

The Empirical Validity of the Heckscher-Ohlin Model

Eric O’N. Fisher*

Professor, California Polytechnic State University

efisher@calpoly.edu

and

Kathryn G. Marshall

Assistant Professor, California Polytechnic State University

kgmarsha@calpoly.edu

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Abstract

Using recent data from a wide sample of countries, we show that the Heckscher-Ohlin model predicts the volume and direction of trade remarkably well. There is no missing trade, and one can reject that the null hypothesis that the model has no predictive power with marginal significance levels that exceed 99%. We use a consistent set of data for technology matrices and endowments and allow for country-specific technology matrices. It is not necessary to make any special assumption about home bias in consumption, not traded goods, or trade costs.

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I. Introduction

The Holy Grail for empirical international trade economists—at least since the time of Leontief (1954)—has been a simple empirical verification of the Heckscher-Ohlin-Vanek model. This paradigm asserts that trade in goods is really just a veil for the underlying trade in embodied factor services. It is the font of traditional trade theory, and its main implication is that relative factor abundance is the real source of comparative advantage. Leamer (1984) began the quest in earnest, and his work has had great influence on a subsequent generation of scholars. Important milestones on this journey were reached by Harkness (1978), Bowen, Leamer, and Sveikauskas (1987), Trefler (1995), and Davis and Weinstein (2001) among others.¹

We deliver the Chalice. Our paper finds overwhelming support for the Heckscher-Ohlin paradigm in new data from a wide sample of thirty-three countries in the last decade. Our work differs from the literature in two main respects. First, we are very careful to use a consistent set of data. Second, we make sure that our empirical analysis accords completely with the theory, once one allows for different technology matrices among countries. Our tests are extremely simple, and thus our empirical verification of the paradigm is quite strong. In fact, we show that it is not necessary to impose the assumptions of home bias in consumption, trade costs, the existence of not traded goods, or any other of the panoply of ancillary theoretical postulates that have become the mainstays of the recent literature.

¹ Trefler's (1995) article is seminal. It defines the mystery of missing trade; measured trade in factor services is much smaller than that predicted by factor endowments. Using Trefler's own data, Conway (2002) suggests that sluggish movement of factors across industries may account for the low volume of trade observed in the data. Estevadeordal and Taylor (2002) show that there was too little trade even a century ago. Again using Trefler's data, Debaere (2003) confirms that the model predicts the direction of trade well for country pairs whose factor endowments are quite different.

The hypothesis of identical technology matrices does not hold in the data. Hence the simplest possible test of the theory—imposing identical technologies and factor price equalization—is an immediate dead end. This fact has led much of the rest of the literature to seek statistical modifications of measured endowments or technology matrices that reconcile the theory and the data. It has also caused researchers to explore the effects of trade costs, not traded goods, intermediate inputs, and arcane descriptions of demand as explanations for putative failure of the data to confirm the theory. Our tests render these ancillary assumptions moot.

We are not the first to emphasize the conceptual difficulties inherent in the fact that countries have different technology matrices. Using the United States as a reference country, Bowen, Leamer, and Sveikauskas (1987) tested the assumption of Hicks-neutral technological differences among countries. This specification was their "most preferred" model, and it led them to conclude that differences in technology were likely behind the failure of tests of the theory. Trefler (1993) extended this work by computing a complete list of country-specific and factor-specific productivity differences that allowed him to fit the measured factor content of trade exactly. He did not have as rich a set of data on technology matrices as we have, and part of our analysis evaluates Trefler's productivity adjustments. We find that such simple modifications do not account properly for the heterogeneity of factor services and technologies across countries. Hakura (2001) recognized the difficulty of testing the theory when countries have different local production techniques. She cautions, "Biased factor contents of trade in the strict HOV can lead to a discrepancy between the calculated factor content of trade and that predicted

from endowments.” Our results show that missing trade itself can be explained by the failure to correct adequately for technology differences across countries.

Trefler and Zhu (2006) emphasize the importance of differences in technology and also find fault with previous attempts to address this problem. Using very restrictive demand assumptions, these authors define a measure of the factor content of trade that is consistent with Vanek’s theoretical predictions. In effect, their measure accounts for the factors everywhere in the world that produce a country’s imports. Implementation of this approach requires extensive bilateral trade data for both final goods and intermediate inputs. Our measure of factor content uses only a single country’s technology matrix, either a reference country’s or the local one, and we define the predicted factor content of trade in a way that is consistent with our measure of factor content. This approach is far more empirically tractable, and the associated demand restrictions are much simpler; we impose identical homothetic preferences and that all goods are traded. In a world of different technologies, our approach might be termed the “relative” factor content of trade, compared with Trefler and Zhu’s “absolute” factor content.

Eschewing *ad hoc* econometric techniques, we pursue two different tacks. First, we define a country’s *virtual endowment* as the factor services that would be needed to produce its observed vector of output, if it had to produce them using a reference country’s technology. The usual reference country has been the United States; in this case, the virtual endowment of France is the vector of factor services that France would need if it were to produce its own output using the American technology matrix. This

simple modification of the theory works brilliantly, and it solves the mystery of missing trade, almost as an afterthought.²

Our second tack uses a simple technique that maps factor endowments in the exporting country into those in the importing country. We call this technique a modified Rybczynski effect. It shows how a marginal change in the exporting country's endowment is best translated into changes in the importing country's own factors of production. The measured factor content of trade in this test is the vector of local factor services that would be needed to produce the local net trade vector. Hence we are not imposing identical technologies in this test. But then the theoretical predictions of the model are subtle: each country views the world endowment vector through the prism of its own local technology. Thus the predicted factor content of trade differs country by country. This test does not perform as well as the first one, but it still predicts the direction and volume of trade with uncanny accuracy. Again, it solves the mystery of missing trade.

In view of the importance of differences in technology we hope our research will spur further investigation into the underlying sources of these differences across countries. We have made full use of recent OECD input-output data on the technology of production across thirty-three countries in the year 2000. We use the same source of data for each country's technology matrix, its vector of net exports, and its vector of local absorption. We also use these data to measure each country's endowment vector exactly; this aspect of consistency is by far the most important, and it entails that we are

² Davis, Weinstein, Bradford, and Shimp (1997) construct imputed world endowments for their analysis of regional trade within Japan. These endowments are akin to our virtual endowments. They too show that relaxing the assumption of identical technologies improves the model's predictions dramatically. Thus our work confirms their findings using a broad and recent set of international data.

measuring the exact vector of *local* factor services that is used to produce the observable vector of *local* outputs using the *local* technology. We feel that an important shortcoming of the literature heretofore has been the measurement error in the factor services that are used to define local endowments.

The simplest possible explanation for different technology matrices observed in our data is that the forty-eight sectors defined in the OECD input-output data are too aggregated to account properly for the wide array of products and services--each with its associated technique of production--that constitute traded goods in an integrated world economy.³ Indeed we find that the variation of factor content within the same industry across the thirty-three countries is often as great as the variation in a single country across forty-eight industries. Still, the OECD data are an invaluable tool for better understanding the pattern of world trade, and we have developed empirical techniques that overcome their limitations and confirm the power of relative factor endowments to explain the pattern of world trade.

Section II presents the theory that we are testing. In this section we develop a new technique that allows international economists to compare factor endowments when countries' technologies differ; this technique will be of considerable interest in its own right because it is theoretically elegant and also easy to implement empirically. Section III gives a description of the data; here we emphasize how we use the recent OECD data to get consistent measurements of endowments, technology matrices, net trade vectors,

³ The recent literature has been careful in its treatment of imported intermediate goods. Reimer (2006) develops a method for measuring the factor content of traded intermediate inputs; he concludes that a careful treatment of intermediate goods may make it more difficult to account for missing trade. We are sympathetic with this important strand of the literature, but our verification of the theory shows that it may not be of primary importance if one is very careful to use data that treats endowments, trade vectors, and technology matrices consistently.

and measures of absorption for the 33 countries in our sample. Section IV presents our results, and we emphasize there how robust is the support that we find for the Heckscher-Ohlin-Vanek paradigm. Section V presents our brief conclusions and gives suggestions for future research.

