

NBER WORKING PAPER SERIES

MULTICOUNTRY, MULTIFACTOR TESTS  
OF THE FACTOR ABUNDANCE THEORY

Harry P. Bowen

Edward E. Leamer

Leo Sveikauskas

Working Paper No. 1918

NATIONAL BUREAU OF ECONOMIC RESEARCH  
1050 Massachusetts Avenue  
Cambridge, MA 02138  
May 1986

This paper has benefited from comments by participants in the International Economics Workshop at New York University. The original version of the paper was presented at the Western Economic Association meetings, 1982. The research reported here is part of the NBER's research program in International Studies. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

Multicountry, Multifactor Tests of the Factor Abundance Theory

ABSTRACT

This paper presents conceptually correct tests of the Heckscher-Ohlin proposition that trade in commodities can be explained in terms of an interaction between factor input requirements and factor endowments. Most prior work that claims to present tests of this hypothesis have used intuitive but inappropriate generalizations of the traditional two by two model to deal with a multidimensional reality. Moreover, prior work has in general used measurements on only two of the three variables (trade, factor input requirements and factor endowments) that are required for a proper test of the H-O theory.

We derive an exact specification of the H-O interaction in a multicountry, multicommodity, multifactor world in the form of the Heckscher-Ohlin-Vanek (H-O-V) theorem which equates the factors embodied in net trade to excess factor supplies. This theorem implies sign and rank propositions analogous to those implicitly studied by Leontief, but it also implies hypotheses about the parameters linking factor contents and factor supplies. Accordingly, we conduct tests of the sign and rank propositions as well as several parametric hypotheses which permit various assumptions about measurement errors, nonproportional consumption and technological differences. Our analysis uses separately measured data on trade, factor input requirements and endowments for twenty-seven countries and twelve factors in 1967.

Tests of the Leontief type sign and rank propositions sharply reject this facet of the H-O-V model. In particular, the sign of net factor exports infrequently predicts the sign of excess factor supplies and therefore does not systematically reveal factor abundance.

The results from an extended set of tests conducted in a regression context reject the H-O-V hypothesis of an exact relationship between factor contents and national factor supplies. Support is found for the H-O-V assumption of homothetic preferences, but estimates of the parameters linking factor contents and factor supplies are found to differ significantly from their theoretical values. We find there is clear evidence that the departure of the estimated coefficients from their theoretical values is importantly related to differences across countries in the matrix of factor input requirements and, by implication, to violation of the assumption of factor price equalization. We also find that errors of measurement in both trade and national factor supplies are an important reason for rejection of the H-O-V hypothesis.

Harry P. Bowen  
Department of Economics  
Graduate School of Business  
New York University  
New York, NY 10003

Edward E. Leamer  
Department of Economics  
University of California  
Los Angeles, CA 90024

Leo Sveikauskas  
Department of Economics  
R.P.I.  
Troy, NY 12181

## I. Introduction

The Heckscher-Ohlin (H-O) hypothesis is most widely understood in its two-good two-factor form: a country exports the commodity which uses intensively its relatively abundant resource. Tests of this hypothesis have been inconclusive for two reasons. First, the three pairwise comparisons required by this 2 x 2 model cannot be made unambiguously in a multifactor, multicommodity world. Most previous papers that claim to present tests of the hypothesis have used intuitive but inappropriate generalizations of the two by two model to deal with a multidimensional reality. Second, the H-O hypothesis is a relation among three separately observable phenomena: trade, factor input requirements and factor endowments. A proper test of the hypothesis requires measurements of all three of these variables. Much prior work that claims to have tested the hypothesis has used data on only two of the three hypotheticals.

This paper reports conceptually correct tests of the H-O hypothesis as suggested by Leamer (1980) and Leamer and Bowen (1981). We use a valid multidimensional extension of the two by two model known as the Heckscher-Ohlin-Vanek (H-O-V) theorem which equates the factors embodied in a country's net exports to the country's excess supplies of factor endowments. And we use separately measured data on trade, factor input requirements and factor endowments to conduct the first systematic and complete evaluation of the relationships implied by the H-O hypothesis among these three sets of variables.

Our methods contrast sharply with traditional approaches to testing the H-O hypothesis. The classic test of the H-O hypothesis is Leontief's (1953) which compares the capital per man embodied in

a million dollars worth of exports with the capital per man embodied in a million dollars worth of imports. Leamer (1980) shows this comparison does not reveal the relative abundance of capital and labor in a multifactor world. Moreover, Leontief's study uses data on trade and factor input requirements but not factor endowments and, in addition, his data are only for a single country.

A second type of purported test uses a regression of trade of many commodities on their factor input requirements for a single country (e.g., Baldwin (1971), Branson and Monoyios (1977), Harkness (1978, 1983), Stern and Maskus (1981)). If the estimated coefficient of some factor is positive, the country is inferred to be abundant in that resource. Leamer and Bowen (1981) show this also is an inappropriate inference in a multifactor world since there is no guarantee that the signs of the regression coefficients will reveal the abundance of a resource. Moreover, these studies do not use factor endowment data.<sup>1</sup>

A third approach used to study the sources of comparative advantage involves regressions of net exports of a single commodity for many countries on measures of national factor supplies (Bowen (1983), Chenery and Syrquin (1975) and Leamer (1974, 1984)). This approach is conceptually correct but does not constitute a complete test of the theory because data on factor input requirements are not used.

The present study computes the amount of each of twelve factors embodied in the net exports of twenty-seven countries in 1967 using a U.S. matrix of total input requirements for 1967. The factors embodied in trade are then compared with direct measures of

factor endowments to determine the extent to which the data conform to the H-O-V theory's predictions.

We first test the traditional interpretation of the H-O hypothesis that trade reveals relative factor abundance.<sup>2</sup> This analysis is analogous to Leontief's attempt to determine the relative abundance of capital and labor in the United States using U.S. data alone. Our empirical results amount to a disaster for this facet of the H-O model. Several types of measurement error could account for this disaster. Moreover, the H-O-V model implies a set of equalities, not inequalities, among the variables. We therefore extend the analysis of the H-O-V model to a regression context, and conduct a second set of tests which examine these equalities while allowing different hypotheses about preferences, technological differences, and various forms of measurement error.

Overall, our results do not support the H-O-V proposition of an exact relationship between factor contents and factor supplies. Although support is found for the H-O-V assumption of homothetic preferences, our estimates of the parameters linking factor contents and factor supplies are found to differ significantly from their theoretical values. Our work leads us to believe that the poor performance of the H-O-V model is importantly related to technological differences (and by implication, factor price differences) across countries, as well as measurement errors.

## **II. Theoretical Framework**

Derivation of the relationships studied here starts with the equilibrium identity expressing a country's net factor exports as the difference between factors absorbed in production and factors

absorbed in consumption:

$$(1) \quad A_i T_i = A_i Q_i - A_i C_i$$

where

$A_i$  =  $K \times N$  matrix of factor input coefficients which indicate the total (direct plus indirect) amount of each factor needed to produce one unit of output.

$T_i$  =  $N \times 1$  vector of net trade flows of country  $i$ .

$Q_i$  =  $N \times 1$  vector of country  $i$ 's final outputs.

$C_i$  =  $N \times 1$  vector of country  $i$ 's final consumption.

