theta \geq 1$, we can see that the theory is satisfied directly for twenty-one of the twenty-eight country pairs in our sample. Note that even for the seven pairs for which the theory is not satisfied, θ falls below 0.99 in only three cases. Table 3 presents values of θ calculated using Euro II and Capital I factor prices. The move from the Euro I classification to the more disaggregated Euro II classification does not seem to affect the results by much. The success rate for the theory stays about the same. Twenty-one of the twenty-eight country pairs satisfy the theory directly. Of the seven remaining pairs, only three fall below 0.99. Values of θ calculated using Capital II factor prices and Euro I labor classification are presented in Table 4. As the numbers presented there indicate, there is now a slight improvement in the extent to which the data are consistent with the theory. Specifically, twenty-two of the twenty-eight country pairs in our sample now satisfy the theory. Of the six remaining pairs, none fall below 0.99. Values with the Capital II and Euro II measures are equally supportive of the theory. Once again, twenty-two of the twenty-eight country pairs directly satisfy the theory. Of the rest, none fall below 0.99.

Overall, the results in Tables 2, 3, 4 and 5 appear to support the theory substantially. It is true that for any given combination of factor price measures, the data are inconsistent with the theory for roughly one quarter of the country pairs, as we have discussed above. However, a number of these "failures" are minor in magnitude − with the ratio θ being greater than 0.99 but less than 1 in a great proportion of these cases. To what extent could these failures be driven by simply measurement error in factor prices? To examine this, measurement error in factor prices can be modeled in the following fashion (an alternate methodology that gives nearly equivalent results is described in Footnote 14 below):

$$w_{obs} = w_{true} + \epsilon_w, \quad \epsilon_w \; N(0, \sigma_w^2) \tag{11}$$

That is, the observed value of any given factor price, w_{obs}, can be assumed different from the true value of the factor price, w_{true}, by an amount equal to the measurement error ϵ_w where ϵ_w itself is assumed to be distributed normally with zero mean and variance σ_w^2. Consider a single factor price at a time. Taking the values of all other observed factor prices used in calculating the left hand side of (9) as being true, for the particular factor price being considered, w_{true} can be set equal to a value $\tilde{w}$ so that the theory is just right (i.e., so that (9) is just satisfied). Then taking a large number of draws of w_{obs} (10,000 draws in our exercises) under particular assumptions on the magnitude of σ_w (that, for instance, it is 5 percent of the value of w_{obs}), the left hand side of (9) can computed in each case and its distribution thus obtained. Given the calculation of (9) using observed factor prices, we can then ask if we can reject the null that the theory is right (i.e., that the left hand side of (9) ≥ 0). This can then be done for all factor prices for each country pair and the exercise repeated for every country pair so we can finally ask, how often we unable to reject that the theory is right.[14]

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[14] A nearly equivalent exercise (in Bayesian spirit) treating all factor prices together would model the

The results of these exercises are presented in Table 6 where the headers of the three columns indicate the extent of measurement error assumed in drawing w_{obs} – with σ_w equal to 2.5 percent, 5 percent and 10 percent of the mean of w_{obs} respectively. For a given combination of factor price measures chosen (say, Euro I and Capital II) the rows correspond to the significance level for the test. The entries in the table corresponding to a given level of significance and a given level of measurement error indicate the fraction of cases in which we were unable to reject that the theory is right. [15] As the figures in Table 6 indicate, allowing for measurement error in factor prices, we are unable to reject the null that the theory is right in a very large fraction of cases. With the standard deviation of measurement error assumed to be even just ten percent of w_{obs}, the success rate for the theory (i.e., the fraction of cases for consistent with the theory being true) is about ninety percent with the Capital I rental measure and a full hundered percent with the Capital II measure.

