Multicountry, Multifactor Tests of the Factor Abundance Theory

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The Heckscher-Ohlin-Vanek model predicts relationships among industry input requirements, country resource supplies, and international trade in commodities. These relationships are tested using data on twelve resources, and the trade of twenty-seven countries in 1967. The Heckscher-Ohlin propositions that trade reveals gross and relative factor abundance are not supported by these data. The Heckscher-Ohlin-Vanek equations are also rejected in favor of weaker models that allow technological differences and measurement errors.

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 two × two 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×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 Edward Leamer (1980) and Leamer and Harry Bowen (1981). We use a valid multidimensional extension of the two × 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-V 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 Wassily 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 (for example, Robert Baldwin, 1971; William Branson and Nicholas Monoyios, 1977; Jon Harkness, 1978, 1983; Robert Stern and Keith Maskus, 1981). If the estimated coefficient of some factor is posi-

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tive, 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.[1]

A third approach used to study the sources of comparative advantage involves regression of net exports of a single commodity for many countries on measures of national factor supplies (Bowen, 1983; Hollis Chenery and Moses Syrquin, 1975; and Leamer, 1974, 1984). These papers use no measures of factor input requirements and they study the weakened hypothesis that the structure of trade can be explained by the availability of resources. This contrasts with the stricter H-O-V hypothesis studied here that factor supplies, factor input requirements, and trade fit together in a special way.

The present study computes the amount of each of twelve factors embodied in the net exports of 27 countries in 1967, using the 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 predictions of the H-O-V theory.

We first test the traditional interpretation of the H-O hypothesis that trade reveals relative factor abundance.[2] 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 offer little support for this facet of the H-O-V model. Several types of measurement error could account for these results. 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 consumer's preferences, technological differences, and various forms of measurement error.

Overall, our results do not support the H-O-V hypothesis of an exact relationship between factor contents and 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. The data suggest that the poor performance of the H-O-V hypothesis is importantly related to measurement error in both trade and national factor supplies across countries, and the data favor a model that allows neutral differences in factor input matrices across countries.

I. 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.

$$\mathbf{A}_i\mathbf{T}_i = \mathbf{A}_i\mathbf{Q}_i - \mathbf{A}_i\mathbf{C}_i, \quad (1)$$

where $\mathbf{A}_i = K \times N$ matrix of factor input requirements which indicate the total (direct plus indirect) amount of each of K factors needed to produce one unit of output in each of N industries,

$\mathbf{T}_i = N \times 1$ vector of net trade flows of country i,

$\mathbf{Q}_i = N \times 1$ vector of country i's final outputs,

$\mathbf{C}_i = N \times 1$ vector of country i's final consumption.

Full employment implies $\mathbf{A}_i\mathbf{Q}_i = \mathbf{E}_i$, where $\mathbf{E}_i$ is the $K \times 1$ vector of country i's factor

[1]An exception is Jon Harkness (1978, 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 estimated coefficients need not correspond either in sign or rank to a country's true excess factor supplies. See Leamer and Bowen (1981).

[2]Maskus (1985) reports conceptually correct tests of this interpretation of the H-O-V theorem for the United States using 1958 and 1972 data.

supplies. Thus, the vector of factors embodied in net trade is

$$\mathbf{A}_i\mathbf{T}_i = \mathbf{E}_i - \mathbf{A}_i\mathbf{C}_i. \tag{2}$$

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

(A1) Assumption 1: *All individuals face the same commodity prices.*

(A2) Assumption 2: *Individuals have identical and homothetic tastes.*

(A3) Assumption 3: *All countries have the same factor input matrix*, $\mathbf{A}_i = \mathbf{A}$.

Ordinarily, the assumption of identical input matrices (A3) would be replaced by the assumption of factor price equalization and internationally identical technologies. 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 therefore produce different subsets of commodities.

Assumptions (A1) and (A2) imply that the consumption vector of country i is proportional to the world output vector ($\mathbf{Q}_w$), $\mathbf{C}_i = s_i\mathbf{Q}_w$, where s_i is country i's consumption share. The consumption share can be derived by premultiplying the net trade identity ($\mathbf{T}_i = \mathbf{Q}_i - s_i\mathbf{Q}_w$) by the vector of common goods prices

$$s_i = (Y_i - B_i)/Y_w, \tag{3}$$

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.[3]

If, in addition, the factor input matrices are identical, we can write $\mathbf{A}_i\mathbf{C}_i = s_i\mathbf{A}\mathbf{Q}_w = s_i\mathbf{E}_w$, where $\mathbf{E}_w = \Sigma_i\mathbf{E}_i$ is the $K \times 1$ vector of world factor supplies. Then, (2) can be written as

$$\mathbf{A}\mathbf{T}_i = \mathbf{E}_i - \mathbf{E}_w(Y_i - B_i)/Y_w. \tag{4}$$

Equation (4) specifies an exact relationship between factor contents and factor endowments. This relationship can be tested by measuring the net export vector $\mathbf{T}_i$, the factor input matrix $\mathbf{A}$, and the excess factor supplies $\mathbf{E}_i - s_i\mathbf{E}_w$, 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. In Section II 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. In Section III we then report tests against alternatives involving nonproportional consumption, measurement errors, and differences in input matrices.

