The Factor Content of Bilateral Trade: An Empirical Test

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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) on the factor content of trade flows that hold even under nonequalization 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 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) are available.

We are most grateful to Steve Levitt and two anonymous referees for many detailed comments on this paper. We are also grateful to Don Davis, Rob Feenstra, Ron Findlay, Gordon Hanson, James Harrigan, Scott Taylor, Daniel Trefler, David Weinstein, and seminar participants at the University of Chicago, Columbia University, and the National Bureau of Economic Research for a number of helpful discussions and comments and to Elena Urgelles for excellent research assistance. Choi thanks Brown University for providing its Stephen Robert Fellowship and to the Korea Development Institute, where revisions to this paper were conducted. The views expressed here do not necessarily represent those of the Korea Development Institute.

[*Journal of Political Economy,* 2004, vol. 112, no. 4]
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We find that restrictions implied by the theory cannot be rejected for the vast majority of country pairs considered in our analysis.

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. They 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.

This central standing of the factor proportions model in international economics has appropriately prompted, particularly recently, intense empirical scrutiny.[1] 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 magnitude and direction of net factor content flows among 27 countries were predicted extremely poorly by the theory—a finding that established a mood of deep pessimism with regard to the empirical validity of the model.[2]

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

[1] See Leamer and Levinsohn (1995), Trefler (1995), Helpman (1998), and Davis and Weinstein (2003) for comprehensive discussions.

[2] 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 that use their abundant factors more intensively.

used in the empirical exercises.[3] In a series of remarkable contributions, Trefler (1993, 1995) and Davis and Weinstein (2001) 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 (2001) 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.

Our paper contributes to this literature on empirical testing of the factor proportions theory. Our methodology contrasts strongly with most earlier work, however. Nearly all the tests of the factor content predictions of the model (including the ones we have discussed above) have assumed full factor price equalization (FPE) across countries and identical homothetic preferences across countries (i.e., they have tested the HOV prediction) or have attempted very specific relaxations 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 that relies neither on 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 nonhomothetic 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) are available.[4]

Helpman's (1984) result, itself an intuitive (and general) formaliza-

[3] Also, a growing literature has examined other aspects and predictions of the neoclassical trade model: Prominent recent contributions include Harrigan (1995, 1997), Bernstein and Weinstein (2002), Hanson and Slaughter (2002), Debaere (2003), and Schott (2003), among others.

[4] See, however, the earlier work of Brecher and Choudhri (1993), which does undertake a bilateral analysis somewhat similar to the one conducted here—although just between the United States and Canada (and on an industry by industry basis).

tion of important 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.[5]

Our results are as follows: The restrictions implied by the theory for overall (i.e., bidirectional) bilateral trade flows are satisfied for the vast majority of country pairs in our sample. Having said this, we must note that in many cases, the theory is only "just" satisfied. Nevertheless, this finding stands in strong contrast with many previous tests of the theory that were conducted under the restrictive assumptions of identical factor prices and identical homothetic preferences across countries in which the theory fared very poorly—as was reported in the early tests of Bowen et al. (1987) and confirmed in more recent implementation of these tests using the country-specific data (which are also used in the present study) by Davis and Weinstein (2001), among others. Thus our finding that the theory, when tested without the imposition of these restrictions, is not rejected by the data is a significant one. Our results are robust to a wide variety of methods used to measure factor prices. Allowing for even a small degree of measurement error in factor prices brings greater "success" to the theory. In some configurations, the data are unable to reject the null that the theory is right in 100 percent of the cases (i.e., country pairs).

The rest of the paper is structured as follows: Section II presents Helpman's (1984) basic result regarding restrictions on bilateral trade flows, incorporating additionally into the analysis the use of intermediates in production. 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 presents concluding remarks. Appendix A provides a detailed description of data sources and construction. Appendix B discusses ex-

[5] It is worth noting that the theoretical restrictions that we test here are easily extended to accommodate the possibility of technological differences (aggregate Hicks-neutral differences and industry-specific, i.e., Ricardian, differences) across countries. We discuss this extension in App. B.