Full employment implies  $A_i Q_i = E_i$  where  $E_i$  is the  $K \times 1$  vector of country  $i$ 's factor supplies. Thus, the vector of factors embodied in net trade is

$$(2) \quad F_i = A_i T_i = E_i - A_i C_i.$$

This identity is transformed into a testable hypothesis by making one or more of the following three assumptions:

(A1) All individuals face the same commodity prices.

(A2) Individuals have identical and homothetic tastes.

(A3) All countries have the same factor input matrix,  $A_i = A$ .

Ordinarily, the assumption of identical input matrices (A3) would be replaced by the assumption of factor price equalization. The alternative to factor price equalization permitted here is that input requirements are technologically fixed and identical across countries but countries have different factor prices and thus produce different subsets of commodities.

Assumptions (A1) and (A2) imply that the consumption vector of country  $i$  is proportional to world output,  $C_i = s_i Q_w$ , where  $Q_w$  is the world output vector and  $s_i$  is country  $i$ 's consumption share. The consumption share can then be derived by premultiplying the

identity for net trade ( $T_i = Q_i - s_i Q_w$ ) by the vector of common goods prices:

$$(3) \quad s_i = (Y_i - B_i) / Y_w$$

where  $Y_i$  is GNP and  $B_i$  is the trade balance. If trade is balanced, then  $s_i$  equals country  $i$ 's share of world GNP.<sup>3</sup>

If, in addition, the factor input matrices are identical, we can write  $A_i C_i = s_i A Q_w = s_i E_w$  where  $E_w = \sum_i E_i$  is the  $K \times 1$  vector of world factor supplies. Then, (2) can be written as

$$(4) \quad F_i = E_i - E_w (Y_i - B_i) / Y_w.$$

Note that if the exact relationship given by (4) were studied using regression analysis, a test of the H-O-V model would involve testing whether the parameter linking factor contents  $F_i$  and national resource supplies  $E_i$  differed significantly from unity.

### III. Methods of Testing

Equation (4) specifies an exact relationship between factor contents and factor endowments. This relationship can be tested by measuring the net export vector  $T_i$ , the factor input matrix  $A$ , and the excess factor supplies  $E_i - s_i E_w$  and computing the extent to which these data violate the equality given by (4). Such analysis requires some sensible way of measuring the distance between two matrices: the matrix with columns equal to the factor contents of trade for each country, and the matrix with columns equal to the excess factor supplies for each country. We first examine the extent to which row and column elements of these matrices conform in sign and rank without reference to any specific alternative hypotheses. Then we report tests against alternatives involving nonproportional consumption, measurement errors and differences in

input matrices.

A typical  $k^{\text{th}}$  element of (4), scaled by factor consumption, is

$$(5) \quad F_{ki}/(s_i E_{kw}) = [E_{ki}/(s_i E_{kw})] - 1.$$

If the right hand side of (5) is positive, the country is defined to be abundant in resource  $k$ , in the sense of having an endowment share  $E_{ki}/E_{kw}$  which exceeds the consumption share.<sup>4</sup> If equation (5) is accurate then the sign of the net exports of the factor  $F_{ki}$  will conform in sign with the abundance indicator  $((E_{ki}/E_{kw}) - 1)$ . This sign proposition is tested for each factor (country) by computing the frequency of sign matches between corresponding elements in each row (column) of the factor contents matrix and the excess factor supply matrix. Fisher's Exact test (one-tail) is used to test the hypothesis of independence between the sign of the factor contents and of the excess factor supplies against the alternative of a positive association.

Equation (5) also implies that trade should reveal the complete ordering of factor abundance ratios. For each country or factor, the ranking of scaled net factor exports  $(F_{ki}/[s_i E_{kw}])$  should conform to the ranking of factors by their abundance,  $E_{ki}/(s_i E_{kw})$ .<sup>5</sup> These rank propositions are tested for each country (factor) by computing the rank correlation between corresponding columns (rows) of the scaled factor content matrix and the scaled excess factor supplies matrix.

These sign and rank tests do not refer to specific alternative hypotheses and they may generate evidence against the H-O-V hypothesis for a variety of reasons including nonproportional consumption, various kinds of measurement errors and differences in factor input matrices. These alternatives are studied by



regressions of factor contents on endowments as described below.

The general hypothesis of nonidentical, nonhomothetic tastes cannot be allowed since then trade, which is the difference between production and consumption, would be completely indeterminate<sup>6</sup>.

Instead, we study a specific alternative to assumption A2:

(A2') All individuals have identical preferences with linear Engel curves; within each country income is equally distributed.

The modification of (4) implied by (A2') is derived by noting that (A2') implies per capita consumption is a linear function of per capita income. Therefore, we can write country  $i$ 's total consumption of commodity  $j$  ( $C_{ij}$ ) as a linear function of its population  $L_i$  its total income  $Y_i$ :<sup>7</sup>

$$(6) \quad C_{ij} = \lambda_j L_i + \psi_j (Y_i - L_i Y^0)$$

where

$\lambda_j$  = per capita "autonomous" consumption of commodity  $j$

$\psi_j$  = marginal budget shares,  $\sum_j \psi_j = 1$

$Y^0 = \sum_j \lambda_j$ .

Summing (6) over  $i$  gives the marginal budget shares  $\psi_j$ :

$$(7) \quad \psi_j = (Q_{wj} - \lambda_j L_w) / (Y_w - L_w Y^0)$$

where  $L_w$  is world population. Inserting (7) into (6) and then premultiplying by the  $k^{\text{th}}$  row of  $A$  ( $a_k$ ), the amount of factor  $k$  absorbed in consumption  $a_k C_i$  is

$$(8) \quad a_k C_i = (\theta_k - \beta_k Y^0) L_i + \beta_k Y_i$$

where

$$\theta_k = \sum_j a_{kj} \lambda_j$$

$$\begin{aligned} \beta_k &= (\sum_j a_{kj} Q_{wj} - \sum_j a_{kj} \lambda_j L_w) / (Y_w - L_w Y^0) \\ &= (E_{kw} - \theta_k L_w) / (Y_w - L_w Y^0) \end{aligned}$$

Equation (8) implies that equation (4) can be written

$$(9) \quad F_i = E_i - \theta L_i - \beta(Y_i - B_i)$$

where  $\theta$  and  $\beta$  are  $K \times 1$  vectors with positive elements. Maintaining assumption (A2) involves the restriction that  $\theta = 0$  and  $\beta_k = E_{kw}/Y_w$ .

The possibility of measurement errors is incorporated in our analysis in several ways. We assume measurement of net trade differs from its true value by a constant plus a random error:

$$(M1') \quad T_i^m = \omega + T_i + T_{ie}$$

where the vector  $T_i^m$  is the measured value of the vector  $T_i$ ,  $\omega$  is an  $N \times 1$  vector of constants and  $T_{ie}$  is the error vector. The null hypothesis is that there is no measurement error bias

$$(M1) \quad \omega = 0$$

Assumption (M1') implies the factor content vector is also measured with error:

$$(10) \quad F_i^m = AT_i^m = A\omega + AT_i + AT_{ie} \\ = \alpha + F_i + F_{ie}$$

where  $F_i^m$  is the measured value of  $F_i$ ,  $\alpha = A\omega$  is a  $K \times 1$  vector of unknown constants and  $F_{ie}$  is the error vector with covariance matrix that is assumed diagonal for convenience.