The robustness of our results were checked by performing the tests of (9) under various other configurations and data construction methods. These alternative configurations include,

(i) using different depreciation rates (3% and 10%) in calculating net capital stocks,

(ii) using gross capital stock (readily available from ISDB) instead of net capital stocks,

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measurement error in factor prices in the following fashion:

$$w_{true} = w_{obs} + \theta_w, \quad \epsilon_w \ N(0, \sigma_w^2)$$

. Now, under assumptions regarding the magnitude of $sigma_w$ for each factor price, say that it equals 5 percent of w_{obs}, we can take 10,000 draws on w_{true} for each of the factor prices. The left hand side of (9) can be computed in each of the 10,000 cases and the distribution of true value of the left hand side of (9) can be obtained. We can then examine where along this distribution the minimum acceptable value of (9) for the theory to be right (i.e., the number zero) lies. This would allow us to answer the question of how likely it is for the "truth" to lie in the acceptable region given our observations on factor prices. This exercise gives us answers that are quantitatively very close to those we get from the exercise described in the main body of the text.

[15] It should be easily recognized that tests of this nature do not necessarily have large power against alternatives. Our results should then be viewed as only confirming the extent of *consistency* of the data with the theory.

(iii) using the total (domestic + foreign) input-output matrix rather than domestic inputs matrix prescribed by Staiger (1988).

None of these variations changed the tests results greatly. The success rate for the theory was about the same as the results under the configuration we described earlier in the text (i.e., using net capital stock calculated using a five percent depreciation rate and with the I/O matrix simply reflecting the usage of domestic inputs as prescribed by Staiger (1986)).

V. Concluding Remarks

This paper has used OECD production and trade data to test the restrictions (derived by Helpman (1984)) on the factor content of trade flows which hold even under non-equalization of factor prices and in the *absence* of any assumptions regarding consumer preferences. Our results provide greater support for the theory than have many previous exercises: We are unable to reject the restrictions implied by the theory for the vast majority of country-pairs. Our results are quite robust to the factor price measures used and to a variety of assumptions made in the construction of necessary variables from observed data. [More To Be Added]

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Appendix A.1.

Data

The selection of countries was mainly based on the availability of related data sets. These included five European countries (Denmark, France, Germany, the Netherlands and the United Kingdom) and three non-European countries (United States, Canada and, Korea). All data pertained to 1980 and were converted into 1980 US dollars unless otherwise stated.

Industry Coverage and Labor Disaggregation

Industrial activities are disaggregated according to the ISIC classification system (Rev 2, 1968) with one a digit level of disaggregation for non-manufacturing industries (giving us eight sectors) and a two digit level of disaggregation for manufacturing (giving us nine sectors). Thus, we have a total of seventeen industrial sectors. Since some data for European countries (taken from Eurostat's *Structure of Earnings* (SOE)) follow the NACE categorization, these data were converted into the ISIC code using Table 3.3 in OECD's Inter-Sectoral Database (ISDB). The industrial coverage used in this paper is described in Table A1.

Labor input factors for non-European countries were disaggregated into seven categories according to ISCO-1968 which included professional/technical workers (code 0/1), administrative/managerial workers (2), clerical workers (3), sales workers (4), service workers (5), agricultural workers (6) and production workers (7/8/9). For European countries, labor was disaggregated into production workers and non-production workers. Non-production workers consisted of top management executives, other senior executives, assistants, clerical workers and supervisors. The labor categorization used in this paper (Euro I and Euro II) and its concordance with ISCO and SOC classifications are in Table A2.

Technology

The technology matrices consist of two parts: the direct input matrix (**A**) and input-output matrix (**B**).

1. Direct Input Matrix

This measures how much labor and capital is actually employed in each industry at a given point of time. The disaggregated occupational distribution of labor was taken from the table of the *economically active population by occupation* in the ILO's *Statistical Yearbook* (1945-1989). However, in this table the manufacturing sector was not disaggregated at the sectoral level. To obtain the occupational distribution of labor in each sector of manufacturing, we relied on each country's census of population data for non-European countries[16] and on the SOE for European countries. The numbers of workers in each occupation in each manufacturing sector collected in this way was rescaled so that the total numbers of occupational workers in manufacturing equalled those in the ILO's *Yearbook*.