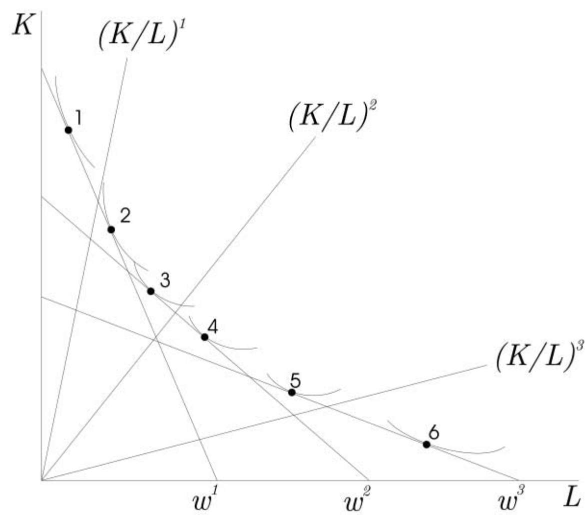

FIG. 1.—Lerner diagram

tensions 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), building on the work of Brecher and Choudhri (1982), derived intuitive restrictions on the factor content of bilateral trade between countries—relating factor content of trade to relative factor scarcities in the trading countries. The basic insight behind Helpman's result can be easily explained using a Lerner diagram. Figure 1 depicts a Lerner diagram for the two-factor/six-good/three-country case.

The isoquants in figure 1, numbered from 1 to 6, describe output levels of goods 1–6, 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 of 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, nonequalization of factor prices will still result in the use of different techniques of production 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 $\mathbf{B}^c$. 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, $\mathbf{Y}^c$, is denoted by $\mathbf{A}^c$. For any country c, the trade vector ($\mathbf{T}^c$) is the difference between net production ($\mathbf{Q}^c$) and consumption ($\mathbf{C}^c$):

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

In the presence of intermediates in production, we have net and gross output related as

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

Then $\mathbf{B}^c(\mathbf{I} - \mathbf{A}^c)^{-1}$ is 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) in country c. This matrix can also be used to determine the factor content of exports by c. Thus consider bilateral trade between two countries, with $\mathbf{T}^{c'c}$ denoting the gross import vector by country c' from country c and $\mathbf{T}_V^{c'c}$ denoting the corresponding gross import vector of factor content by country c' from country c. Given the gross import vector, $\mathbf{T}^{c'c}$, and the technology matrix employed in c, $\mathbf{B}^c(\mathbf{I} - \mathbf{A}^c)^{-1}$, the corresponding factor content, $\mathbf{T}_V^{c'c}$, can be written as

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

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 (convex) 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.[6] 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 ($\mathbf{pT}^{c'c}$). This and the concavity of $\mathbf{\Pi}$ in $\mathbf{V}$ (used to arrive at the second inequality in what follows) give us that

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

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

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

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

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

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 (1984) 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.[7] It should be readily evident that all the variables in (9) relate to the equilibrium with trade. Inequality (9) may therefore

[6] 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).

[7] It is tempting to interpret (9) as a measure of the savings in production costs in country c' because 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 incorrect, however. 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).

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 of traded intermediate goods. Therefore, we perform the tests described above using input-output matrices that include only domestically produced intermediates.[8]

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 in which technologies are instead characterized by Hicks-neutral differences across countries, where 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 ($\mathbf{pT}^{c'c}$) times the ratio $1/\lambda$. Equations (5)–(9), mutatis mutandis, are then easily derived. Alternatively, 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. While we do not implement here tests of the theory with technological differences of the sort discussed above, we develop these expressions in detail in Appendix B in order to demonstrate the flexibility of the framework being used here.

We have derived here theoretical restrictions on the factor content of bilateral trade flows that may be tested using "observable" data. These tests offer some 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 discussed). The focus here on bilateral trade flows also enables the examination of trade flows between only a subset of countries for which quality data (relatively speaking) are available. The dis-

[8] See App. A for a detailed discussion and a simple example illustrating the need for the modification of Helpman's measure as suggested by Staiger (1986). On the issue of the proper measurement of the factor content of trade in the presence of intermediates, see also Antweiler and Trefler (2002).

advantages 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. 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

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

A. Technology

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 because of the general difficulty of obtaining the relevant data for a cross section of countries at any given time.[9] 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 and the input-output matrices for each country. As noted

[9] 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 (2001) used country-specific direct input matrices as well as input-output matrices, as Davis and Weinstein (2001) did.

earlier, taking trade in intermediates into account implies that we need to use input-output matrices that include only 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 Appendix A.

B. Factor Prices

For the purposes of empirical implementation, production technology was assumed to admit two types of primary input factors: capital and (disaggregated) labor. 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 these data in order to arrive at internationally comparable factor price vectors and variation in this methodology to ensure the robustness of our results are described below (with some additional details provided in App. A).

When we compiled the data for our analysis, one issue that arose was the lack of availability of internationally comparable data on factor prices. A second and equally compelling problem was that the factor price data that were reported were sometimes inconsistent with gross domestic product data (i.e., the inner product of factor prices and the factor endowment vector do not sum to GDP).