II. Theory

Each country has f factors and ℓ goods used for final demand. Then v^c is the $f \times 1$ vector describing the endowment of country c , measured in units of factor service per year. Let B^c be the $f \times \ell$ vector of direct factor services, A^c be the $\ell \times \ell$ matrix whose canonical element a_{ij}^c is the intermediate input requirements of good i in the production of good j . Finally, let y^c be the output vector of goods produced for final demand in country c . Then the full employment condition is:

$$v^c = B^c(I - A^c)^{-1}y^c \tag{1}$$

We emphasize that *local factors* are fully employed using *local techniques*. This will be a maintained assumption in much of our empirical work, and we will thus identify factors of production v^c with the measurable vector $B^c(I - A^c)^{-1}y^c$ that is available in our data. There is abundant empirical support for equation (1); Davis and Weinstein (2001) demonstrate its empirical validity in their production tests, and Fisher and May (2006) confirm it using data on OECD countries from the 1980's. The aggregate world endowment is $v = \sum_c v^c + v^r$, where v^r is the factor content of net exports from the rest of the world.⁴

⁴ We are being careful in how we treat trade with the rest of the world. Taking net trade with the rest of the world as given, we follow Kemp and Wan (1976) and define equilibrium conditional on the factor content

Let x^c be the $\ell \times 1$ vector of exports in country c , and let m^c be the analogous vector of imports. Then the measured factor content of trade is:

$$B^c(I - A^c)^{-1}(x^c - m^c).$$

Our data measure net exports at the same level of aggregation as the local matrices of direct and indirect factor requirements. Hence we have very accurate and consistent measures of the local factor content of trade.

Let $a^c = y^c - (x^c - m^c)$ be the $\ell \times 1$ vector denoting each country's absorption. This vector is observable in our data, and we use it to define each country's consumption share:

$$s^c = \sum_{i=1}^{\ell} a_i^c / \sum_c \sum_{i=1}^{\ell} a_i^c.$$

In this expression, we are again taking advantage of the fact that our data are measured in values, not physical units. Thus $\sum_{i=1}^{\ell} a_i^c$ is not adding apples and oranges; it is adding dollars of apples and dollars of oranges.

We make the usual stringent assumptions that countries have identical and homothetic preferences and that all goods are traded. These strong postulates imply that the predicted factor content of trade is:

$$v^c - s^c v \tag{2}$$

where s^c is country c 's share in world absorption. We make (3) operational in three different ways. The details of this work constitute the primary empirical contribution of our work.

of this net trade. Although this net trade vector is observed without error in our data, the definition of v^r depends upon the details of the theory being tested.

The traditional test of the Heckscher-Ohlin-Vanek model assumes that all countries have identical technologies and that factor prices are equalized. Hence every country's technology matrix satisfies $B^c(I - A^c)^{-1} = B^0(I - A^0)^{-1}$ for some reference country 0 (often the United States). Then the measured factor content of trade is

$$B^c(I - A^c)^{-1}(x^c - m^c) = B^0(I - A^0)^{-1}(x^c - m^c) \quad (3)$$

The typical test compares (2) with (3).⁵ We show below that this test fares very poorly and that it suffers from missing trade, no matter which reference country is used. Thus the first step in our empirical work replicates the existing literature with our new and wider set of consistent data.

What if technologies differ between countries? Trebler (1993) assumes that the technology matrices differ systematically according to country-specific and factor-specific parameters π_f^c . Then he uses the data on the factor content of trade measured according to (3) (with the United States as the reference country) to construct exact measures π_f^c for ten factors and thirty-three countries. He uses independent data on real wages to verify empirically that factor prices for labor seem to satisfy $w_f^c / w_f^0 = \pi_f^c / \pi_f^0$ where w_f^c is the price of factor f in country c . He concludes that Leontieff was right to conjecture that technological differences may explain important aspects of the factor content of trade.

If Trebler's specification is correct, then our tests based on (2) and (3) are exact. Because we implement our tests using input-output account that are expressed in

⁵ Let $x^r - m^r$ denote net exports from the rest of the world; its factor content $v^r = B^0(I - A^0)^{-1}(x^r - m^r)$ is measured using the reference country's technology matrix. This vector is used to define the world endowment in (2).

values—not physical units—we achieve a level of consistency that has been lacking in the literature. Hence, we are actually measuring payments to local factors of production, and our predicted factor content is based upon the physical endowment of each country’s evaluated at local factor prices. Trefler’s particular form of factor-augmenting technological differences implies that each row of $B^c(I - A^c)^{-1}$ is increased by the ratio π_f^0 / π_f^c when compared with the corresponding row of $B^0(I - A^0)^{-1}$. Thus our use of data in value terms entails that we are making the proper factor price corrections. Since we show that the model does poorly empirically, we conclude that Trefler’s (1993) sanguine conclusion may have been premature.

Our next test is novel and quite simple. Since the full employment assumption uses the local technology, the strict assumptions of the Heckscher-Ohlin theory make moot the strong empirical fact that $v^c = B^c(I - A^c)y^c$. Full employment occurs only when local factors are employed using local techniques, not when local factors are employed according to the foreign technology. This observation leads us to define a *virtual endowment* for each country as:

$$\tilde{v}^c = B^0(I - A^0)^{-1}y^c. \quad (4)$$

This virtual endowment depends upon the reference country’s technology, and it shows the local resources that would be needed to produce local output using the reference country’s technology.⁶ Now $\tilde{v} = \sum_c \tilde{v}^c + v^r$ is our measure of the aggregate endowment. In this expression, we are still implicitly imposing the assumption of factor price equalization since each country has the same technology as the reference country;

⁶ The factor content of net exports from the rest of the world is still $v^r = B^0(I - A^0)^{-1}(x^r - m^r)$.

however, we are defining virtual endowments *that make the measured factor content of trade and the predicted factor content of trade consistent*. Our test then compares the factor content of trade measured according to (3) with $\tilde{v}^c - s^c \tilde{v}$. It performs brilliantly, no matter which reference country is chosen.

Since net exports satisfy $x^c - m^c = y^c - a^c$, our test based upon (4) is an identity if preferences are indeed homothetic. In essence, a test based upon virtual endowments is simply a test of the assumption of identical homothetic preferences in a world where all goods are traded. Because the empirical results are so compelling, we conclude that the demand side of these models is indeed simple.⁷ Hence one need assume neither home bias in consumption nor the existence of not traded goods. Likewise, transport costs are not important in these data. Thus the literature that imposes these important ancillary assumptions about the demand side may be off pursuing an unwarranted tangent.

The reader may feel uncomfortable with our second test because it relies so heavily upon the notion of a virtual endowment. In our data, a virtual endowment is the vector of values of the factors of production that would be needed to produce the local country's observable output using the reference country's technology. The requisite resources are evaluated at the factor prices of the reference country, not at local factor prices. If we are willing to assume that factor prices are equalized, then the distinction between local factor prices and those in the reference country is moot. But if countries' technologies are different, then it is quite likely that their factor prices are too. Our third test deals directly with this issue.

⁷Bowen, Leamer, and Sveikauskas (1987) also could not reject the assumption of identical homothetic preferences. Thus our work validates their conclusions using a more recent and consistent set of data.

The third test uses the factor conversion matrices defined in Fisher and May (2006). The complete set of outputs that can be produced with country c 's resources is

$$y^c = [B^c(I - A^c)^{-1}]^+ v^c + H^c q. \quad (5)$$

where the $\ell \times f$ matrix $[B^c(I - A^c)^{-1}]^+$ is the Moore Penrose pseudo-inverse of the local technology matrix, $H^c = I - [B^c(I - A^c)^{-1}]^+ B^c(I - A^c)^{-1}$ is an $\ell \times \ell$ matrix, and q is an arbitrary $\ell \times 1$ vector. In this expression, the particular solution $[B^c(I - A^c)^{-1}]^+ v^c$ is the vector of goods of minimum norm that fully employs the local endowments. The homogeneous solution $H^c q$ consists of all the output vectors that lie in the null space of the local technology matrix. These outputs all have the identical local factor content because they trade off one good against another while maintaining full employment. In essence, there are $\ell - f$ degrees of freedom in defining the output vector that uses all the local factors with the local technology.