The measurements of the endowments are also assumed to be imperfect but in a different way:

$$(M2') \quad E_i^m = \Gamma E_i$$

where  $E_i^m$  is the measured value,  $E_i$  the true value and  $\Gamma$  is a  $K \times K$  diagonal matrix with positive elements  $\gamma_k$ . The null hypothesis of no measurement errors is

$$(M2) \quad \Gamma = I$$

The form of the measurement error contained in (M2') is also chosen

for convenience since random measurement errors in more than one variable would force us into consideration of an "errors-in-variables" model which entails regressions in more than one direction. With our assumptions, factor contents are always the dependent variable.

A third source of measurement error we consider is the incomplete coverage of countries. World endowments and world GNP are estimated here by summing across the sample of countries. The resulting underestimates of the world totals would not affect our analysis if excluded countries had total endowments proportional to the sample totals. As an alternative to this assumption we can assume that the calculated totals contain no information about world totals. This latter assumption can be stated formally as

$$(M3') \quad E_w = Q_s E_s$$

$$Y_w = q_s Y_s.$$

The subscript  $s$  refers to the subset of countries in the sample;  $Q_s$  is a diagonal matrix containing unknown positive elements and  $q_s$  is an unknown positive scalar. The null hypothesis is

$$(M3) \quad Q_s = I \text{ and } q_s = 1.$$

Combining the assumption of nonproportional consumption (A2') with the measurement error assumptions (M1') - (M3'), the expression for country  $i$ 's net trade in factor  $k$  becomes

$$(11) \quad F_{ki} = \alpha_k + \gamma_k E_{ki} - \theta_k L_i - \beta_k (Y_i - B_i) + F_{kie}$$

where the superscript "m" is suppressed for notational convenience.

The alternative to the assumption of identical input matrices (A3) that we consider is the assumption that input matrices differ by a proportional constant. This amounts to assuming neutral differences in technology across countries. Since we calculate

factor contents using the U.S. input matrix, the proportional difference in input matrices is measured relative to the U.S. input matrix. This assumption can be written

$$(A3') \quad A_{us} = \delta_i A_i$$

where  $\delta_i > 0$  and  $\delta_{us} = 1$ .

Assumption (A3') implies that  $\theta_k$ ,  $\beta_k$  and  $F_{ki}$  are now  $\theta_k/\delta_i$ ,  $\beta_k/\delta_i$  and  $F_{ki}^{us}/\delta_i$ , respectively, where  $F_{ki}^{us}$  is country  $i$ 's net trade in factor  $k$  computed using the U.S. input matrix. Substituting these new values into (11) gives

$$(12) \quad (1/\delta_i)F_{ki}^{us} = (1/\delta_i)\alpha_k + \gamma_k E_{ki} - (1/\delta_i)\theta_k L_i \\ - (1/\delta_i)\beta_k(Y_i - B_i) + (1/\delta_i)F_{kie}$$

The  $E_{ki}$  do not involve the term  $(1/\delta_i)$  since they are measured independent of the input matrix. Multiplication of (12) by  $\delta_i$  yields the bi-linear form:

$$(13) \quad F_{ki}^{us} = \alpha_k + (\delta_i \gamma_k) E_{ki} - \theta_k L_i - \beta_k (Y_i - B_i) + F_{kie}.$$

Equation (13) identifies our most general model<sup>8</sup> which we estimate using an iterative maximum likelihood procedure discussed below.

In addition to the general hypothesis contained in (13) (hereafter denoted HG), we consider ten alternative hypotheses H1-H10 selected from the set of possibilities corresponding to different choices from the list of assumptions about the theory and the nature of measurement errors. Table 1 states each alternative in terms of the restrictions it imposes on the parameters of (13).

Hypotheses HG-H10 each maintain the assumption of common goods prices (A1). Hypotheses H1-H7 further maintain the assumption of proportional consumption while allowing tests of the assumptions of identical input matrices (A2), measurement error in trade and the endowments, and incomplete coverage of countries. The hypotheses

Table 1

Alternative Assumptions and Parameter Restrictions

Hypothesis	Assumptions <sup>a</sup>						Parameter Restrictions				
	A1	A2	A3	M1	M2	M3	$\alpha_k$	$\delta_i$	$\gamma_k$	$\theta_k$	$\beta_k$
HG	*										
H1	*	*	*					1		0	$E_{ks}/Y_s$
H2	*	*		*	*	*	0		1	0	$E_{ks}/Y_s$
H3	*	*				*				0	$E_{ks}/Y_s$
H4	*	*	*	*	*		0	1	1	0	
H5	*	*	*					1		0	
H6	*	*		*	*		0		1	0	
H7	*	*								0	
H8	*		*	*	*	NA	0	1	1		
H9	*		*			NA		1			
H10	*			*	*	NA	0		1		

<sup>a</sup> Absence of an \* indicates selection of the alternative Ai' or Mi'

Definitions:

- A1 : Identical commodity prices.
- A2 : Identical and homothetic tastes.
- A3 : Identical input intensities.
- M1 : Unbiased measurement of factor contents.
- M2 : Perfect measurement of endowments.
- M3 : Complete coverage of countries.

of special interest are: H4, which leaves only  $\beta_x$  unrestricted and corresponds to the H-O-V hypothesis that the parameter linking factor contents and national factor supplies is unity; H3, which maintains the assumptions of proportional consumption (A2) and complete coverage of countries (M3); H9, which maintains only the assumption of identical technologies (A3); and H10, which maintains the hypothesis that both trade and the endowments are measured without error (M1 and M2).

Given estimates of the unrestricted parameters in (13) under each hypothesis, a method is required to determine the overall performance of each alternative. One possibility is to form indexes based on the maximized value of the likelihood function associated with (13):

$$(14) \quad L = (\text{ESS})^{-(\text{NK}/2)}$$

where ESS is the error sum-of-squares (summed over countries and factors) and NK is the number of observations. Values of L, like an  $R^2$ , necessarily increases as the number of parameters increases and some form of degrees of freedom correction is required. We adopt the asymptotic Bayes formula proposed in the context of regression by Leamer (1978, p. 113) and more generally by Schwarz (1978):

$$(15) \quad L^* = L (\text{NK})^{-p/2}$$

where p is the number of parameters estimated under a given hypothesis. Given an alternative hypothesis j and a null hypothesis i we form the ratio:

$$(16) \quad \Lambda = L^*_j / L^*_i = (\text{ESS}_i / \text{ESS}_j)^{\text{NK}/2} (\text{NK})^{(p_i - p_j)/2}.$$

The evidence is then said to favor the alternative if  $\Lambda > 1$ . If the parameter values associated with each hypothesis are considered

equally likely a priori, then  $\Lambda$  is interpreted as the posterior odds in favor of the alternative.