Our strategy in dealing with these problems was to collect factor price data from various sources that were perhaps not directly comparable in the first instance and then to process them so as to get comparability across nations *and* a match with GDP data. This was achieved as follows: the Annual National Account database of the OECD provides data on cost components of GDP, with GDP decomposed into the following terms: compensation of employees, operating surplus, and an aggregate of other components 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 disaggregated returns. Thus, to begin with, we require that the total return to labor in any country be equal to its compensation of employees; that is, we *set* compensation equal to $\sum_i w_i L_i$, where the summation is across disaggregated labor categories (described in greater detail below).

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 operating surplus equal to rK).[10] 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. To ensure robustness, 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 disaggregated labor. This was accomplished in the following manner. 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 (SOE) for the five European countries in our data set. There are two problems with using these 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 employee compensation 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 employment levels (L_i), and compensation of employees, we calculated the modified wage rate ($\hat{w}_i$) for each occupation by solving

$$\sum_{i=1}^{n} \hat{w}_i L_i = \text{employee compensation},$$

$$\frac{w_i}{w_j} = \frac{\hat{w}_i}{\hat{w}_j}, \quad \forall i, j \in n.$$

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.[11] Thus some recategorization 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 Industrial Standard

[10] 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.

[11] For details on publication sources, see App. A.

Classification of Occupations (ISCO) 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 data were at a substantially higher level of aggregation than the data for the non-European countries. We considered two types of recategorization. The first was simply to divide the labor force for all countries into production workers and nonproduction workers (henceforth Euro I categorization). The other one was to disaggregate the nonproduction workers into three categories: managerial, clerical, and others (henceforth Euro II categorization).[12]

Overall then, we have two measures of returns to capital and two classifications of labor. The Capital I measure is the reported operating surplus of the economy per unit of capital (and, as measured, is net of taxes), and the Capital II measure (perhaps theoretically more appropriate) is the residual when employee compensation is taken out of GDP per unit of capital (and is gross of taxes). Labor is disaggregated at two levels: Euro I separates labor into production and nonproduction workers. Euro II separates workers into production workers, managerial workers, clerical workers, and other workers. These factor prices, for the countries in our sample, are reported in table 1. Wages for both labor classifications—the Euro I and Euro II classifications described above—are presented in panel A. As can be seen from a comparison, say, of U.S. 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. Panel B in table 1 reports the rental price of capital calculated in this way for each country. Denmark has the lowest rental price of capital (5.3 percent), whereas that for the United States is a bit higher (8 percent) and that for 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 employee compensation and dividing this number by the net

[12] Appendix table A2 describes the labor categories in greater detail. As in the ISCO 1968 (for non-European countries) and the SOE for European countries, nonproduction workers in both the manufacturing and nonmanufacturing sectors include managerial, clerical, and "other" workers (where "other" includes assistants, supervisors, accountants, managers, and salespeople, e.g.). Production workers include all manual workers in the SOE and all workers classified as production, service, and agricultural workers in the ISCO.

TABLE 1
FACTOR PRICES

Category	United States	Canada	Denmark	France	Germany	United Kingdom	Netherlands	Korea
	A. Labor (in U.S. Dollars)							
Euro I:								
Production	13,059	12,592	13,137	14,141	17,151	12,327	17,423	1,638
Nonproduction	20,375	15,657	16,878	23,290	23,496	13,510	23,886	2,822
Euro II:								
Production	13,059	12,592	13,333	14,715	18,789	12,595	18,177	1,638
Managerial	26,589	21,165	24,985	40,855	34,011	21,011	36,670	7,189
Clerical	14,869	11,460	17,313	16,221	16,389	9,323	18,363	2,910
Others	21,578	16,960	15,788	22,859	24,544	14,529	25,083	2,495
	B. Capital							
Capital I	.080	.103	.053	.078	.091	.075	.097	.155
Capital II	.165	.190	.174	.180	.203	.203	.185	.234

NOTE.—For labor, the factor price figures presented denote average annual compensation in U.S. dollars to an employee of the designated type. See App. table A2 for a detailed breakdown of labor categories. 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 minus compensation to employees)/K, where K denotes net capital stock.

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 panel B of table 1. By the Capital II method, the 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 (from 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.[13]

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 give us an unnormalized numerical sum, whose extent of conformance or departure

[13] Note that, as we may expect in a world with some degree of capital mobility, the net of taxes measure of return to capital, the Capital I measure, is closer across countries than the gross of taxes measure, the Capital II measure.

from the theory cannot be easily ascertained,[14] we first rewrite (9) in the following manner:

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

Equation (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 the importer's factor prices and exporter's factor usage) to the total ("actual") cost of production in the exporting countries (i.e., using the actual producer's factor prices and factor usage). 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) above, the theory predicts that $\theta \geq 1$. Importantly (and this is what has motivated 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 the data's conformance to or departure from the theory for those countries.[15]

We describe first the values of θ obtained using the raw factor price measures reported in table 1. 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.

[14] 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.