Let p be an $\ell \times 1$ vector of common international prices for goods. At these prices, national revenue is

$$p^T y^c = p^T [B^c(I - A^c)^{-1}]^+ v^c + p^T H^c q. \quad (6)$$

Since this equation is true for any choice of the slack variable q , we may conclude that $p^T H^c = 0$. Hence, even when there are more goods than factors of production, national revenue is uniquely determined by endowments for fixed output prices and a given local technology matrix. The intuition is that national revenue must be equal to total factor payments under the assumption of constant returns to scale, and only the particular solution in (6) depends upon the endowment vector.

Fisher and May (2006) argue that $[B^c(I - A^c)^{-1}]^+$ is country c 's Rybczynski matrix because its (i, j) -th element is the most natural description of the change in the output of good i when the supply of factor j changes. Even though (5) gives a supply correspondence, $(w^c)^T = p^T [B^c(I - A^c)^{-1}]^+$ is a row vector whose elements are local factor prices. Hence the particular solution in (5) preserves the duality between the Rybczynski and Stolper-Samuelson matrices that is at the heart of trade theory.

Now consider the factor content in importing country c of the endowments in exporting country c' . Fisher and May (2006) define an $f \times f$ factor conversion matrix

$$F(c, c') = B^c(I - A^c)^{-1}[B^{c'}(I - A^{c'})^{-1}]^+. \quad (7)$$

The matrix in (7) describes the local factor content in the importing country of the Rybczynski effects in the exporting country. In other words, its columns show how local factors would need to be changed to accommodate the marginal output effect of a change in the foreign endowment. In particular, it might be that an extra unit of capital in the exporting country corresponds to marginal changes in *all the factors* in the importing country. If all technological differences were country and factor specific, then $F(c, c')$ would be a diagonal matrix whose canonical element is Treffer's $\pi_f^{c'} / \pi_f^c$. In empirical applications, almost all of these factor conversion matrices are far from diagonal.

There is another interesting interpretation of these factor conversion matrices. Since goods are priced at local cost, we may write $p = [B^c(I - A^c)^{-1}]^T w^c$ if all goods are produced locally. Then (6) implies that

$$(w^{c'})^T = (w^c)^T B^c(I - A^c)^{-1}[B^{c'}(I - A^{c'})^{-1}]^+ = (w^c)^T F(c, c'). \quad (8)$$

Hence the rows of the factor conversion matrices translate factor prices in the importing country to those in the exporting country. Since (8) is a linear mapping but not necessarily a diagonal matrix, the exporting country c' would recognize, for example, that the wage rate in the importing country c actually corresponds to a vector of factor payments in c' .

Here is how we implement our third test using these factor conversion matrices. The measured factor content of trade is again $B^c(I - A^c)^{-1}(x^c - m^c)$; hence we allow for the possibility that technologies may differ and that factor prices may not equalized. The predicted factor content of trade is

$$v^c - s^c \bar{v}^c \tag{9}$$

where $\bar{v}^c = \sum_{c'} F(c, c') v^{c'} + v^r(c)$ is the aggregate endowment seen from the perspective of country c . In this expression, $F(c, c) = I$ and $v^r(c) = B^c(I - A^c)^{-1}(x^r - m^r)$ is the factor content of net exports from the rest of the world, measured according to country c 's technology. The main empirical advantage of (9) is that one need not have data on the actual outputs of the sample countries, a restriction in keeping with the historical literature. It also has the advantage of not imposing the Procrustean theoretical assumptions of factor price equalization and identical technologies on data where these postulates are clearly violated. Finally, it performs well empirically, and it shows again that the data do not suffer from missing trade.

III. Data

The technology matrices are from the OECD's STAN input-output data for the year 2000; they span a set of thirty-three countries, and each country reports data on

forty-eight sectors and three factors of production.⁸ All data on absorption, exports, and imports are from the same source, assuring a high degree of internal consistency. We convert all values to 2000 United States dollars using the purchasing power parity exchange rates in the Penn World Table Version 6.2.⁹ Our sample of countries represents 75 percent of world GDP and 67 percent of world trade. Although the majority of these countries have high gross domestic product per capita, the sample includes China, Brazil, and Indonesia, large countries that are not advanced industrial economies. This broad range of economies has very disparate factor supplies.

Davis and Weinstein (2001) and Hakura (2001) have already demonstrated that there are important technological differences in the factor use matrices among smaller and more uniform groups of OECD countries. Still, these authors did not take full advantage of the consistent measures of factor services included in the OECD input-output data. By using factor services measured in OECD data themselves, we avoid many measurement problems inherent in attempts to measure factors in physical quantities. Hence we enjoy the significant advantage of using the extensive and consistent input-output data constructed by the OECD.

A. Consistent Definitions of Factor Services and Factor Uses

Every study of the Heckscher-Ohlin-Vanek paradigm draws upon data describing the use of commodities and factors in the many sectors of an economy. Input-output accounts describe commodity flows, but data on factor requirements and endowments usually come from other sources. Many studies have used industry-level surveys on

⁸ The URL is: http://www.oecd.org/document/3/0,3343,en_2649_34263_38071427_1_1_1_1,00.html

⁹ It can be found at this URL: http://pwt.econ.upenn.edu/php_site/pwt_index.php

machines, land, and workers per unit of output. Could it be that confounding sources of data have caused some of the difficulty reconciling theory and data?

We are also concerned about measuring stocks and their corresponding flows accurately for some factors. Consider an acre of farmland in Ohio. Its price is around \$2000, and if the real interest rate is 3% and there is no depreciation, the user cost of an acre is \$60 per year. But how much of that price is actually attributed to the raw factor cropland? Every acre is a combination of raw land and all the capital improvements that have gone into it. Rents on land are really payments for the services of a bundle of land and capital, just as wages reflect human capital. This is true *both* when computing factor usage for an industry *and* the physical endowments of a country. An acre of cropland in Ohio is very different from an acre of cropland near Montepulciano in Tuscany, even though one can grow corn or wine grapes in either place. Measuring endowments in physical units is a tricky business at best.

Concern with proper measurement of factors compels us to take a novel approach in this paper: We let the data speak for themselves. For us, the value of capital used in production is what actually appears in the input output account. Since we follow the input output accounts as closely as possible, we must pay a cost. The data allow us to identify only three factors of production: undifferentiated labor, private capital, and social capital. The input output tables report three measures of value added: compensation to employees, gross operating surplus, and indirect taxes. Thus those three categories are our notions of factors of production. The first category corresponds to the flow of service of undifferentiated labor, the second to the rent on private capital, and the third to the rent on social capital.

It is not as unusual as one might think to consider a sector's indirect taxes as payments for the rents on social capital. Consider two countries that have identical physical technologies but different sector-specific patterns of indirect taxation. Even if world trade equalized all commodity prices, these countries would have different factor prices and thus disparate factor uses. There is one important qualification: occasionally a sector is subsidized. Thus although factor shares in each sector always sum to unity, it may be the case that social capital's share in that sector is negative and thus the sum of labor and private capital's share is greater than one. Still, indirect taxes are treated identically with the payments to capital and labor in input-output accounts, and logical and empirical consistency compels us to define an aggregate factor called social capital for each country.

B. Input Output Accounting in Quantities and in Values

Consider the following partitioned matrix:

$$\begin{bmatrix} A & Z \\ B & 0 \end{bmatrix}_{(\ell+f) \times (\ell+q)}$$

where again A is the matrix of input requirements for the ℓ sectors, B is the matrix of direct factor requirements for the f factors, Z is a matrix of exogenous demands for goods for q different uses, and 0 is a conformable matrix of zeros. Each row totals gives the gross output or total supply of the corresponding good or factor. Likewise, each of the first ℓ column totals shows the input usage of any good, and each of the last q columns gives the total demand for an exogenously specified category. In our data, there are $\ell = 48$ sectors, $f = 3$ factors, and $q = 3$ exogenous demands. These three columns

correspond to exports, imports, and total output of final goods, and they allow us to compute the pattern of absorption for each country.