#### IV. Estimation Issues

The covariance matrix of the residual vector in equation (13) is assumed to be diagonal with each diagonal element corresponding to a different factor. Processing of the data would be relatively easy if these variances were all equal. For example, if the endowments were all measured without error ( $\gamma_k = 1$ ), then equation (13) could be estimated by ordinary least squares with dummy variables. But the assumption of equal variances makes little sense unless the data are scaled in comparable units. To achieve comparability, we scale all the data by the world endowment levels  $E_{kw}$ . Furthermore, to eliminate heteroscedasticity associated with country size, we also divide by the adjusted GNP:  $Y_i - B_i$ . Thus, after these adjustments, equation (13) becomes

$$(17) \quad F_{ki}^{us}/S_{ki} = \alpha_k(1/S_{ki}) + (\gamma_k \delta_i)(E_{ki}/S_{ki}) - \theta_k(L_i/S_{ki}) \\ - \beta_k(1/E_{kw}) + F_{kie}^*$$

where  $S_{ki} = (Y_i - B_i)E_{kw}$ .<sup>9</sup> The errors  $F_{kie}^* = F_{kie}/E_{kw}$  are assumed to be normally distributed with mean zero and variance  $\sigma^2$ .

The parameters in (17) are estimated using an iterative procedure which solves the set of first order conditions for maximizing the likelihood function (14). Given estimates  $\delta_i^o$  ( $= 1$  initially), estimates  $\alpha_k^o$ ,  $\gamma_k^o$ ,  $\theta_k^o$ , and  $\beta_k^o$  are obtained by estimating the following equation for each factor:

$$(18) \quad F_{ki}^{us}/S_{ki} = \alpha_k(1/S_{ki}) + \gamma_k(\delta_i^o E_{ki}/S_{ki}) - \theta_k(L_i/S_{ki}) - \beta_k(1/E_{kw})$$

The estimates are then used to obtain new estimates  $\delta_i^o$  by estimating the following equation for each country:

$$(19) \quad W_{ki} = \delta_i (\gamma_k^o E_{ki}/E_{kw})$$

where  $W_{ki} = F_{ki}^{us}/S_{ki} - \alpha_k^o/S_{ki} - \theta_k^o(L_i/S_{ki}) - \beta_k^o/E_{kw}$ .

Prior to using the new estimates  $\delta_i$  obtained from (19) to re-estimate (18), each estimate of  $\delta_i$  is divided by the estimated value for the United States. The process of iteratively estimating (18) and (19) continues until the value of (14) converges.

The above two-step procedure is used to estimate the parameters in (17) under hypotheses HG, H1, H5, H7 and H9 since each involves the specification that  $\gamma \neq 1$ . However, since hypotheses H2, H4, H6, H8 and H10 restrict  $\gamma = 1$ , estimates of the unrestricted parameters under these five hypotheses are derived using a dummy variables model applied to the data set pooled across countries and factors, and imposing the restriction  $\delta_{us} = 1$ .

#### IV. Empirical Analyses

Table 2 summarizes the factor content data by listing for each country the ratio of net exports of each factor in 1967 to the endowment of the corresponding factor in 1966,  $F_{ki}/E_{ki}$ . In theory, a country's factor abundance is revealed by the sign and magnitude of these numbers since (5) can be rewritten

$$(20) \quad F_{ki}/E_{ki} = 1 - (s_i E_{kw}/E_{ki}).$$

Thus, given assumptions A1-A3, the ordering of net factor export/endowment ratios conforms to the ordering of resource abundance ratios  $E_{ki}/E_{kw}$ . Further, (20) indicates net factor exports are positive if and only if the corresponding resource is abundant in the sense that the resource share exceeds the consumption share, that is,  $E_{ki}/E_{kw} > s_i$ .

Table 2 indicates that the United States exports .73% of the



Table 2  
Ratios of Net Trade in Factor to National Endowments  
(in percent)

Country	Capital	Labor	Prof/Tech	Managerial	Clerical	Sales	Service	Agricultural	Production	Arable	Forest	Pasture
ARG	3.613	0.914	-0.169	-0.008	0.178	0.311	0.172	5.916	-0.237	21.692	-6.229	2.631
AUSL	-4.159	-0.948	-3.427	-2.137	-2.104	-0.365	-0.779	16.938	-4.090	17.070	-13.979	0.782
AUST	-6.867	-1.193	-1.812	-2.687	-1.267	-0.720	-0.476	-1.810	-1.028	-91.749	-4.896	3.899
BLUK	-4.158	-0.198	-0.615	-0.300	0.061	-0.196	-0.164	-11.015	1.271	-374.382	-968.531	23.146
BRAZ	-4.590	-0.071	-0.437	-0.193	-0.326	-0.040	-0.015	0.054	-0.260	2.325	nil	0.108
CAN	2.467	-2.198	-2.497	-1.624	-2.901	-1.151	-0.753	6.843	-5.509	12.416	6.285	4.291
DEN	-10.202	0.036	-2.311	-5.992	-1.745	0.253	-0.333	15.614	-4.025	27.298	689.607	1634.570
FIN	2.832	-0.083	-1.315	-1.798	-1.455	-0.510	-0.279	-0.524	1.092	-26.745	29.556	291.499
FRA	-4.835	-0.162	-0.051	-0.183	-0.032	-0.107	-0.030	-1.029	0.118	-22.685	-205.546	-3.209
GER	0.316	1.314	2.584	3.924	1.785	0.597	0.637	-8.437	3.516	-316.218	-350.723	-98.775
GRCE	-18.789	-1.223	-3.111	-9.863	-2.947	-0.706	-0.707	0.369	-3.499	40.809	-89.846	-10.052
HOKO	-71.025	-1.864	-5.255	-1.515	-2.713	-1.064	-0.625	-40.240	1.965	-22551.200	-34594.300	nil
IRE	-15.340	-0.877	-3.638	-9.927	-3.659	-0.371	-0.878	5.452	-5.276	8.068	-299.313	64.957
ITLY	-7.729	0.145	0.409	2.085	0.639	-0.056	0.048	-2.278	1.371	-40.932	-439.770	-139.383
JAP	-5.291	0.217	0.601	0.636	0.427	0.027	0.114	-1.446	1.300	-340.168	-267.668	-1883.160
KORA	-49.432	-0.523	-2.140	-2.895	-1.544	-0.205	-0.402	-0.189	-1.389	-48.458	-36.126	-725.800
MEX	-3.827	-0.391	-1.471	-1.576	-1.057	-0.164	-0.156	0.430	-1.769	11.776	5.026	0.412
NETH	-9.527	-1.297	-0.862	-2.797	-1.251	-0.270	-0.486	7.698	-3.906	44.184	-1116.770	261.286
NOR	-13.199	-7.012	-6.010	-8.667	-9.025	-2.431	-2.666	-2.796	-9.903	-154.257	95.430	280.826
PLIP	-15.801	-0.286	-1.016	-0.629	-1.511	-0.231	-0.183	0.071	-1.209	10.109	-9.105	-26.034
PORT	-22.926	-0.700	-2.893	-4.122	-1.475	-0.470	-0.290	-0.971	-0.314	-31.318	13.925	-42.311
SPAN	-14.022	-1.257	-2.618	-7.127	-1.913	-0.652	-0.528	-0.473	-1.808	-6.058	-27.616	-8.683
SWE	-0.328	-0.561	-0.385	-1.192	-0.996	-0.663	-0.394	-4.437	0.524	-69.982	29.720	7.034
SWIT	-9.080	-1.718	0.470	-0.568	-0.190	-0.453	-0.285	-12.491	-1.195	-910.815	-414.534	-38.934
UK	-15.573	-1.575	-0.152	-0.842	-0.480	-0.618	-0.364	-31.837	-0.520	-323.253	-2701.830	-106.948
US	0.733	0.998	1.035	0.418	0.698	0.471	0.276	6.976	0.819	20.157	-22.520	-0.430
YUG	-6.128	-0.204	-0.687	-1.611	-0.886	-0.383	-0.209	0.097	-0.473	-1.317	-0.888	10.306