Our analysis uses data on the 367-order U.S. input-output table for 1967, and the 1967 trade and the 1966 supply of twelve resources for 27 countries.[4] The countries are those for which both occupational data and detailed trade data were available. The twelve resources are net capital stock, total labor, professional/technical workers, managerial workers, clerical workers, sales workers, service workers, agricultural workers, production workers, arable land, pastureland, and forestland.

Net capital stocks were computed as the sum of discounted real investment flows in domestic currency and converted to U.S. dollars using 1966 nominal exchange rates. Industry capital requirements (plant, equipment, and inventories) were constructed from data on U.S. industry capital stocks.

The seven labor categories are those defined at the one-digit level of International

[3] If factor prices are equalized, s_i can also 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.

[4] The Data Appendix provides detailed discussion of the data.

Standard Classification of Occupations. Total labor is a country's economically active population. Input requirements for each type of labor were constructed using occupational data from the 1971 *U.S. Survey of Occupational Employment* and the 1970 *U.S. Census of Population*. Labor data are measured in numbers of people.

The three land types conform to the definitions used by the Food and Agricultural Organization. Industry land requirements were based on the U.S. input-output table; I/O sector 1 was used for pastureland, I/O sector 2 was used for arable land, and I/O sector 3 (forest and fisheries) was used for forestland. Land is measured in hectares.

Finally, data on each country's trade in 1967 were obtained at the four- and five-digit level of the Standard International Trade Classification (SITC) and concorded to input-output sectors to perform the required vector multiplications.

II. Tests of Qualitative Hypotheses

The traditional implication of the H-O theory is that factor abundance determines which commodities are exported and which are imported, in other words, the sign of net exports. In this section we report tests of the analogous qualitative implications of the H-O-V equations concerning the sign and ordering of the factor content data.

A typical kth element of (4) can be written as

$$(5)\quad (F_{ki}^A/E_{kw})/(Y_i/Y_w) = [(E_{ki}/E_{kw})/(Y_i/Y_w)]-1,$$

where F_{ki} is the kth element of the factor content vector $\mathbf{F}_i=\mathbf{A}\mathbf{T}_i$, and $F_{ki}^A=(F_{ki}-E_{kw}B_i/Y_w)$ is the factor content if trade were balanced. The quantity on the right-hand side of (5) is a measure of the relative abundance of resource k. If this equation is accurate, the factor content of trade can be used as an indirect measure of factor abundance. We study here two qualitative implications of (5); first, that trade reveals the abundance of resources compared with an average of all resources, and second, that trade reveals the relative abundance of resources.

The income share in (5) is an average of the resource shares weighted by world earnings: $(Y_i/Y_w)=\Sigma_k[w_kE_{ki}/\Sigma_kw_kE_{kw}]=\Sigma_k[(w_kE_{kw})(E_{ki}/E_{kw})/\Sigma_kw_kE_{kw}]$, where w_k is the world price of factor k. If equation (5) is accurate, then the sign of the net trade in factor services, corrected for the trade imbalance, will reveal the abundance of a resource, compared with other resources on the average.[5] This sign proposition is tested for each factor (country) by computing the proportion of sign matches between corresponding elements in each row (column) of the matrix of adjusted factor contents and the matrix of factor abundance ratios. In addition, 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 shares against the alternative of a positive association.

Equation (5) also implies that trade reveals the relative abundance of resources when considered two at a time. If equation (5) is accurate, the adjusted net exports of country i of factor k exceed the adjusted net exports by country i of factor k', $(F_{ki}^A/E_{kw})/(Y_i/Y_w) > (F_{k'i}^A/E_{k'w})/(Y_i/Y_w)$, if and only if factor k is more abundant than factor k', $(E_{ki}/E_{kw})/(Y_i/Y_w) > (E_{k'i}/E_{k'w})/(Y_i/Y_w)$; and the adjusted net exports by country i of