There are only two consistent ways to do input-output accounting: the quantity approach or the value approach. Leontief himself (1986, p. 23) recommended using quantities, and in this case a_{ij} , the canonical element of the matrix A , describes how many units of good i are used in the producing the output of good j . The direct factor requirement b_{ij} , the typical element of B , tells how many units of factor i are used in producing the output of good j . The value approach--the one used in the OECD STAN database--is such that all of the elements of this matrix are denominated in units of local currency, not in physical quantities. In this case, the normalized input output matrix gives the cost shares of intermediate inputs and primary factors for each activity.

Let $B^c(I - A^c)^{-1}$ be the matrix describing the direct and indirect factor requirements in country c in *quantity terms*. The analog in the *value approach* is:

$$\Theta^c = \underset{f \times \ell}{W^c} \underset{f \times f}{B^c} \underset{f \times \ell}{(I - A^c)^{-1}} \underset{\ell \times \ell}{P^{-1}},$$

where W^c is the diagonal matrix whose typical element gives the local price for each factor and P is the diagonal matrix whose typical element is the world price of each commodity. In our empirical work we actually use the observable factor share matrices Θ^c instead of the unobservable matrix of direct and indirect factor requirements $B^c(I - A^c)^{-1}$ that is measured in physical units. Since $B^c(I - A^c)^{-1} = (W^c)^{-1}\Theta^c P$, one can go back and forth easily between the two approaches if one knows local factor prices and global goods prices. In the data, neither factor prices nor goods prices can be measured, but the factor share matrices can.

Given world goods prices, the full employment condition in value terms is:

$$W^c v^c = \Theta^c P y^c$$

Finally, consider a reference country with factor prices W^0 . Then the virtual endowment of country c in value terms is defined by $W^0 \tilde{v}^c = \Theta^0 P y^c$. Since

$$\tilde{v}^c = (W^0)^{-1} \Theta^0 P y^c = B^0 (I - A^0)^{-1} y^c,$$

the virtual endowments used in our empirical work where data are measured in values correspond exactly with their physical analogs defined in Section II. In a similar manner, we can measure the factor content of trade using local factor payments and local technologies, or we can compute the factor content of trade using a reference country's technology matrix. Hence every computation we make in value terms corresponds to its proper analog in physical terms.

We conclude this section by making an observation about an important shortcoming of the literature. The net trade vector for any country is always measured in value terms, but almost every author uses physical units for some columns of the matrix of direct factor requirements. Hence the measured factor content of trade confounds values and quantities. Some authors are careful to match endowments with the computed factor uses, but it is almost always true that the author is measuring physical units of one factor—such as hectares of pasture land—with dollar uses of capital. (A country's endowment of capital is often computed using the perpetual inventory method.) Most authors are careful to match units for the predicted factor content of trade with the measured factor content of trade, but almost everyone adjusts measured factors and endowments for “heteroskedasticity” using factor-specific and country-specific constants that make the units comparable. Our consistent use of the data obviates all of these

problems, and every number that we report is based upon the actual data that we observe, not numbers that have been massaged to make units comparable.

IV. The Volume and Direction of the Factor Content of Trade

In this section, we present the results of three different tests of the Heckscher-Ohlin-Vanek paradigm. The first test assumes that countries have identical technologies and that factor prices are equalized. In our data, local endowments are measured at local factor prices, so our first test encompasses Trefler's (1993) correction for productivity differences. In theory, the measured factor content of trade is identically equal to the predicted content of trade if the demand-side assumptions are taken seriously and if local factor payments really do reflect simple productivity differences. We have the luxury of choosing any reference country in our sample; our results typically do not depend upon the choice of reference country. The first test is a red herring; we include it just to replicate the existing literature with our new and wider set of consistent data.

Our second tests allows for the fact that local technologies differ. This is the test based upon our notion of a country's virtual endowment. In its simplest form, this analysis is a pure test of the demand-side assumptions. Again, we can choose any reference country; we present the results for the United States and the reference country that performs best. In its slightly more complicated form, we measure the local factor content of trade using the local technology but allow for the predicted factor content of trade to depend upon the prism of each country's own technology. This test allows factor prices to differ between countries, but it adjusts the model's predictions in a simple and appropriate way by defining virtual endowments that depend upon the importing country's particular perspective.

In our final test, we abandon the notion of a virtual endowment and use the observable technologies to create factor conversion matrices. Again, we measure the factor content of trade using local technology and local factor prices. However, in this case, the predicted factor content converts foreign factor services into local ones using a bilateral matrix that depends upon the importing and exporting countries' technologies. This test can be implemented even when output vectors are not observable. We are again allowing factor prices to differ, so we consider this a test of the technology adjusted HOV *without* factor price equalization.

A. *The Traditional Test*

Table 1 presents the results of our first test. It seems to corroborate the general notion that the theory is devoid of empirical content. What is new here is the result that the paradigm performs poorly even with the productivity correction implicit in local factor payments. In almost every case, there is significant missing trade, and the sign test for the direction of trade is often no better than a coin toss. The average amount of trade explained is often higher than the median because the average is dominated by a few outliers whose absolute values are always large positive numbers. Even though the literature uses average amounts of trade explained, it is best to focus on the median amount of missing trade explained so that these outliers don't have undue influence.

The results for the United States and Italy as reference countries are presented in boldface. The United States is the traditional reference country in this literature, and Italy is the reference country with the best fit. Still, we note that among the 33 possible reference countries only 6 passed the sign test of size 5%, and there still is a lot of

missing trade. Table 1 shows that there is nothing really special about using the United States as a reference country.