\* Factor content data are for 1967, endowment data are for 1966.

services of its capital stock, .99% of the services of its labor force and 1.03% of the services of its professional/technical workers. Thus, among these resources, U.S. trade reveals the United States to be most abundant in professional/technical workers, labor and then capital. Among all resources, however, the United States is revealed most abundant in arable land; only forest and pasture land are revealed to be scarce.<sup>10</sup>

Leamer (1980) computed these factor content ratios using Leontief's 1956 data and found the United States to be abundant in capital compared to labor, thus reversing Leontief's paradoxical finding. The Leontief paradox is evident in Table 2 since trade reveals labor to be more abundant than capital whereas the ordering of U.S. resource abundance ratios (not shown) indicates the opposite. This result, and others like it, allows us to reject the Heckscher-Ohlin theorem using a rank test.

Another contradictory finding is that while the U.S. is a net exporter of labor services, the U.S. share of world labor does not exceed its consumption share ( $s_i$ ) even after adjusting for trade imbalance. Brecher and Choudhri (1982) point out that this form of the Leontief paradox also exists in Leontief's 1956 data. This result, and others like it, allows us to reject the Heckscher-Ohlin theorem using a sign test.

One obvious anomaly in Table 2 is that Denmark's data reveal the seemingly impossible result that it exports 1,634% of the services of its pasture land and 690% of the services of its forest land. This likely reflects problems in applying U.S. input-output coefficients to other countries. Denmark is a substantial exporter of agricultural products and the U.S. input coefficients apparently

overstate the amount of pasture land used per unit of output in Denmark. The formal data analysis conducted below will test the assumption of identical input coefficients and it is clear that this sort of evidence suggests that assumption (A3) is likely to be rejected.<sup>11</sup>

Formal measures of the conformity of the net export data in Table 2 with the factor abundance data are reported in Tables 3 and 4. The first column of Table 3 lists the frequency of sign matches between net factor exports and excess factor supplies for each factor. The first column of Table 4 lists comparable frequencies for each country. For example, the sign of net capital exports and of excess capital supplies matched in fifteen of the twenty-seven countries.

In general, the proposition of conformity in sign between factor contents and excess factor supplies receives little support when tested for each factor (Table 3). The frequency of sign matches exceeds fifty percent for only seven of the twelve factors. Among these, pasture land has the most sign matches with twenty-one of twenty-seven. The three land variables, the most immobile of the resources considered, provide the greatest support for the sign proposition. However, the hypothesis of independence between the sign of the factor contents and of the excess factor supplies can be rejected (results not shown) at the 95% level for only one resource: pasture land.

The sign proposition also receives weak support when tested for each country (Table 4). The proportion of sign matches equals or exceeds seventy-five percent for only seven out of twenty-seven

Table 3

Sign and Rank Tests, Factor by Factor

<u>FACTOR</u>	<u>SIGN TEST<sup>a</sup></u>	<u>RANK TEST<sup>b</sup></u>
Capital	15	.346 <sup>c</sup>
Labor	14	-.249
Prof/Tech	6	-.363 <sup>c</sup>
Managerial	16	-.166
Clerical	10	-.134
Sales	12	-.337 <sup>c</sup>
Service	12	-.432 <sup>c</sup>
Agricultural	18	.123
Production	11	-.072
Arable	19	.680 <sup>c</sup>
Pasture	21	.716 <sup>c</sup>
Forest	18	.524 <sup>c</sup>

---

<sup>a</sup> Frequency of sign matches between net trade in factor and excess supply of factor among 27 countries.

<sup>b</sup> Coefficients of rank correlation.

<sup>c</sup> Sign of correlation significant at least at 5 percent level.

Table 4

Sign and Rank Tests, Country by Country

<u>COUNTRY</u>	<u>SIGN TEST<sup>a</sup></u>	<u>RANK TEST<sup>b</sup></u>
Argentina	7	.23
Australia	7	.009
Austria	6	.34
Belgium-Luxemburg	9	.52 <sup>c</sup>
Brazil	5	.82 <sup>c</sup>
Canada	9	.41
Denmark	6	-.73
Finland	10	.60 <sup>c</sup>
France	9	.54 <sup>c</sup>
Germany	7	.64 <sup>c</sup>
Greece	5	.55 <sup>c</sup>
Hong Kong	6	.91 <sup>c</sup>
Ireland	6	.29
Italy	6	.48
Japan	11	.76 <sup>c</sup>
Korea	2	.83 <sup>c</sup>
Mexico	5	.89 <sup>c</sup>
Netherlands	6	-.29
Norway	10	.009
Philippines	3	.15
Portugal	3	.38
Spain	6	.07
Sweden	8	.64 <sup>c</sup>
Switzerland	9	.58 <sup>c</sup>
United Kingdom	8	.77 <sup>c</sup>
United States	1	.55 <sup>c</sup>
Yugoslavia	2	.12

<sup>a</sup> Frequency of sign matches between net trade in factor and excess supply of factor among twelve factors.

<sup>b</sup> Coefficients of rank correlation (excludes total labor).

<sup>c</sup> Sign of correlation significant at least at 5 percent level.

countries. Moreover, the hypothesis of independence of signs is rejected (95% level) only for Japan.<sup>12</sup>

The sign proposition deals with the abundance of a resource compared with a price weighted average of other resources (the consumption share  $s_i$ ), but we can also compare resources two at a time. For example, the data in Table 2 indicate the United States is more abundant in labor than capital, yet the U.S. resource share data indicate the opposite. The many possible pairwise comparisons are summarized by the rank proposition which states that the order of the data in Table 2 and the order of the resource abundance ratios conform.

As indicated in Tables 3 and 4, support for this rank proposition is also mixed.<sup>13</sup> The hypothesis of a zero or negative rank correlation is rejected (95% level) for only four resources (capital and the three land variables). All but one of the correlations (agricultural workers) associated with the labor variables are of the wrong sign. However, when tested country by country (Table 4), the rank proposition receives stronger support; twenty-six of the twenty-seven correlations are of the expected sign and of these, fourteen are significant (5% level).

Overall, the tests of the sign and rank propositions are something of a disaster for the H-O-V model. The one hopeful finding is that the rank proposition works rather well when tested country by country. This suggests something is affecting all the data for each country similarly since adding a number that is constant within a country to the data would not affect the country rank test results but would destroy the other three tests. Possible sources of this kind of problem are differences in factor

input matrices across countries and measurement errors in factor consumption; the latter due either to a violation of the assumption of proportional consumption or to errors in measuring the consumption share.<sup>14</sup>

The tradition since Leontief's study has been to examine only propositions concerning factor rankings. But as shown in Section II, the H-O-V model actually implies an equality between factor contents and resource supplies and it is the study of this equation to which we now turn. This has the advantage that it allows explicit and relatively easy consideration of nonproportional consumption, various forms of measurement error and technological differences.