Data on net capital stocks (at the sectoral level) were not directly available for the various countries in our sample. Measures of net capital stock had therefore be constructed instead.[17] Our measure of the net stock of capital was constructed as follows: We computed first the initial net capital stock in each industry in 1970. This was done by taking the *aggregate* net capital stock in 1970 from the *Penn World Table* and the gross capital stock of each industry in 1970 from the ISDB. Then, the net capital stock in each industry was computed by distributing the total net capital stock number into each industry using the industrial ratio in ISDB. Second, data on annual gross fixed capital formation in each industry during

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[16] For Uthe S and Korea, the data are available from 1980 *Census of Population* in each country. But for Canada, the occupational distribution in disaggregated manufacturing industries is available only from 1996 census. Thus we assume that the ratio of occupational distribution to total manufacturing workers does not change very much over time and use the information from the 1996 census

[17] Measuring the capital stock in each industry is an important issue not only because it is a component of the direct input matrix but also because it affects directly the calculated rate of return to capital.

1971-1980 were taken from the ISDB. (Since the ISDB does not have data on Korea, we obtained this data from National Account Department of the Bank of Korea.) Taking the initial disaggregated net capital stock and each year's disaggregated capital formation data, we used the Perpetual Inventory Method to compute net capital stock in each industry in 1980. The test results reported in Section IV used a depreciation rate of percent. To check sensitivity, we repeated the same procedure with depreciation rates of 3 percent and 10 percent. The results were not sensitive to these changes.

2. Input-Output (I/O) Matrix (Indirect Input Matrix)

The entries in this matrix represent the amount of intermediate inputs that a sector purchases from other sectors to produce one unit of output. The OECD's I/O Database provides three sets of Input-Output matrices for each country. The first is the "Domestic I/O matrix" which shows the usage of domestically produced intermediate goods in each sector. The second is the "Imported I/O matrix" which measures how many intermediate goods are imported from abroad in each sector. Finally, the "total I/O matrix" is a simple summation of domestic and imported I/O matrix.

Given Staiger's (1986) proposed modification of the factor content calculations suggested in Helpman (1984), the domestic I/O matrix (which does include the factor content of traded intermediate goods) is a more appropriate choice than the total I/O matrix. To see the underlying logic of his argument, consider the following simple three country-four commodity case. Good 1 and good 2 are final goods which use good 3 and good 4 as intermediate goods. In particular, to produce one unit of good 1, we need α units of good 3 and β units of good 4. Also assume that the unit labor requirement is one both for good 3 and 4. Countries A, B and C produce good 1, 2 and 3, respectively and good 4 is produced both by countries A and B. Now, suppose country A exports one unit of good 1 to country B. Then country A's production cost will be

$$w^A\beta + w^C\alpha$$

If this were produced in country B, the production cost will be

$$w^B\beta + w^C\alpha$$

For country A to be an exporter of good 1,

$$w^A\beta + w^C\alpha \leq w^B\beta + w^C\alpha$$

or

$$(w^B - w^A)\beta \geq 0$$

This last expression is nothing but what we derived in Section II. Note that in the end, the relevant input-output coefficient is not that of imported intermediate good (α) but that of domestically produced intermediate good (β).

Bilateral Trade

The manufacturing sector's bilateral trade data were directly obtained from the OECD's *Bilateral Trade* Database for each pair of countries in our sample. This data is organized according to the ISIC categorization and so is readily conformable with technology matrix described above. The bilateral trade for non-manufacturing sectors were not available. So, as was done by Davis and Weinstein (1998), bilateral imports of non-manufacturing sectors were set equal to the share of manufacturing imports from that country times total non-manufacturing imports in that sector, where total non-manufacturing imports were taken from the OECD I/O Database.

Factor Prices

The construction of factor price data was described in Section III in detail, so only a brief description is provided here. For capital, the *ex-post* rental rate was calculated by dividing the Operational Surplus from the OECD's *Annual National Accounts* Database by the total capital stock from OECD's International Sectoral Database. The occupational wage rate was taken from the *Census of Population* for each non-European country and the *Structure of Earnings* for European countries. For the purpose of international compatibility, these data were modified as described in Section III.

Appendix A.2.