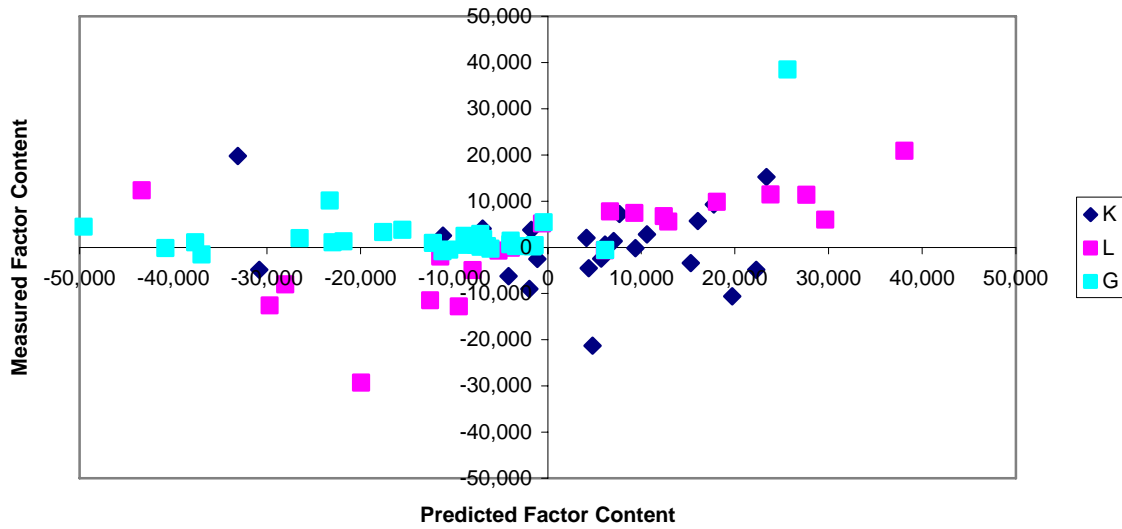
Table 1: The Traditional Test

| Reference Country | Correct Signs | p-value | Average Share of Trade Explained | Median Share of Trade Explained |
|----------------------|---------------|-------------|----------------------------------|---------------------------------|
| Australia | 47 | 0.69 | 52% | 17% |
| Austria | 52 | 0.31 | 58% | 21% |
| Belgium | 51 | 0.38 | 67% | 17% |
| Brazil | 53 | 0.24 | 54% | 26% |
| Canada | 47 | 0.69 | 59% | 19% |
| Switzerland | 57 | 0.07 | 52% | 14% |
| China | 52 | 0.31 | 68% | 29% |
| Czech Republic | 57 | 0.07 | 63% | 22% |
| Germany | 52 | 0.31 | 97% | 40% |
| Denmark | 57 | 0.07 | 70% | 19% |
| Spain | 52 | 0.31 | 66% | 15% |
| Finland | 56 | 0.10 | 59% | 22% |
| France | 60 | 0.02 | 59% | 18% |
| United Kingdom | 50 | 0.46 | 66% | 19% |
| Greece | 54 | 0.18 | 148% | 17% |
| Hungary | 59 | 0.03 | 61% | 14% |
| Indonesia | 52 | 0.31 | 163% | 39% |
| Ireland | 45 | 0.82 | 73% | 15% |
| Israel | 49 | 0.54 | 52% | 17% |
| Italy | 66 | 0.00 | 86% | 21% |
| Japan | 56 | 0.10 | 59% | 19% |
| Korea, Republic of | 65 | 0.00 | 115% | 26% |
| Netherlands | 54 | 0.18 | 57% | 21% |
| Norway | 56 | 0.10 | 64% | 20% |
| New Zealand | 57 | 0.07 | 60% | 21% |
| Poland | 51 | 0.38 | 63% | 17% |
| Portugal | 57 | 0.07 | 79% | 20% |
| Russia | 54 | 0.18 | 379% | 19% |
| Slovak Republic | 52 | 0.31 | 67% | 25% |
| Sweden | 53 | 0.24 | 70% | 18% |
| Turkey | 60 | 0.02 | 293% | 13% |
| Taiwan | 63 | 0.00 | 102% | 27% |
| United States | 49 | 0.54 | 67% | 23% |

Note: There are 99 observations (country-specific factors) for each test. The p-values report the probability of observing a higher value of the test statistic under the null hypothesis that the model predicts the direction of trade no better than a coin flip.

Figure 1 shows the data and the predictions for the United States. It confirms the usual dismal performance of the theory with these new and consistent data. The main point of this subsection is that the traditional test of the theory is a dead end, even one when goes to extraordinary pains to make sure that all the data are consistent. There is a lot of missing trade too, but the picture is not as bad as some that have appeared in the literature.

**Fig. 1: Traditional HOV, USA Reference Country
(millions of 2000 dollars)**



B. The Tests with Virtual Endowments

Inspection of the technology matrices led Davis and Weinstein (2001) to conclude that there was not factor price equalization in their data from the 1980's, and the last two decades have not been kind to that hypothesis in our data either. So where does this leave us? What happens if we actually give the theory a chance? In particular, we define the virtual endowments of every country in the world as the resources that would be necessary to produce its actual output if it had to use the reference country's technology. Then we measure the factor content of trade in the same way. When we do this adjustment, the theory performs spectacularly.

Table 2 reports the results. There is nothing anywhere in the literature that approaches the success of these tests. It predicts the direction of trade quite well, and there is hardly any missing trade at all. These results do not depend upon the reference country chosen. We illustrate our empirical results for the historical norm that uses the United States in Figure 2 and for the best case that occurs with Korea as a reference country in Figure 3. The results for these two countries are in boldface in the table.

Table 2: The Test Using Virtual Endowments

| Reference Country | Correct Signs | p-value | Average Share of Trade Explained | Median Share of Trade Explained |
|---------------------------|---------------|-------------|----------------------------------|---------------------------------|
| Australia | 81 | 0.00 | 692% | 102% |
| Austria | 79 | 0.00 | 120% | 75% |
| Belgium | 84 | 0.00 | 107% | 74% |
| Brazil | 82 | 0.00 | 147% | 89% |
| Canada | 80 | 0.00 | 165% | 83% |
| Switzerland | 83 | 0.00 | 163% | 90% |
| China | 85 | 0.00 | 414% | 99% |
| Czech Republic | 86 | 0.00 | 102% | 96% |
| Germany | 87 | 0.00 | 172% | 101% |
| Denmark | 85 | 0.00 | 136% | 93% |
| Spain | 83 | 0.00 | 126% | 84% |
| Finland | 79 | 0.00 | 287% | 79% |
| France | 83 | 0.00 | 285% | 94% |
| United Kingdom | 83 | 0.00 | 152% | 102% |
| Greece | 82 | 0.00 | 212% | 76% |
| Hungary | 89 | 0.00 | 152% | 92% |
| Indonesia | 87 | 0.00 | 172% | 88% |
| Ireland | 83 | 0.00 | 414% | 77% |
| Israel | 81 | 0.00 | 498% | 90% |
| Italy | 78 | 0.00 | 199% | 89% |
| Japan | 84 | 0.00 | 128% | 93% |
| Korea, Republic of | 94 | 0.00 | 188% | 100% |
| Netherlands | 82 | 0.00 | 338% | 87% |
| Norway | 81 | 0.00 | 101% | 83% |
| New Zealand | 87 | 0.00 | 118% | 85% |
| Poland | 73 | 0.00 | 135% | 82% |
| Portugal | 87 | 0.00 | 452% | 102% |
| Russia | 77 | 0.00 | 156% | 64% |
| Slovak Republic | 86 | 0.00 | 282% | 97% |
| Sweden | 89 | 0.00 | 109% | 80% |
| Turkey | 83 | 0.00 | 117% | 81% |
| Taiwan | 93 | 0.00 | 173% | 101% |
| United States | 85 | 0.00 | 120% | 90% |

Note: There are 99 observations (country-specific factors) for each test. The p-values report the probability of observing a higher value of the test statistic under the null hypothesis that the model predicts the direction of trade no better than a coin flip.

Fig 2: Virtual Endowments, USA Reference Country
(millions of 2000 dollars)

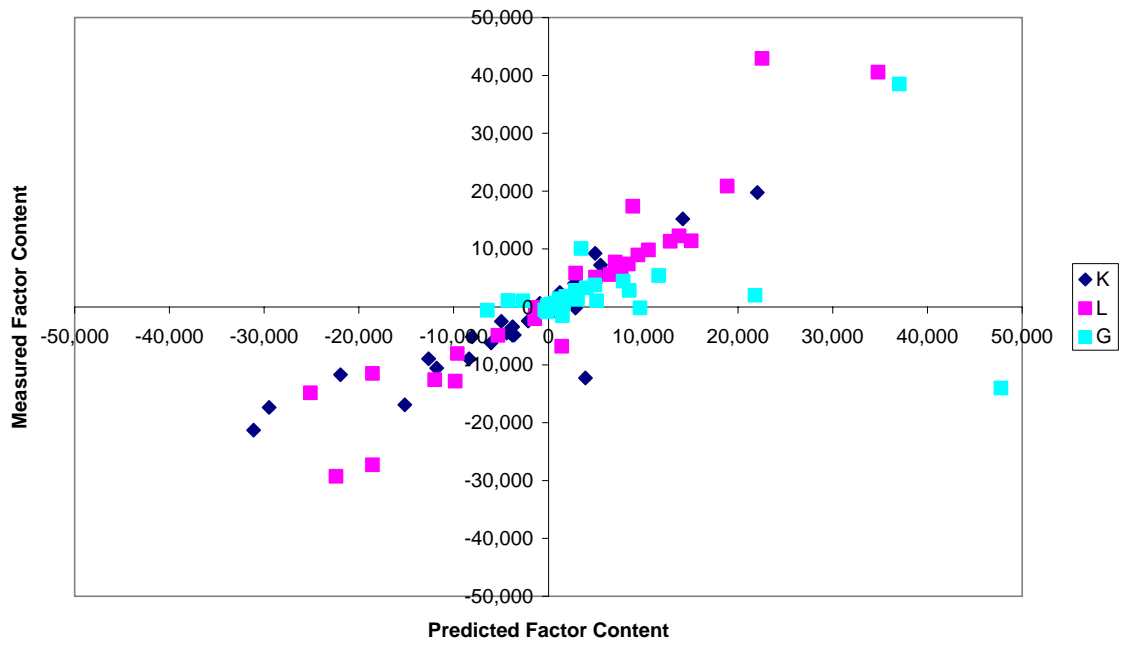
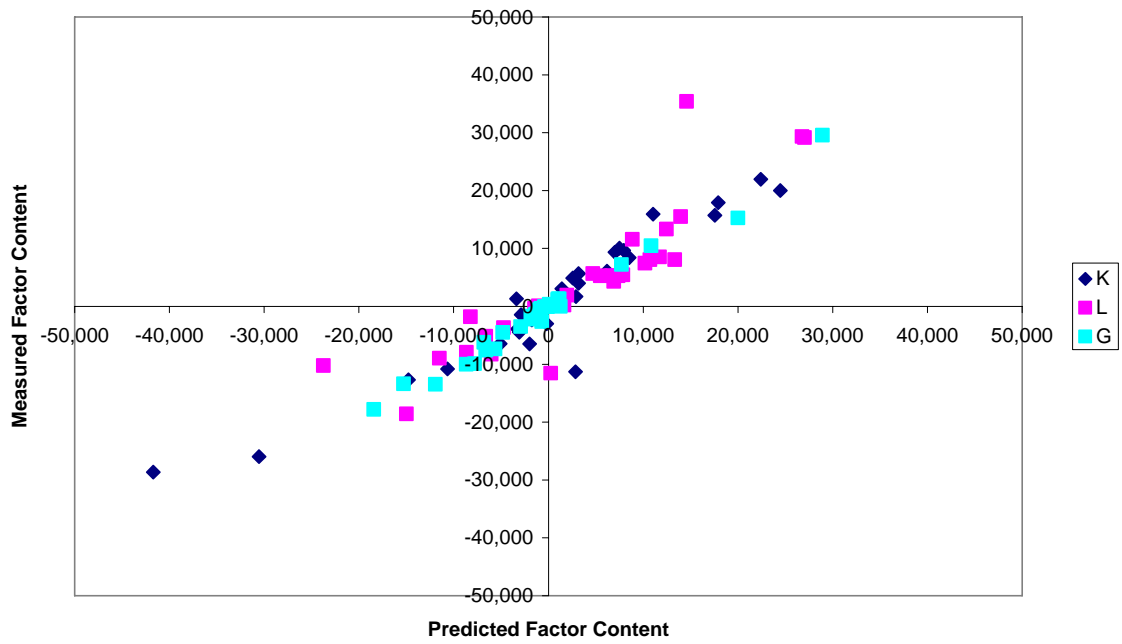