[15] Thus, e.g., if the calculated value of θ were to work out to be 0.5 in the case of a given country pair, this would be a strong violation of the theory, since this would imply that, on average, costs could be 50 percent lower if domestic production were substituted for bilateral imports.

TABLE 2
VALUES OF θ WITH EURO I AND CAPITAL I MEASURES

	Canada	Denmark	France	Germany	United Kingdom	Netherlands	Korea
United States	.99	1.00	1.03	1.01	.98	1.16	1.95
Canada		1.06	1.01	.99	.97	1.12	1.83
Denmark			1.07	.99	1.04	1.03	2.76
France				.99	1.04	1.03	3.00
Germany					.97	1.01	2.70
United Kingdom						1.10	2.11
Netherlands							4.04

TABLE 3
VALUES OF θ WITH EURO II AND CAPITAL I MEASURES

	Canada	Denmark	France	Germany	United Kingdom	Netherlands	Korea
United States	.99	1.02	1.05	1.01	.98	1.18	1.92
Canada		1.05	1.02	.99	.97	1.14	1.81
Denmark			1.07	.99	1.03	1.04	2.72
France				.99	1.04	1.03	2.98
Germany					.97	1.00	2.76
United Kingdom						1.11	2.10
Netherlands							4.08

Consider the results presented in table 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 21 of the 28 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 28 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 the 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, 22 of the 28 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 in table 5 are even more supportive of the theory. Twenty-

TABLE 4
Values of θ with Euro I and Capital II Measures

	Canada	Denmark	France	Germany	United Kingdom	Netherlands	Korea
United States	.99	.99	1.05	1.02	1.02	1.12	1.69
Canada		1.01	1.02	1.00	1.01	1.09	1.60
Denmark			1.02	.99	1.04	1.01	2.23
France				.99	1.04	1.02	2.52
Germany					.99	.99	2.30
United Kingdom						1.07	1.86
Netherlands							3.39

TABLE 5
Values of θ with Euro II and Capital II Measures

	Canada	Denmark	France	Germany	United Kingdom	Netherlands	Korea
United States	1.00	1.00	1.06	1.02	1.03	1.14	1.67
Canada		1.01	1.03	1.00	1.01	1.10	1.59
Denmark			1.02	.99	1.03	1.02	2.22
France				.99	1.03	1.02	2.51
Germany					.99	.99	2.36
United Kingdom						1.08	1.85
Netherlands							3.43

four of the 28 country pairs directly satisfy the theory. Of the rest, none fall below 0.99.[16]

The raw values of θ and the number of cases for which these values

[16] A previous version of this paper also reported measures of the left-hand sides of (7) and (8), i.e., unnormalized measures of cost differences for imports in each direction for each bilateral pair of countries. We found that when we considered import flows in each direction separately, the fraction of cases for which the theoretical restriction is met is smaller (although still greater than 50 percent). However, for tests of the theoretical idea that cheaper factors are exported by countries, on average, testing (9) (and [10]) is more appropriate than testing (7) and (8) individually. The reason is that considering (7) and (8) separately does not allow for cost differences across countries to be weighted by the volume of trade (as can be seen from the fact that in testing [7], dividing the left-hand side of [7] by the trade flow, $\mathbf{T}^{c'c}$, or indeed any other scalar does not change the test). To see why this matters more clearly, consider the following example. Consider a country that has a cost disadvantage in nearly all industries because of high factor prices relative to those in a particular partner. Consider further that it exports an infinitesimal amount to its partner but that bilateral trade between the partners consists nearly entirely of its imports from the low-cost partner. Here, trade patterns reflect our theoretical intuition: goods flow from low-cost suppliers to high-cost ones, and factors are exported from the country in which they are cheaper. However, considering (7) and (8) separately may give us only a 50 percent success rate for the theory (since imports by the low-cost supplier [even if infinitesimally small in volume] will violate the theory and exports by the low-cost supplier will be consistent with the theory). On the other hand, (9) and (10) weight cost differences by trade flows and would find the theory to be validated. We are therefore now convinced that (9) provides a more appropriate test of the theory. We are grateful for discussions with Don Davis and Rob Feenstra on this point.

exceed one are indicative of the degree of "success" of the theory. A more formal analysis requires us to take into account the fact that our calculations of θ are subject to stochastic errors and that some assumptions about these errors are needed to interpret the results above. One possibility is to assume a stochastic model in which the estimated value of the statistic θ equals its true value plus an error term that is symmetrically and independently distributed with zero mean. The probability that the value of the statistic exceeds one is .5 under the null hypothesis and greater than .5 under the alternative (that $\theta > 1$). When the normal approximation to the binomial distribution (with 28 observations and with probability of "success" in any given trial of .5) is used, the probability of finding 21 or more cases with the value of the statistic above unity (as we find in our analysis of the data using the Capital I measure) is .007 and that of finding 22 or more cases to be greater than one (as we at least do with our use of the Capital II measure) is .002. Thus the results reported in tables 2, 3, 4, and 5 reject the null hypothesis that the true value of the statistic is equal to one (against the alternative that it is greater than one) at even the 1 percent level.[17]