Hicks-neutral Technology Differences

An attractive feature of the framework described above is that it relaxes a number of unrealistic assumptions regarding factor prices and consumer preferences that have traditionally been made in the empirical literature in this area. However, as we have already noted, one rather restrictive assumption remains: identical CRS technologies across countries. To relax this somewhat, we allow for Hicks-neutral factor efficiency differences across countries (just as in Trefler (1993, 1995)). The derivation of the restrictions analogous to (7)-(9) is straightforward: Suppose that all input factors in country c' are more productive than those in country c by the factor of λ ($\lambda > 0$). Then, equation (4) becomes

$$\begin{aligned}\mathbf{p}(\mathbf{Q}^{c'} + \mathbf{T}^{c'c}) &\leq \mathbf{\Pi}(\mathbf{p}, \mathbf{V}^{c'} + \frac{1}{\lambda}\mathbf{T}_V^{c'c}) \\ &\leq \mathbf{\Pi}(\mathbf{p}, \mathbf{V}^{c'}) + \mathbf{\Pi}_V(\mathbf{p}, \mathbf{V}^{c'})\frac{1}{\lambda}\mathbf{T}_V^{c'c} \\ &= \mathbf{p}\mathbf{Q}^{c'} + \frac{(\mathbf{w}^{c'})}{\lambda}\mathbf{T}_V^{c'c} \qquad (12)\end{aligned}$$

because now country c' could do better than country c (in terms of output) even with only $\frac{1}{\lambda}\mathbf{T}_V^{c'c}$. Applying the zero profit condition in country c ($\mathbf{p}\mathbf{T}^{c'c} = (\mathbf{w}^c)\mathbf{T}_V^{c'c}$), we have the following equation (corresponding to equation (7) in the previous section):

$$(\frac{\mathbf{w}^{c'}}{\lambda} - \mathbf{w}^c)\mathbf{T}_V^{c'c} \geq 0 \qquad (13)$$

In general, if λ^i is the Hicks-neutral technology parameter describing factor efficiency levels in country i relative to some benchmark country, (7)-(9) would be rewritten as

$$\begin{aligned}(\frac{\mathbf{w}^{c'}}{\lambda^{c'}} - \frac{\mathbf{w}^c}{\lambda^c})\mathbf{T}_V^{c'c} &\geq 0 \qquad (14) \\ (\frac{\mathbf{w}^{c}}{\lambda^{c}} - \frac{\mathbf{w}^{c'}}{\lambda^{c'}})\mathbf{T}_V^{cc'} &\geq 0 \qquad (15) \\ (\frac{\mathbf{w}^{c'}}{\lambda^{c'}} - \frac{\mathbf{w}^c}{\lambda^c})(\mathbf{T}_V^{c'c} - \mathbf{T}_V^{cc'}) &\geq 0 \qquad (16)\end{aligned}$$

Results To be Added

Table A1. Seventeen Industries and its Concordance with ISIC and NACE

Description	ISIC Code	NACE R6/R25
1. Agriculture, Hunting, Forestry and Fishing	1	01
2. Mining and Quarrying	2	12,14
3. Food, Beverages and Tobacco	31	36
4. Textiles, Apparel and Leather	32	42
5. Wood Products	33	48
6. Paper, Paper Products and Printing	34	47
7. Chemical Products	35	17,49
8. Non-metallic Mineral Products	36	15
9. Basic Metal Industries	37	13
10. Fabricated Metal Products and Machinery	38	19,21,23,25,28
11. Other Manufacturing	39	48
12. Electricity, Gas and Water	4	06
13. Construction	5	53
14. Wholesale and Retail Trade, Restaurants and Hotels	6	56,59
15. Transport, Storage and Communication	7	61,63,65,67
16. Finance, Insurance, Real Estate and Business Services	8	69A
17. Community, Social and Personal Services	9	74

Table A2. Concordance of Labor Categories

Euro I	Euro II	ISCO-1968 (Non-European Countries)	Structure of Earnings (European Countries)
production	production	service (5) agricultural (6) production (7/8/9)	manual workers
non-production	managerial	administrative / managerial (2)	top management executives other senior executives
	clerical	clerical (3)	clerical
	others	professional / technical (0/1) sales (4)	assistants supervisors