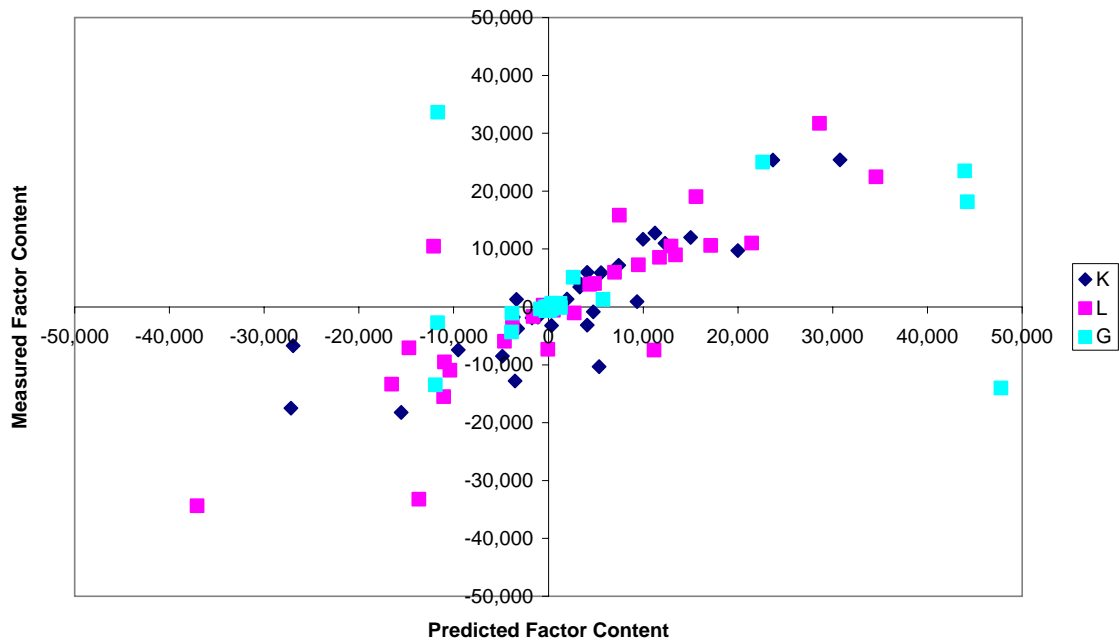
Fig 3: Virtual Endowments, Korea Reference Country
(millions of 2000 dollars)



There is one slightly unsatisfactory element of these simple tests with virtual endowments. The factor content of trade should be measured in terms of the local resources that would have been used to produce the net trade vector. Until now in this subsection, we have constructed virtual endowments and also imposed factor price equalization at the reference country's factor prices. But the whole notion of the factor content of trade inclines one to use local technologies to measure the factor content of net exports. A French person is interested in how many French factors are saved if France imports apples instead of producing them locally.

But if we are going to measure the factor content of trade using the local technology, then the predicted factor content of trade will depend upon the prism of the local reporting country too. Hence, a slightly more sophisticated version of the test using virtual endowments relaxes the assumption of strict factor price equalization and reports the measured factor content of trade against the predicted factor content, when one allows measures and predictions to vary by importing country. Figure 4 shows the results. The p-value for the sign test is again 0.00, the average share of trade explained is 265%, and the median share of trade explained is 86%. In a nutshell, the virtual endowments test that does not impose factor price equalization performs brilliantly too.

Fig. 4: HOV with Virtual Endowments, no FPE
(millions of 2000 dollars)



The main lesson from this analysis is what we do not need to make the theory conform to the data. First, we do not need to adjust endowments and the measured factor content of trade using any econometrics at all; the data speak for themselves. Second, we do not need to assume any home bias in consumption; identical homothetic preferences are indeed strongly corroborated in the data.¹⁰ Third, there is no need to assume any home bias in consumption. Fourth, it is not necessary to posit the existence of not traded goods; the model works even though we assuming that a sector called hotels & restaurants is traded just like any manufactured commodity. Fifth, we do not need to worry about trade costs or generalized notions of trade barriers. Sixth, we do not need to make any adjustments for traded intermediate goods in these data.

¹⁰Analyzing bilateral trade flows from two decades ago among a smaller subset of countries than ours, Choi and Krishna (2004) test a theoretical prediction that is robust with respect to the specification of preferences. Our works shows that the assumption of identical homothetic preferences is not rejected if one uses a consistent set of data and to define absorption shares carefully.

The elegance of the traditional Heckscher-Ohlin-Vanek paradigm is that there is a simple identity between the measured and predicted factor content of trade under the two key assumptions that technology is identical across countries and that countries have identical and homothetic preferences. We have shown conclusively that it is only the first of these two assumptions that is restrictive. When complex differences in technology are accurately accounted for and factor inputs are appropriately measured, the identity is as solid as an empiricist could hope for among a large and diverse group of countries.

C. Differences in Technology and Missing Trade

Our measure of a country's technology is its matrix of factor cost shares across 48 industries. In a world with identical technologies and factor price equalization, these matrices would be identical. Table 3 shows the coefficients of variation of these shares (across countries) for each of the 48 industries in our data. Table 4 reports the same statistics across industries within a country for each of the 33 sample countries in our sample. We draw two important conclusions from these statistics. First, the factor shares are as variable within the same industry across countries as they are within the same country across many industries. This is perhaps the most salient feature of the data, and it implies that a serious test of the theory must address disparate technologies or factor price differences (or both) in a fundamental manner. Second, the industries that we would expect to be subsidized do indeed have negative average shares of social capital: agriculture, motor vehicles, and research and development.¹¹

¹¹ These coefficients of variation are based upon simple sample averages. Thus if one country subsidizes only one sector heavily, Table 4 may show that the average share of social capital is negative. Likewise, the cross-country sample mean for that sector may also be negative.