It should be fully recognized that the findings reported here stand in strong contrast to previous tests of the theory that were conducted under the restrictive assumptions of identical factor prices and identical homothetic preferences across countries. That the theory fared very poorly when tested under these maintained assumptions is widely known, having been confirmed in the early tests of Bowen et al. (1987) and also in more recent implementation of these tests using the country-specific data (which are also used in the present study) by Davis and Weinstein (2001), among others. Thus our finding that tests of the theory that do not impose these restrictions are not rejected by the data is a significant one.

A point regarding the magnitude of the calculated θ's is worth noting: While they are greater than one in most cases and while the theory is therefore not met with rejection in the data, it can easily be seen from even a cursory examination of the results that, in our data, exporters' costs do not seem much lower than importers' costs of production (as reflected in values of θ not much greater than one in most cases). How is this to be understood? What magnitude of θ should we expect to see in the first place? And should one infer that values of θ close to one reflect near equalization of factor prices among the countries in our sample?

[17] See also Brecher and Choudhri (1993) for a similar analysis. As with their tests, this procedure is subject to the criticism that it assumes θ to be drawn from the same distribution for all country pairs. Thus our argument here should be thought of as being only a tentative one, but one that is nevertheless suggestive of the degree of "success" of the theory.

It is worth recalling that the present theoretical framework offers no further insight into what the value of θ ought to be other than to require it to be greater than one. Nevertheless, given that θ simply measures ratios of production costs, one may imagine that the literature offers priors on what values of θ one should expect to see. This is, however, not immediately the case. First, it should be recognized that the ratio θ is not a measure of autarky production cost differences between countries. Rather, it reflects differences in production costs in a trading equilibrium, which, given the tendency toward equalization of factor prices through trade, and even in the absence of full equalization of factor prices, can be reasonably expected to be smaller than any measure of differences in production costs in autarky. The academic literature, to date, provides us with few priors on the extent of (economywide) cost differences across countries in trade equilibria and certainly none, to our knowledge, that are based in analysis of the data. Thus it is hard to arrive at judgments about where the production cost ratio should stand and how our measured values of θ compare.

Nevertheless, with values of θ so close to one, one may still suspect that the measured values of θ simply reflect nearly full equalization of factor prices rather than trading patterns (i.e., export of cheaper factors, on average, as implied by the theory). Could the dot product on the left-hand side of (9) be close to zero, that is, θ be close to one, simply because each term in the product is zero owing to identical factor prices across countries? We examined this possibility in two ways. A casual examination of the wage rates and returns to capital indicates that wage factor price differences (in particular for labor) on the order of 20–30 percent are prevalent among the countries in our sample (even after we exclude Korea). Thus, for instance, production workers are reported to earn a 30 percent higher measured wage in the United States than in Germany, with nonproduction workers higher by about 15 percent. Wage gaps between the United States and the United Kingdom are even wider. So, as such, measured factor price differences are quite large in our sample.[18] Second, we conducted an industry by industry analysis in which values of θ were determined for each industry for each country pair. If our reported findings on θ were driven simply by nearly equalized factor prices across countries, it must be the case that θ take values very close to unity for each industry as well. This is, however, most definitely not the case. Indeed, combining measures of θ across industries for all

[18] If anything, the measured values of θ are too small given the extent of the difference in factor prices. To see this, note that, if all else were equal, a 30 percent wage difference would be reflected in a value of θ that is about 1.3 (or a bit less since the share of labor in production is less than 100 percent). That this is not the case is indicative, among other things, of the fact that production methods (i.e., technology matrices) are correspondingly different as well (themselves reflecting the factor price differences).

country pairs and analyzing them gives us the following breakdown: Of the 476 industry–country pair combinations, over 250 take values greater than 1.05 and over 150 take values greater than 1.1.[19] This implies immediately that it is not full FPE that is driving our findings of values of θ close to one.