In Section III hypotheses were stated which allowed one form of nonproportional consumption, various forms of measurement error and one form of technological differences. To test these hypotheses, observations on factor contents, resource supplies and population were used to estimate (17) under each hypothesis using either the iterative maximum likelihood or the dummy variables procedure. Table 5 reports information on the performance of each hypothesis.

The second column of Table 5 indicates that the value of the error sum-of-squares (ESS) for each hypothesis. The ESS is of course smallest for the least restricted model (HG), although hypotheses H3 and H7 do almost as well. The corresponding log-likelihood values are reported in the next column. Conventional hypothesis testing would compare the difference between these log-likelihood values with  $\chi^2$  values at arbitrarily selected levels of





significance. For example, the  $\chi^2$  statistic for testing H3 against the null is 52 ( $= -18.4 - (-70.4)$ ) which would be compared against a number like 33.92, the upper 5% of a  $\chi^2$  random variable with 22 degrees of freedom (the number of restrictions). The suggested conclusion is then that the restrictions embodied in hypothesis H3 can be rejected in comparison with the unrestricted model HG. But this kind of treatment inadequately deals with the power of the test which is inappropriately allowed to grow with the sample size while the significance level is held fixed. This emphasis on power leads to tests that avoid type II errors merely by rejecting the alternative hypothesis and creates a serious tendency to reject restrictions as the sample size grows. This problem is alleviated here through the use of the asymptotic Bayes factor (16), which has a certain arbitrariness in construction, but nonetheless has the effect of lowering the significance level as the sample size grows and thus maintains some reasonable relationship between the significance level and the power.

The fifth column of Table 5 reports the log-likelihood values adjusted for the dimensionality of the parameter space according to (15). A constant has been added to these numbers so that they are all nonnegative. The corresponding Bayes factors (or odds ratios) are reported in the last column. Hypothesis H3 emerges as the clear winner. The unrestricted model HG is the closest, although far behind H3. The other hypotheses are essentially "impossible" given the data evidence. Such extreme values for the Bayes factors are not uncommon, and should probably be viewed with suspicion since they depend on a number of assumptions, normality being a

potentially important example.

The clearly favored hypothesis H3 allows neutral differences in factor input matrices, biased measurements of factor contents and multiplicative errors in the endowments,<sup>15</sup> but maintains the assumptions of identical homothetic tastes and complete coverage of countries. Hypothesis H7, which weakens H4 by allowing for incomplete coverage of countries, is the third best hypothesis. The second best is HG, the unrestricted model.

The parameters of the model estimated under hypothesis H3 are reported in Tables 6a and 6b. The hypothesis that  $\delta_i = 1$  can be rejected for all but two countries (Australia and Mexico) and for eight countries, the estimates of  $\delta_i$  are of the wrong sign. Moreover, these parameters are the factors that divide the U.S. input matrix to produce a factor input matrix for the selected country. Numbers in excess of one indicate countries with factors that are more productive than the United States. Overall, the great dispersion of the estimates of  $\delta_i$ , particularly the negative values, is cause for alarm.

Although the assumption of factor price equalization is not explicit in our analysis, the performance of hypothesis H3 together with the results shown in Tables 6a could be taken as evidence against the hypothesis of factor price equalization. The possibility of factor price differences might help explain the variability in the estimates of  $\delta_i$  since such differences would imply non-neutral differences in factor input matrices. We intend to examine the possibility of non-neutral technological differences in later research.

The estimates reported in Table 6b are also cause for concern.

**Table 6a**

H-O-V Regressions<sup>a</sup>  
Country Coefficients  
Hypothesis H3

Country	$\delta^b$	Std. Err.	t-Stat <sup>c</sup>
Argentina	1.5769	0.0941	6.129
Australia	1.1315	0.0751	1.751
Austria	3.9479	0.8720	3.380
Belgium-Luxembourg	-7.1774	2.7668	-2.955
Brazil	0.1327	0.0474	-18.281
Canada	0.9431	0.1225	-0.463
Denmark	7.2536	0.6196	10.092
Finland	4.4885	0.2966	11.758
France	-0.7803	0.7591	-2.345
Germany	-16.9248	2.0573	-8.712
Greece	6.1582	0.2809	18.357
Hong Kong	-174.4016	24.7673	-7.081
Ireland	13.4523	0.4147	30.024
Italy	-1.5930	0.7419	-3.494
Japan	-21.3424	2.2211	-10.059
Korea	3.0928	0.2646	7.906
Mexico	1.1999	0.1121	1.782
Netherlands	18.5644	3.2888	5.340
Norway	13.0655	0.8802	13.706
Philippines	2.2965	0.1057	12.258
Portugal	1.9940	0.1640	6.060
Spain	0.3709	0.2131	-2.950
Sweden	2.9687	0.7193	2.736
Switzerland	-16.2249	5.0798	-3.390
United Kingdom	-17.4481	2.0614	-8.949
United States	1.0000	NA	NA
Yugoslavia	1.7798	0.1524	5.115

<sup>a</sup> Number of observations = 297.

<sup>b</sup> Values divided by estimate for the United States ( $\delta_{us} = 1.0012$ ).

<sup>c</sup> Asymptotic t-values for testing  $\delta = 1$ .

**Table 6b**

H-O-V Regressions  
 Factor Coefficients  
 Hypothesis H3

Resource	Parameters	
	$\alpha$	$\gamma^b$
Capital	-990620794 (-6.665)	13.431 (2.142)
<u>Labor:</u>		
Agricultural	-7853 (-1.376)	13.631 (2.721)
Clerical	-4628 (-1.426)	-1.111 (-0.386)
Prof/Tech	-4376 (-1.866)	-0.360 (-0.128)
Managerial	-1815 (-1.587)	-0.528 (-0.370)
Production	-19608 (-1.997)	-2.671 (-2.152)
Sales	-1214 (-0.515)	0.216 (0.175)
Service	-1302 (-0.498)	0.053 (0.052)
<u>Land:</u>		
Arable	-2570651 (-62.891)	1718.648 (52.545)
Forest	-2454843 (-21.263)	833.206 (20.427)
Pasture	-202638 (-2.275)	199.930 (9.163)

<sup>a</sup> Asymptotic t-values in parentheses.

<sup>b</sup> Values of  $\gamma$  are times 1,000.

Table 7a

H-O-V Regressions<sup>a</sup>  
Country Coefficient  
Hypothesis HG

Country	$\delta^b$	Std. Err.	t-Stat <sup>c</sup>
Argentina	0.8591	0.0445	-3.1662
Australia	0.6659	0.0364	-9.1796
Austria	2.9930	0.4109	4.8510
Belgium-Luxembourg	-1.3253	1.3137	-1.7700
Brazil	0.1001	0.0205	-43.9369
Canada	0.5825	0.0545	-7.6662
Denmark	4.4952	0.2952	11.8398
Finland	2.4707	0.1318	11.1555
France	0.0477	0.3617	-2.6324
Germany	-7.5203	0.9775	-8.7166
Greece	3.4483	0.1333	18.3691
Hong Kong	-25.8389	8.0610	-3.3295
Ireland	7.9279	0.1982	34.9619
Italy	-0.5149	0.3538	-4.2820
Japan	-9.0437	1.0061	-9.9828
Korea	1.0444	0.1264	0.3510
Mexico	0.6201	0.0524	-7.2501
Netherlands	11.9176	1.5632	6.9843
Norway	7.2010	0.3894	15.9236
Philippines	0.9829	0.0509	-0.3359
Portugal	1.1759	0.0778	2.2600
Spain	0.2554	0.1016	-7.3306
Sweden	2.2638	0.3197	3.9524
Switzerland	-2.7211	2.3625	-1.5751
United Kingdom	-8.0380	0.9833	-9.1913
United States	1.0000	na	na
Yugoslavia	0.9198	0.0724	-1.1070

<sup>a</sup> Number of observations = 297.