Table 1. Factor Prices

Factors			USA	CAN	KOR	DEN	FRA	GER	NET	UK
Labor (in U$)	Euro I	Production	13,059	12,592	1,638	13,137	14,141	17,151	17,423	12,327
		Non-Production	20,375	15,657	2,822	16,878	23,290	23,496	23,886	13,510
	Euro II	Production	13,059	12,592	1,638	13,333	14,715	18,789	18,177	12,595
		Managerial	26,589	21,165	7,189	24,985	40,855	34,011	36,670	21,011
		Clerical	14,869	11,460	2,910	17,313	16,221	16,389	18,363	9,323
		Others	21,578	16,960	2,495	15,788	22,859	24,544	25,083	14,529
Capital	Capital I Method		0.080	0.103	0.155	0.053	0.078	0.091	0.097	0.075
	Capital II Method		0.165	0.190	0.234	0.174	0.180	0.203	0.185	0.203

For Labor, the factor price figures presented in the Table above denote average annual compensation in US dollars to an employee of the designated type.
For capital, the factor price denotes the rate of return. Rates of return were calculated as follows Capital I Method: Operating Surplus / K
Capital II Method: (GDP - CE) where K denotes net capital stock, GDP gross domestic product and CE compensation to employees.

Table 2 Bilateral Importer's Cost / Bilateral Exporter's Cost with Euro I and Capital I Method

	USA	CAN	KOR	DEN	FRA	GER	NET	UK
1. USA		0.99	1.95	1.00	1.03	1.01	1.16	0.98
2. CAN			1.83	1.06	1.01	0.99	1.12	0.97
3. KOR				2.76	3.00	2.70	4.04	2.11
4. DEN					1.07	0.99	1.03	1.04
5. FRA						0.99	1.03	1.04
6. GER							1.01	0.97
7. NET								1.10
8. UK								

Table 3 Bilateral Importer's Cost / Bilateral Exporter's Cost with Euro II and Capital I Method

	USA	CAN	KOR	DEN	FRA	GER	NET	UK
1. USA		0.99	1.92	1.02	1.05	1.01	1.18	0.98
2. CAN			1.81	1.05	1.02	0.99	1.14	0.97
3. KOR				2.72	2.98	2.76	4.08	2.10
4. DEN					1.07	0.99	1.04	1.03
5. FRA						0.99	1.03	1.04
6. GER							1.00	0.97
7. NET								1.11
8. UK								

Table 4 Bilateral Importer's Cost / Bilateral Exporter's Cost with Euro I and Capital II Method

	USA	CAN	KOR	DEN	FRA	GER	NET	UK
1. USA		0.99	1.69	0.99	1.05	1.02	1.12	1.02
2. CAN			1.60	1.01	1.02	1.00	1.09	1.01
3. KOR				2.23	2.52	2.30	3.39	1.86
4. DEN					1.02	0.99	1.01	1.04
5. FRA						0.99	1.02	1.04
6. GER							0.99	0.99
7. NET								1.07
8. UK								

Table 5 Bilateral Importer's Cost / Bilateral Exporter's Cost with Euro II and Capital II Method

	USA	CAN	KOR	DEN	FRA	GER	NET	UK
1. USA		1.00	1.67	1.00	1.06	1.02	1.14	1.03
2. CAN			1.59	1.01	1.03	1.00	1.10	1.01
3. KOR				2.22	2.51	2.36	3.43	1.85
4. DEN					1.02	0.99	1.02	1.03
5. FRA						0.99	1.02	1.03
6. GER							0.99	0.99
7. NET								1.08
8. UK								

Table 6 Sign Test Results with Measurement Error Simulation

Euro I and Capital I

		Degree of Measurement Error		
		2.5%	5.0%	10.0%
Significance Level	1%	75.0%	82.1%	96.4%
	5%	75.0%	78.6%	92.9%

Euro II and Capital I

		Degree of Measurement Error		
		2.5%	5.0%	10.0%
Significance Level	1%	75.0%	85.7%	96.4%
	5%	75.0%	78.6%	89.3%

Euro I and Capital II

		Degree of Measurement Error		
		2.5%	5.0%	10.0%
Significance Level	1%	89.3%	96.4%	100.0%
	5%	82.1%	89.3%	100.0%

Euro II and Capital II

		Degree of Measurement Error		
		2.5%	5.0%	10.0%
Significance Level	1%	89.3%	96.4%	100.0%
	5%	85.7%	92.9%	100.0%