While it should be clear from the preceding discussion that FPE does not drive our findings of values of θ close to unity, one final observation regarding factor price differences and the "success" of the theory (fraction of country pairs for which the value of θ is greater than one) is nevertheless worth making. Correlating the success rate of the theory with measures of factor price differences (aggregating across factors) gives us a positive correlation.[20] Consider the following measure of "differences" in factor price vectors between c and c':[21]

$$(\mathbf{w}^{c'} - \mathbf{w}^{c})^2 \left(\frac{L}{Y}\right)^2 + (\mathbf{r}^{c'} - \mathbf{r}^{c})^2 \left(\frac{K}{Y}\right)^2 .$$

If c' has wages that are 10 percent higher and a rental rate of capital that is 10 percent lower than in c, the expression above takes the value 0.02 (for average values of the ratio L/Y and K/Y values in the sample). For a 20 percent difference, it takes the value 0.08. For a 30 percent difference, it takes the value 0.18. In our data, for country pairs for which the expression above took values greater than 0.02, the theoretical restriction was satisfied in over 90 percent of the cases. For higher values of the expression, the success rate increased. For country pairs for which the expression above took values greater than 0.03, the theoretical restriction was satisfied in 100 percent of the cases—indicating an increasing success rate with increased differences in factor prices. While it is unwise to speculate out of sample, this raises the expectation that the theory would hold with even greater "success" outside of the OECD countries we are working with, where factor price differences may be expected to be even larger.

A. *Measurement Error in Factor Prices*

A final set of results we present here concerns measurement error in factor prices. Our data are inconsistent with the theory for roughly one-quarter of the country pairs (i.e., as discussed above, for six or seven

[19] Interestingly, even at the industry level, θ takes values greater than one in the overwhelming majority of cases. In contrast, fewer than 35 observations take values below 0.9, and fewer than 70 take values below 0.95.

[20] We are most grateful to David Weinstein for suggesting this analysis.

[21] Note that this "difference measure" takes value zero if factor prices are equal across the two countries and uses weights $(K/Y)^2$ and $(L/Y)^2$ to get away from the problem of units of measurement of w and r.

country pairs out of a total of 28, θ takes values less than unity). However, a number of these "failures" are minor in magnitude, with the ratio θ being greater than 0.99 but less than one 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 alternative methodology that gives equivalent results is described in n. 22 below):

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

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. When the values of all other observed factor prices used in calculating the left-hand side of (9) are taken as 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 when a large number of draws of w_{obs} (10,000 draws in our exercises) under particular assumptions on the magnitude of σ_w (that, e.g., it is 5 percent of the value of w_{obs}) are taken, the left-hand side of (9) can be computed in each case and its distribution thus obtained. Given the calculation of (9) using observed factor prices, we can then ask whether we can reject the null that the theory is right (i.e., that the left-hand side of [9] is greater than or equal to zero). This can then be done for all factor prices and the exercise repeated for every country pair, so we can finally ask how often we are unable to reject that the theory is right.[22]

The results of these exercises are presented in table 6, where the headings 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

[22] An alternative exercise (in Bayesian spirit) would model the measurement error in factor prices in the following fashion:

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

Now, under assumptions regarding the magnitude of σ_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 the true value of the left-hand side of (9) can be obtained. We can then examine where along this distribution the number zero lies (the minimum acceptable value of [9] for the theory to be right). This tells us again, given our observations on factor prices, whether we are able to reject the null that the theory is right. Given the linearity of (9) and the normality assumptions, this exercise gives us results that are identical to those obtained from the analysis described in the text.

TABLE 6
SIGN TEST RESULTS WITH MEASUREMENT ERROR SIMULATION (%)

Significance Level	Degree of Measurement Error		
	2.5%	5.0%	10.0%
	Euro I and Capital I		
1%	75.0	82.1	96.4
5%	75.0	78.6	92.9
	Euro II and Capital I		
1%	75.0	85.7	96.4
5%	75.0	78.6	89.3
	Euro I and Capital II		
1%	89.3	96.4	100.0
5%	82.1	89.3	100.0
	Euro II and Capital II		
1%	89.3	96.4	100.0
5%	85.7	92.9	100.0

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.[23] 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 10 percent of w_{obs}, the success rate for the theory (i.e., the fraction of cases consistent with the theory being true) is about 90 percent with the Capital I rental measure and a full 100 percent with the Capital II measure.

B. *Robustness*

In our analysis of the data so far, we have confirmed the robustness of our findings to particular ways of measuring factor prices. Any of the combinations of factor measures chosen (gross or net measures of rate of return to capital and aggregated and less aggregated measures of wages) gave us results of strong similarity.

In addition, the robustness of our results was checked by performing the tests of (9) under various other configurations and data construction methods. These alternative configurations include (i) using different

[23] 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.

depreciation rates (3 percent and 10 percent) in calculating net capital stocks, (ii) using gross capital stock (readily available from the International Sectoral Database [ISDB]) instead of net capital stocks, (iii) using a variety of other accounting definitions for measuring return to capital as prescribed by Gollin (2002), and (iv) using the total (domestic plus foreign) input-output matrix rather than domestic inputs matrix prescribed by Staiger (1986). None of these variations changed the test 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 5 percent depreciation rate and with the input-output 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 that hold even under nonequalization of factor prices and in the *absence* of any assumptions regarding consumer preferences. 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.