What accounts for this substantial variation of these cost shares? A promising explanation is offered by Schott (2003), who uses three-digit International Standard Industrial Classification (ISIC) data on manufacturing to examine problems arising from the aggregation of different production processes. These industrial categories group together a wide range of good. He notes, for example, that electrical machinery “includes both low-end portable radios and high-tech communications satellites.” Since such goods are probably not produced using the same technology, the taxonomic aggregation is unlikely to match predictions of Heckscher-Ohlin theory. The OECD’s input-output data are aggregated by ISIC primarily at the two-digit level, a taxonomy that exacerbates the aggregation problem. We have shown that the theory is verified empirically when we control for the heterogeneity of technologies in a simple but appropriate way. Still, general aggregation bias by sector creates measured differences in technology that cannot be easily corrected. With the kind of data used to evaluate the paradigm, one is unable to determine if these technology matrices reflect differences in how similar goods are made in each country or an inherent aggregation bias that arises from combining quite disparate goods within the same rubric.¹²

¹² Feenstra and Hanson (2000) make this point in a slightly different context.

Table 3: Coefficients of Variation of Cost Shares by Industry

| Industry | Social | | |
|---|-------------|-------------|-------------|
| | Capital | Labor | Capital |
| Agriculture, hunting, forestry and fishing | 0.26 | 0.37 | -3.13 |
| Mining and quarrying (energy) | 0.53 | 0.67 | 11.43 |
| Mining and quarrying (non-energy) | 0.25 | 0.22 | 1.33 |
| Food products, beverages and tobacco | 0.25 | 0.24 | 3.31 |
| Textiles, textile products, leather and footwear | 0.26 | 0.19 | 1.64 |
| Wood and products of wood and cork | 0.27 | 0.24 | 2.63 |
| Pulp, paper, paper products, printing and publishing | 0.26 | 0.22 | 1.89 |
| Coke, refined petroleum products and nuclear fuel | 0.46 | 0.62 | 7.66 |
| Chemicals excluding pharmaceuticals | 0.22 | 0.23 | 1.68 |
| Pharmaceuticals | 0.23 | 0.21 | 1.35 |
| Rubber & plastics products | 0.25 | 0.20 | 1.67 |
| Other non-metallic mineral products | 0.23 | 0.21 | 1.41 |
| Iron & steel | 0.28 | 0.24 | 1.77 |
| Non-ferrous metals | 0.26 | 0.26 | 1.10 |
| Fabricated metal products, except machinery & equipment | 0.29 | 0.20 | 1.73 |
| Machinery & equipment, nec | 0.27 | 0.19 | 1.74 |
| Office, accounting & computing machinery | 0.36 | 0.27 | 2.20 |
| Electrical machinery & apparatus, nec | 0.28 | 0.20 | 1.69 |
| Radio, television & communication equipment | 0.30 | 0.26 | 1.96 |
| Medical, precision & optical instruments | 0.27 | 0.22 | 3.07 |
| Motor vehicles, trailers & semi-trailers | 0.56 | 0.21 | -14.62 |
| Building & repairing of ships & boats | 0.36 | 0.21 | 2.54 |
| Aircraft & spacecraft | 0.30 | 0.20 | 2.06 |
| Railroad equipment & transport equip nec. | 0.24 | 0.18 | 1.10 |
| Manufacturing nec; recycling (include Furniture) | 0.30 | 0.24 | 5.10 |
| Production, collection and distribution of electricity | 0.19 | 0.29 | 1.64 |
| Manufacture of gas; distribution of gaseous fuels through mains | 0.30 | 0.39 | 1.42 |
| Steam and hot water supply | 0.33 | 0.31 | 1.71 |
| Collection, purification and distribution of water | 0.28 | 0.30 | 1.62 |
| Construction | 0.30 | 0.24 | 1.48 |
| Wholesale & retail trade; repairs | 0.36 | 0.30 | 1.64 |
| Hotels & restaurants | 0.30 | 0.25 | 1.56 |
| Land transport; transport via pipelines | 0.32 | 0.23 | 4.66 |
| Water transport | 0.27 | 0.24 | 2.58 |
| Air transport | 0.30 | 0.22 | 1.95 |
| Supporting and auxiliary transport activities | 0.29 | 0.24 | 2.24 |
| Post & telecommunications | 0.22 | 0.23 | 1.52 |
| Finance & insurance | 0.30 | 0.23 | 1.73 |
| Real estate activities | 0.13 | 0.44 | 1.32 |
| Renting of machinery & equipment | 0.25 | 0.38 | 1.37 |
| Computer & related activities | 0.39 | 0.25 | 1.95 |
| Research & development | 0.38 | 0.24 | -20.82 |
| Other Business Activities | 0.31 | 0.24 | 1.49 |
| Public admin. & defence; compulsory social security | 0.35 | 0.12 | 1.88 |
| Education | 0.64 | 0.15 | 2.01 |
| Health & social work | 0.35 | 0.16 | 2.41 |
| Other community, social & personal services | 0.25 | 0.20 | 1.82 |
| Private households with employed persons | 0.71 | 0.39 | 2.76 |
| Median | 0.29 | 0.24 | 1.73 |

**Table 4: Coefficients of Variation
of Cost Shares by Country**

| Country | Capital | Labor | Social Capital |
|--------------------|----------------|--------------|---------------------------|
| Australia | 0.31 | 0.25 | 0.29 |
| Austria | 0.30 | 0.24 | 2.35 |
| Belgium | 0.29 | 0.26 | 1.19 |
| Brazil | 0.29 | 0.39 | 0.33 |
| Canada | 0.34 | 0.25 | 0.71 |
| Switzerland | 0.33 | 0.15 | 1.66 |
| China | 0.21 | 0.20 | 0.22 |
| Czech Republic | 0.17 | 0.23 | -1.76 |
| Germany | 0.35 | 0.28 | -3.75 |
| Denmark | 0.43 | 0.34 | -3.94 |
| Spain | 0.28 | 0.24 | -10.52 |
| Finland | 0.33 | 0.27 | -2.47 |
| France | 0.38 | 0.23 | 0.35 |
| United Kingdom | 0.41 | 0.22 | 0.54 |
| Greece | 0.36 | 0.38 | 0.79 |
| Hungary | 0.21 | 0.18 | 4.34 |
| Indonesia | 0.27 | 0.43 | -9.27 |
| Ireland | 0.37 | 0.29 | 2.11 |
| Israel | 0.40 | 0.22 | 0.94 |
| Italy | 0.23 | 0.36 | 1.86 |
| Japan | 0.35 | 0.24 | 1.58 |
| Korea, Republic of | 0.22 | 0.29 | 1.57 |
| Netherlands | 0.38 | 0.34 | -10.55 |
| Norway | 0.36 | 0.27 | -2.35 |
| New Zealand | 0.21 | 0.23 | 0.71 |
| Poland | 0.25 | 0.26 | 0.84 |
| Portugal | 0.59 | 0.39 | -0.96 |
| Russia | 0.25 | 0.37 | 0.51 |
| Slovak Republic | 0.20 | 0.20 | -1.64 |
| Sweden | 0.31 | 0.18 | 1.08 |
| Turkey | 0.19 | 0.57 | 4.05 |
| Taiwan | 0.31 | 0.26 | 1.87 |
| United States | 0.32 | 0.24 | 0.94 |
| Median | 0.31 | 0.26 | 0.71 |

We argue that the empirical puzzle of missing trade is itself a result of the heterogeneity of local technologies. In our data, the endowment vector is the flow of factor services needed to produce the local output vector using the *local technology*. In the traditional tests of the paradigm, the measured factor content of trade is based on the reference country technology, usually the United States or occasionally some world average technology matrix. Since the reference country technology does not change, the variation in measured factor content is determined solely by the variance in net export vectors across countries. However, the local output vector consists of net exports plus domestic absorption, so it must be more variable than net exports alone, as long as absorption and net exports are not negatively correlated.

The traditional measure of missing trade is the absolute value of $B^0(I - A^0)^{-1}(x^c - m^c)$ relative to the absolute value of $v^c - s^c v$. For given world endowments, we would expect the measured factor content of trade to be far less variable than the predicted factor content of trade since the latter embodies the variation of technologies and output across countries.¹³ Even if the demand assumptions of the model are correct, these differences in technology will lead to an underestimate of the measured factor content of trade relative to predicted factor content of trade.