<sup>b</sup> Values divided by estimate for the United States (= .95528).

<sup>c</sup> Asymptotic t-values for testing that parameter is unity.

**Table 7b**

H-O-V Regressions  
Factor Coefficients  
Hypothesis HG

Resource	Parameters <sup>a</sup>			
	$\alpha$	$\gamma^b$	$\theta$	$\beta$
Capital	-959766253 (-6.65)	4.3834 (1.84)	-7478.2571 (-0.76)	-1623.9604 (-0.86)
<u>Labor:</u>				
Agricultural	-14638 (-2.56)	5.6033 (3.70)	-0.8165 (-2.03)	0.1235 (1.65)
Clerical	-3828 (-1.22)	-0.5550 (-0.39)	-0.0431 (-0.20)	-0.0013 (-0.03)
Prof/Tech	-4143 (-1.82)	-0.2470 (-0.17)	-0.0262 (-0.17)	0.0015 (0.05)
Managerial	-1660 (-1.48)	-0.3309 (-0.39)	-0.0107 (-0.14)	-0.0003 (-0.02)
Production	-14611 (-1.51)	-1.6056 (-2.16)	-0.0844 (-0.13)	-0.0204 (-0.17)
Sales	-1059 (-0.46)	0.1524 (0.22)	-0.0264 (-0.17)	0.0012 (0.039)
Service	-1151 (-0.45)	0.0455 (0.08)	-0.0159 (-0.09)	0.0002 (0.006)
<u>Land:</u>				
Arable	-2956567 (-78.34)	328.3365 (59.03)	41.2827 (15.75)	-3.5280 (-7.01)
Forest	-1560720 (-13.85)	179.9216 (25.24)	-40.9301 (-5.17)	-13.1333 (-8.64)
Pasture	-208920 (-2.38)	33.6311 (9.83)	-7.3932 (-1.23)	1.5352 (1.32)

<sup>a</sup> Asymptotic t-values in parentheses.

<sup>b</sup> Values of  $\gamma$  and  $\theta$  are times 1,000; values for  $\beta$  are times 100,000.

The predicted values of the factor supplies can be found by inserting the observed values into these estimated equations. A negative value of  $\gamma_i$  indicates that the observed endowment and the 'corrected' endowment are negatively correlated. This happens for four of the labor endowments, although three of these coefficients have large enough standard errors that the sign remains in doubt. This leaves only production workers as the anomaly: the number of production workers embodied in trade is negatively related with the measured number of production workers.

Finally, Tables 7a and 7b report the parameters estimated under the general hypothesis HG. The results are similar to those reported for hypothesis H3 in that the estimates of  $\delta_i$  show considerable variation and the signs and levels of significance of the parameters  $\gamma_k$  parallel those shown in Table 6b.

Overall, we conclude that differences in factor input matrices and measurement errors are significant reasons for rejection of the H-O-V hypotheses concerning the value of the parameter linking factor contents and national resource supplies, and thus also rejection of the sharp hypothesis contained in the rank and sign propositions considered previously. However, our evidence does support the assumptions of proportional consumption<sup>16</sup> and complete coverage of countries.

## V. Concluding Remarks

This paper conducted conceptually correct tests of the Heckscher-Ohlin proposition that trade in commodities can be

explained in terms of an interaction between factor input requirements and factor endowments. An exact specification of this interaction in a multicountry, multicommodity, multifactor world was derived in the form of the Heckscher-Ohlin-Vanek (H-O-V) theorem which equates the factors embodied in net trade to excess factor supplies. This theorem implies sign and rank propositions analogous to those implicitly studied by Leontief, but it also implies hypotheses about the parameters linking factor contents and factor supplies. Tests of the sign and rank propositions as well as several parametric hypotheses which allow various assumptions about measurement errors, nonproportional consumption and technological differences were conducted in a sample of twenty-seven countries and twelve factors using 1967 trade and input requirements data and 1966 endowment data.

The Leontief type sign and rank propositions were generally not supported. The sign of net factor exports infrequently predicts the sign of excess factor supplies and therefore does not systematically reveal factor abundance. However, within individual nations, the ranking of net factor exports does predict the ranking of factor supplies fairly well. Differences in the results obtained when the sign and rank propositions were tested for each factor and then for each country suggested bias due to measurement errors may be important.

A more general regression analysis made the possibility of measurement errors in the data explicit and permitted the formulation of several alternative hypotheses implied by the H-O-V theorem. Among these, ten hypotheses which allow nonproportional consumption, specific forms of measurement error, and neutral



differences in technology across countries were subjected to test.

The results obtained in this framework do not support the H-O-V hypothesis of an exact relationship between factor contents and national factor supplies. Our estimates suggest the parameter linking factor contents and national factor supplies departs significantly from the value implied by the H-O-V theorem. We conclude there is clear evidence that the departure of the estimated coefficient from its theoretical value is importantly related to 1) differences across countries in the matrix of factor inputs and, by implication, the violation of the assumption of factor price equalization and 2) errors of measurement in both trade and national factor supplies. However, we find little evidence of nonproportional consumption of the type considered here. Further work is required to determine whether rejection of the H-O-V theorem's parametric hypotheses reflects nonproportionality in consumption, measurement error, or differences in technology of a form different than that considered here.

## Footnotes

<sup>1</sup> An exception is Harkness (1978 and 1983) who tests the H-O-V sign and rank propositions (see below) by comparing measured factor contents with excess factor supplies that are inferred from coefficients estimated by regressing factor contents on input requirements. This analysis is suspect, however, since the regression estimates need not correspond either in sign or rank to a country's true excess factor supplies. See Leamer and Bowen (1981).

<sup>2</sup> Maskus (1986) reports conceptually correct tests of this interpretation of the H-O theorem with respect to the United States using 1958 and 1972 data.

<sup>3</sup> If factor prices are equalized,  $s_i$  can be derived by premultiplying (2) by the vector of factor prices. If factor prices are unequal, (2) can still be premultiplied by the vector of factor prices prevailing in country  $i$  to obtain an expression analogous to (3) but with both internal and external factor earnings evaluated only in terms of country  $i$ 's factor prices.

<sup>4</sup> If factor prices are equalized, the consumption share is a weighted average of other resources:  $s_i = \sum_k E_{ki} (w_k / \sum_k w_k E_{kw})$  where  $w_k$  is the world price of factor  $k$  and trade balance is assumed. Thus, if the left and right hand sides of (5) conform in sign, the trade data can be said to accurately reveal the abundance of a resource compared with other resources on the average.

<sup>5</sup> Scaling by  $s_i$  not be necessary if resources are measured in the same units.

<sup>6</sup> In the sense that complete information on each country's preferences would be required to determine trade.

<sup>7</sup> Equation (6) is based on the Linear Expenditure System.