Appendix A

Data

Countries were selected on the basis of the availability of the relevant data sets. Of the eight countries chosen, five were European (Denmark, France, Germany, the Netherlands, and the United Kingdom) and three were non-European (the United States, Canada, and Korea). All data pertain to 1980, and all relevant data were converted into 1980 U.S. dollars, unless otherwise stated.

A. Industry Coverage and Labor Disaggregation

Industrial activities are disaggregated according to the International Standard Industrial Classification (ISIC) system (revision 3, 1968), at the one-digit level for nonmanufacturing (eight sectors) and at the two-digit level for manufacturing (nine sectors), for a total of 17 industrial sectors. European data categorized according to the Nomenclature Générale des Activités Economiques dans les Communautés Européenes (NACE) (taken from Eurostat's SOE) were converted into ISIC code according to table A1.

Labor input factors for non-European countries were disaggregated into seven categories according to ISCO 1968: 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).

TABLE A1
Seventeen Industries and Their Concordance with ISIC and NACE

Description	ISIC Code	NACE R6/R25
Agriculture, hunting, forestry, and fishing	1	01
Mining and quarrying	2	12, 14
Food, beverages, and tobacco	31	36
Textiles, apparel, and leather	32	42
Wood products	33	48
Paper, paper products, and printing	34	47
Chemical products	35	17, 49
Nonmetallic mineral products	36	15
Basic metal industries	37	13
Fabricated metal products and machinery	38	19, 21, 23, 25, 28
Other manufacturing	39	48
Electricity, gas, and water	4	06
Construction	5	53
Wholesale and retail trade, restaurants, and hotels	6	56, 59
Transport, storage, and communication	7	61, 63, 65, 67
Finance, insurance, real estate, and business services	8	69A
Community, social, and personal services	9	74

Labor input factors for European countries were disaggregated into production workers and nonproduction workers. Nonproduction workers comprised top management executives, other senior executives, clerical workers, assistants, and supervisors. Table A2 presents more detail on the Euro I and II labor categorizations used in this paper and their concordance with ISCO and SOE classifications.

B. Technology

The technology matrices comprise two parts: a direct input matrix (**B**: factor by industry) and an input-output matrix (**A**: industry by industry).

1. Direct Input Matrix

The direct input matrix measures how much labor and capital each industry employs at a given point in time. The disaggregated occupational distribution of labor was taken from the Economically Active Population by Occupation table in the International Labour Office's *Yearbook of Labor Statistics* (1945–89). Because, however, the table did not disaggregate the manufacturing sector at the sectoral level, we relied on each country's census of population data for non-European countries[24] and on the SOE for European countries in order to obtain the occupational distribution of labor in each sector of manufacturing. We then scaled the number of workers in each occupation in each manufacturing sector

[24] For the United States and South Korea, the data were available from the Census of Population conducted in each country in 1980. In the case of Canada, the occupational distribution in disaggregated manufacturing industries was available only from its 1996 census. Thus we had to assume that the ratio of occupational distribution to total manufacturing workers did not change from 1980 to 1996.

TABLE A2
Concordance of Labor Categories

Euro I	Euro II	ISCO 1968 (Non-European Countries)	Structure of Earnings (European Countries)
Production	Production	Service (5)	Manual workers
		Agricultural (6)	
		Production (7/8/9)	
Nonproduction	Managerial	Administrative/managerial (2)	Top management executives
			Other senior executives
	Clerical	Clerical (3)	Clerical
	Others	Professional/technical (0/1)	Assistants
		Sales (4)	Supervisors

so that the total number of occupational workers in manufacturing equaled that in the International Labour Office's yearbook.

Data on net capital stocks at the sectoral level were not directly available for the countries in our sample. Measures of net capital stock therefore had to be constructed.[25] We constructed them in this manner: First we calculated the initial net capital stock in each industry in 1970 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 of the OECD. Then we calculated the net capital stock in each industry by distributing the total net capital stock into each industry using the industrial ratio in the ISDB. Next, we took the data on annual gross fixed capital formation in each industry during 1971–80 from the ISDB.[26] Taking the initial disaggregated net capital stock and each year's disaggregated capital formation data, we used the perpetual inventory method to calculate net capital stock in each industry in 1980. The test results reported in Section IV employed a depreciation rate of 5 percent.

2. Input-Output Matrix (Indirect Input Matrix)

The entries in the input-output matrix, or indirect input matrix, represent the quantity of intermediate inputs that a sector purchases from other sectors to produce one unit of output. The OECD's Input-Output database provides three sets of input-output matrices for each country. The first is the domestic input-output matrix, which shows the usage of domestically produced intermediate goods in each sector. The second is the imported input-output matrix, which measures how many intermediate goods are imported in each sector. The third is the total input-output matrix, a simple summation of domestic and imported input-output matrices.