This problem is exacerbated when one measures endowments in physical quantities, not in the value of the factor services that they generate. For example, a country that is abundantly endowed with pasture land will be predicted to have large net

¹³ By construction, both the measured and predicted factor content of trade for each factor will equal zero if averaged across all countries of the world. If some countries are left out of the sample but the rest of the world is accounted for in the world endowment, both the sum of measured and predicted factor content across countries will equal the factor content of net imports from the rest of the world. Since both measured and predicted factor content have the same average value, the smaller variance of the measured factor content will cause the ratio of the two to tend to be small on average.

exports of that factor. But its local technology will surely have adapted to the fact that pasture land is inexpensive. Hence the value of the flows of factor services will naturally be less variable across countries than the variance of actual physical endowments because factor prices are negatively correlated with physical endowments. The simplest tests of the paradigm make this point moot, since they impose factor price equalization and identical technologies. This assumption has been their weakest point.

D. The Tests with Generalized Rybczynski Effects

The third test uses a technique that does not rely upon having an observable output vector for each country in the sample. This technique can be implemented if only endowment vectors and technology matrices are observable. If the number of goods in the world were equal to the number of factors, each endowment vector would give rise to a unique output vector. Bernstein and Weinstein (2002) present convincing evidence to the contrary; indeed, the world that generates our data has many more goods than factors. Even in an economy with two goods and one factor (the Ricardian world of our textbooks), there are many possible full-employment output vectors.

Here is the simplest possible definition of a generalized Rybczynski effect. Consider a Ricardian world with no intermediate goods and only two final goods. Then the input requirements for the home country are $B^H(I - A^H)^{-1} = [b_1^H \quad b_2^H]$ and that for the foreign country $B^F(I - A^F)^{-1} = [b_1^F \quad b_2^F]$. These two matrices are row vectors that describe the unit labor requirements at home and abroad. The factor conversion matrix converting foreign labor into domestic labor is:

$$[b_1^H \quad b_2^H][b_1^F \quad b_2^F]^+ = \frac{(b_1^H / b_1^F)(b_1^F)^2 + (b_2^H / b_2^F)(b_2^F)^2}{(b_1^F)^2 + (b_2^F)^2}.$$

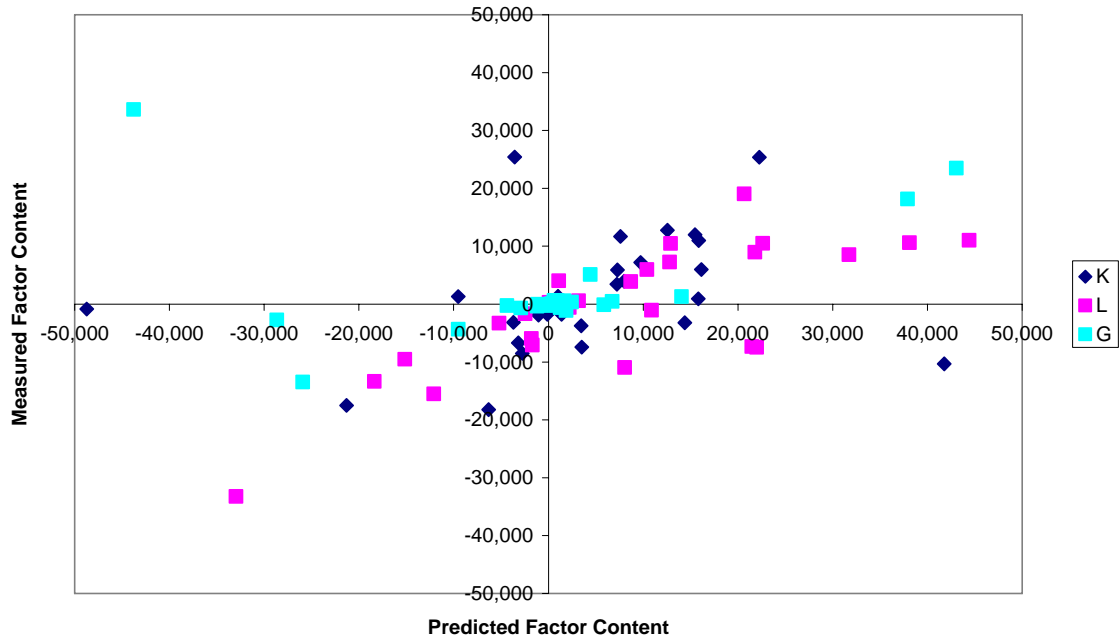
Without loss of generality, assume that the home country has comparative advantage in the first good. Then this expression is a weighted average of the lowest possible double factorial terms of trade $w^F / w^H = b_1^H / b_1^F$ and the highest possible double factorial terms of trade $w^F / w^H = b_2^H / b_2^F$. The weights are determined by the autarky prices in the exporting (foreign) country, with a higher weight being accorded to the good with the higher local autarky price. The techniques developed in Fisher and May (2006) generalize this simple idea, and we implement them here. In sum, one extra unit of labor in the foreign country translates into $\begin{bmatrix} b_1^H & b_2^H \end{bmatrix} \begin{bmatrix} b_1^F & b_2^F \end{bmatrix}^+$ units of labor in the home country. This adjustment is between the lowest and highest possible relative factor prices that are consistent with equilibrium.

Our results demonstrate that the empirical success of our second test is not dependent on a specific vector of outputs. In the spirit of previous tests in most of the literature, we begin with a description of a country's endowment and demonstrate the factor content of trade—measured according to the local technology—can be predicted accurately, as long as one adjusts for differences in technology across countries. Thus this test is a general test of the HOV paradigm where we allow for different technologies and factor prices.

The results are presented in Figure 5. The sign test has 77 correct predictions (of a possible 99) and its p-value is 0.00. The average amount of the absolute value of the ratio of measure trade to predicted trade is 95%, and the corresponding median of these numbers is 49%. These results are not as strong as the one that are based upon virtual endowments, but they are enormously better than anything that has been seen before in the literature. We remind the reader that these numbers come from raw data that are

observable; there are no adjustments to the raw data here. We hope our use of this generalized Rybczynki effects will have a broad appeal to empirical trade economists.

Fig 5: HOV without FPE
(millions of 2000 dollars)



V. Conclusions

We showed strong empirical support for the most elegant paradigm in applied general equilibrium theory, the Heckscher-Ohlin model. We have delivered where the literature has failed for two main reasons. First, we took great care to make sure that our data were consistent. Even the definitions of absorption shares mattered substantially, and we made sure that our net trade vectors, our measures of absorption, our endowments, and our measure of the net trade vector with the rest of the world all came from the same source. Second, we gave the theory a chance in a world where countries' technology matrices differ.

Since we were so sure that our data were accurate, we could focus our attention away from econometric techniques and onto how to make the theory work in a world where technologies differ among countries as a matter of course. Our biggest empirical contribution was the idea of constructing a virtual endowment and applying it to a wide set of international data. Once we had seen the results that lie behind Figures 2, 3, and 4, we knew that the theory itself was correct. Our careful treatment of technological differences also explains the mystery of missing trade. While our own data exhibit missing trade in the traditional test designed to replicate past research, when we construct virtual endowments we can predict roughly 80 to 100 percent of observed trade.

Constructing a virtual endowment depends upon a specific output vector, and in a world of many goods and few factors, there are many possible output vectors that satisfy full employment. We have extended our results with a technique that can account for different technologies when we observe endowments rather than one of many feasible output vectors. This generalized Rybczynki effect is based on some innovative ideas that will have wider application in empirical trade in the future. It shows again that the theory works remarkably well if the data are clean and if one adjusts for technology differences appropriately.

There is a lot of room for future research. We conjecture that the poor performance of the past studies in this literature will be overturned if one goes back and uses the same data to construct virtual endowments wherever local output vectors are observable. We hope that we have restored the profession's confidence in one of our most important paradigms that has ready applications in international economics, public

finance, and development economics. The Heckscher-Ohlin-Vanek paradigm—as a description of the factor content of trade—is too elegant in theory not to be true in fact.

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