<sup>8</sup> This specification was chosen after testing it against the more general specification which sets  $\gamma_k = \pi_k + \mu_k$  where  $\pi_k$  and  $\mu_k$  are unknown constants.

<sup>9</sup> This scaling ignores that M2' and M3' imply  $S_{ki}$  could be measured with error. The  $E_{kw}$  were simply the only available data that could be used to render the measurements of the endowments unit free.

<sup>10</sup> Harkness (1978, Table 3) reports similar numbers for the United States based on 1958 data and obtained a ranking similar to that shown here.

<sup>11</sup> Alternatively, these anomalous data values may reflect substantial errors of measurement in either the factor contents or endowments.

<sup>12</sup> No variation was observed in the sign of net factor exports of Austria, Korea and Spain (each factor was imported) and no variation was observed in the sign of the excess factor supplies of Denmark and the United States (each was negative).

<sup>13</sup> Both the factor content and factor supply data were scaled by  $s_i E_{kw}$  before ranking. This scaling is necessary since the resources are measured in different units.

<sup>14</sup> To examine whether errors in measuring factor consumption might reflect errors in measuring each country's GNP, each country's consumption share was computed using data (Summers, et. al., 1980) on its real GDP corrected for purchasing power parity. In no case did the use of these data reverse the sign of a country's excess factor supplies.

<sup>15</sup> To indicate the extent of measurement error in the endowments we compared measured U.S. endowments with the amount of each factor absorbed directly and indirectly in producing the 1967 vector of U.S. final demand in both manufacturing and services (a total of 354 sectors). The ratio of the amount absorbed in production to the endowment for each factor was: capital 2.1; total labor, .88; prof/tech, .62; managerial, .45; clerical, .92; sales, 1.41; service, .68; agricultural, .98; production, .99. The discrepancy for capital likely reflects that the depreciation rate used to compute an industry's capital stock was lower than the rate used to compute the national capital stock. The discrepancy for managerial workers likely reflects the exclusion of government employees in calculating industry input requirements.

<sup>16</sup> This finding contrasts Horiba's (1979) conclusion from his analysis of the proportional consumption assumption using data on U.S. regional trade. Using a specification similar to ours, his analysis rejected the assumption's hypothesis concerning the value of  $\beta_x$ .

## Data Appendix

Data on trade and factor endowments were collected for twenty-seven countries in 1966. The twelve resources are: capital, total workers, professional/technical workers, managerial workers, sales workers, service workers, agricultural workers, production workers, arable land, pasture land and forest land.

The total content (direct plus indirect) of each factor embodied in net trade was calculated by premultiplying each country's net trade vector by a matrix of total factor input requirements. Total factor input requirements were calculated from data on direct and intermediate factor input requirements for each industry according to the 367 order U.S. input-output table for 1967. Data on each country's trade in 1967 were first taken from the U.N. Trade Tapes at the four and five digit level of the SITC and then concorded to the input-output sectors in order to perform the required vector multiplications.

On the production side, capital (plant, equipment and inventories) inputs were based upon data prepared by the Bureau of Labor Statistics Economic Growth Project which provided capital stock figures measured in 1958 dollars. Labor data, measured in number of persons, were derived from the 1971 Survey of Occupational Employment and the 1970 Census of Population. These data were reclassified, to the extent possible, to be consistent with the occupational categories at the one digit level of the ILO's International Standard Classification of Occupations. Sveikauskas (1983, Appendix) describes the sources of factor input data in greater detail.

Land inputs were constructed from information contained in the U.S. input-output table. Arable land is defined as proportional to total purchases from I/O sector 2; pasture land as proportional to total purchases from I/O sector 1 and forest land as proportional to total purchases from I/O sector 3 (which includes fisheries). This method of measuring land (natural resource) inputs corresponds to a rent definition of quantity and has been used by Baldwin (1971) and Harkness (1978) among others.

Factor endowment data were taken from Bowen (1980 and 1983) with one exception. Since land input coefficients are measured in dollars, each land endowment from Bowen was multiplied by an imputed price so as to measure land endowments in monetary units. Prices were imputed by dividing the total value of each type of land input absorbed in producing total U.S. output in 1967 by the corresponding U.S. endowment of each type of land in 1966. The prices, in 1967 dollars, are: arable land, \$142.767 per hectare; pasture land, \$108.942 per hectare; forest land, \$5.6882 per hectare.

## References

- R. Baldwin, "Determinants of the Commodity Structure of U.S. Trade," American Economic Review, March 1971, 61, 126-46.
- H. Bowen, "Changes in the International Distribution of Resources and Their Impact on U.S. Comparative Advantage," Review of Economics and Statistics, August 1983, 65, 402-14.
- \_\_\_\_\_, "Resources, Technology and Dynamic Comparative Advantage: A Cross-Country Test of the Product Cycle Theory of International Trade," Ph.D. dissertation, UCLA, 1980.
- W. Branson and N. Monoyios, "Factor Inputs in U.S. Trade," Journal of International Economics, May 1977, 7, 111-31.
- R. Brecher and E. Choudhri, "The Leontief Paradox, Continued," Journal of Political Economy, 90, August 1982, 820-23.
- H. Chenery and M. Syrquin, Patterns of Development, 1950-1970, (New York and London: Oxford University Press for World Bank).
- J. Harkness, "Factor Abundance and Comparative Advantage," American Economic Review, December 1978, 68, 784-800.
- \_\_\_\_\_, "The Factor-Proportions Model with Many Nations, Goods and Factors: Theory and Evidence," Review of Economics and Statistics, 65, May 1983, 298-305.
- Y. Horiba, "Testing the Demand Side of Comparative Advantage Models," American Economic Review, December 1979, 69.
- E. Leamer, Sources of International Comparative Advantage: Theory and Evidence, (Cambridge: MIT Press), 1984.
- \_\_\_\_\_, "The Leontief Paradox Reconsidered," Journal of Political Economy, 1980, 88(3), 495-503.
- \_\_\_\_\_, Specification Searches, (New York: John Wiley & Sons), 1978.
- \_\_\_\_\_, "The Commodity Composition of International Trade in Manufactures: An Empirical Analysis," Oxford Economic Papers, November 1974, 26, 350-74.
- \_\_\_\_\_ and H. Bowen, "Cross-Section Tests of the Heckscher-Ohlin Theorem: Comment," American Economic Review, December 1981, 71, 1040-43.
- W. Leontief, "Domestic Production and Foreign Trade: The American Capital Position Re-Examined," Proceeding of the American Philosophical Society, 1953, 97, 332-49.

- K. Maskus, "A Test of the Heckscher-Ohlin-Vanek Theorem: The Leontief Commonplace," Journal of International Economics, forthcoming, 1986.
- R. Stern and K. Maskus, "Determinants of U.S. Foreign Trade, 1958-76," Journal of International Economics, 1981, 11(2), 207-24.
- R. Summers, I. Kravis and A. Heston, "International Comparisons of Real Product and its Composition: 1950-1977," The Review of Income and Wealth, March 1980, 19-60.
- L. Sveikauskas, "Science and Technology in United States Foreign Trade," Economic Journal, September 1983, 93, 542-54.
- G. Schwarz, "Estimating the Dimension of a Model," Annals of Statistics, 6, 461-64.
- Y. Vanek, "The Factor Proportions Theory: The N-Factor Case," Kyklos, October 1968, 21, 749-55.