Given Staiger's (1986) proposed modification to the factor content calculations suggested in Helpman (1984), the domestic input-output matrix, which includes the factor content of traded intermediate goods, is a more appropriate choice than the total input-output matrix. To see the argument behind Staiger's

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

[26] Since the Korean data are not included in the ISDB, we obtained the data from the National Account Department of the Bank of Korea.

modification, consider the following simple three-country, four-commodity case. Goods 1 and 2 are final goods that use goods 3 and 4 as intermediate goods. To produce one unit of good 1, we need α units of good 3 and β units of good 4. Also assume that one unit of labor is required for both good 3 and good 4. Countries A, B, and C produce goods 1, 2, and 3, respectively, and good 4 is produced by both countries A and B. Now, suppose that country A exports one unit of good 1 to country B. Country A's production cost will be

$$w^{A}\beta + w^{C}\alpha.$$

If this good were produced in country B, the production cost would 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

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

The last expression is exactly analogous to what we derived in Section II. Note that the relevant input-output coefficient is not that of the imported intermediate good (α), but that of the domestically produced intermediate good (β).

C. Bilateral Trade

The manufacturing sector's bilateral trade data were obtained directly from the OECD's Bilateral Trade database for each pair of countries in our sample. These data provide the bilateral trade flows according to ISIC categorization and are thus readily conformable with the technology matrix constructed above. The bilateral trade data for nonmanufacturing sectors were not available. So, following Davis and Weinstein (2001), we set bilateral imports of nonmanufacturing sectors equal to the share of manufacturing imports times total nonmanufacturing imports in that sector, where total nonmanufacturing imports were taken from the OECD Input-Output database.

D. Factor Prices

Section III describes the construction of factor price data in detail, so only a brief recapitulation is provided here. We calculated the ex post rental rate of capital by dividing the operational surplus from the OECD's Annual National Account database by the total capital stock from the OECD's ISDB. The occupational wage rate was taken from the Census of the Population for each non-European country and from the SOE for the European countries in our sample. For the purpose of international compatibility, we modified the data as described in Section III.

Appendix B

A. 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 constant returns to scale 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

$$\begin{aligned} \mathbf{p}(\mathbf{Q}^{c'} + \mathbf{T}^{c'c}) &\leq \mathbf{\Pi}\left(\mathbf{p},\ \mathbf{V}^{c'} + \frac{1}{\lambda}\mathbf{T}_V^{c'c}\right) \\ &\leq \mathbf{\Pi}(\mathbf{p},\ \mathbf{V}^{c'}) + \mathbf{\Pi}_V(\mathbf{p},\ \mathbf{V}^{c'})\frac{1}{\lambda}\mathbf{T}_V^{c'c} \\ &= \mathbf{pQ}^{c'} + \frac{\mathbf{w}^{c'}}{\lambda}\mathbf{T}_V^{c'c} \end{aligned} \tag{B1}$$

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

$$\left(\frac{\mathbf{w}^{c'}}{\lambda} - \mathbf{w}^c\right)\mathbf{T}_V^{c'c} \geq 0. \tag{B2}$$

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) can be rewritten as

$$\left(\frac{\mathbf{w}^{c'}}{\lambda^{c'}} - \frac{\mathbf{w}^c}{\lambda^c}\right)\mathbf{T}_V^{c'c} \geq 0, \tag{B3}$$

$$\left(\frac{\mathbf{w}^{c}}{\lambda^{c}} - \frac{\mathbf{w}^{c'}}{\lambda^{c'}}\right)\mathbf{T}_V^{cc'} \geq 0, \tag{B4}$$

and

$$\left(\frac{\mathbf{w}^{c'}}{\lambda^{c'}} - \frac{\mathbf{w}^c}{\lambda^c}\right)(\mathbf{T}_V^{c'c} - \mathbf{T}_V^{cc'}) \geq 0. \tag{B5}$$

B. Ricardian Technology Differences

Let the extent by which industry i in country c' is more productive than industry i in country c be denoted by γ_i. Using expressions analogous to (B1) above, we now have the following final expression relating factor prices and factor flows (and technology):

$$\sum_i \left(\frac{\mathbf{w}^{c'}}{\gamma_i} - \mathbf{w}^c\right)\mathbf{T}_{Vi}^{c'c} \geq 0.$$

Now, if information on the Ricardian technology parameters, the γ's, is available, the expression above can be tested. Thus the tests proposed by Helpman (1984) that we have implemented in this paper are easily extended to account for Ricardian technology differences between countries as well.

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