[5] Other definitions of factor abundance are possible. In an earlier version of this paper, we wrote (5) without adjusting the left-hand side for the trade imbalance as $F_{ki}/s_iE_{kw}=(E_{ki}/E_{kw})-s_i$, where s_i is the consumption share $(Y_i-B_i)/Y_w$. In this form the theory can be said to imply that the sign of the net trade in factor services reveals the abundance of a factor compared with the consumption share. Equivalently, the right-hand side of this equation takes the sign of the difference between world output per factor input and the domestic consumption per factor input. This form of comparison is made by Richard Brecher and Ehsan Choudhri (1982) who point out that Leontief's findings of a positive net trade in labor services is inconsistent with the relatively high consumption per worker of the United States. Though this comparison is appropriate, we have opted here for the comparison suggested by equation (5), because it is based on a more appealing notion of factor abundance. See Kohler (1987) for a related discussion.

TABLE 1—RATIO OF ADJUSTED NET TRADE IN FACTOR TO NATIONAL ENDOWMENT

Country	Capital	Labor	Prof/Tech	Manager	Clerical	Sales	Service	Agriculture	Production	Arable	Forest	Pasture
Argentina	1.32	−0.30	−1.64	−2.60	−1.07	−0.62	−0.83	4.30	−1.46	21.24	−6.94	2.40
Australia	−3.77	−0.41	−2.95	−1.79	−1.68	0.21	−0.11	18.10	−3.65	17.15	−13.68	0.80
Austria	−2.03	3.01	2.74	5.64	2.91	3.81	3.20	3.12	2.59	−80.74	13.52	24.35
Bene-Lux	−2.36	1.81	0.88	1.82	1.90	1.36	2.39	−4.26	2.76	−364.25	−922.53	53.27
Brazil	−5.54	−0.27	−0.85	−0.49	−0.82	−0.32	−0.23	−0.04	−0.61	2.10	−0.04	−0.02
Canada	1.82	−3.49	−3.40	−2.23	−4.00	−2.73	−1.88	4.00	−6.84	12.13	6.16	2.84
Denmark	−4.89	5.82	2.37	8.70	4.25	5.08	4.51	24.56	1.21	33.57	803.73	1763.42
Finland	4.69	2.14	0.49	4.22	1.78	1.94	1.89	1.26	3.21	−24.44	30.48	434.70
France	−4.07	0.82	0.70	1.17	1.02	0.90	1.06	0.16	1.04	−21.33	−198.68	1.79
Germany	−1.05	−0.43	1.01	1.34	0.51	−1.08	−1.05	−11.86	2.07	−323.61	−377.64	−124.77
Greece	−5.50	2.93	4.48	14.95	5.37	4.49	4.68	2.20	2.02	46.92	−61.16	1.08
Hong Kong	−46.06	4.52	5.24	3.68	8.10	3.48	3.03	−14.19	6.46	−21568	−30532	−91627216
Ireland	−1.93	6.73	4.49	13.84	7.19	6.10	8.07	10.59	2.67	17.31	−129.98	72.68
Italy	−7.03	0.74	1.25	4.67	1.42	0.39	1.27	−1.73	1.87	−39.91	−431.67	−131.90
Japan	−5.47	0.10	0.44	0.48	0.33	−0.05	−0.03	−1.54	1.18	−341.42	−268.58	−1998.58
Korea	−30.51	0.61	1.53	2.85	1.81	0.76	1.73	0.27	0.85	−42.34	−29.42	1206.60
Mexico	−0.78	0.57	0.19	0.47	0.51	0.80	0.70	0.87	−0.21	12.40	5.69	0.97
Netherlands	−4.56	4.61	3.49	6.36	3.65	4.72	5.53	22.78	1.41	82.74	−719.88	330.86
Norway	−5.54	5.57	3.75	6.15	7.98	10.22	10.58	14.59	−0.06	−125.48	105.96	660.35
Philippines	−13.94	−0.10	−0.59	−0.36	−0.81	0.03	0.06	0.14	−0.81	10.47	−8.43	−17.03
Portugal	−10.31	1.92	3.92	10.85	3.75	2.83	2.72	0.63	2.49	−28.46	24.79	12.03
Spain	−6.19	3.04	4.56	13.88	4.36	4.13	3.89	2.45	2.23	−2.74	−12.00	4.92
Sweden	0.79	1.36	0.59	2.26	1.05	1.09	1.44	−0.66	2.18	−67.23	30.93	48.00
Switzerland	−5.72	3.42	4.46	11.57	3.52	5.42	4.13	−0.79	3.04	−862.95	−352.36	−12.18
UK	−12.86	0.63	1.77	2.04	1.37	1.30	1.32	−18.57	1.11	−313.42	−2573.99	−91.89
US	0.08	−0.25	0.23	−0.11	−0.19	−1.10	−0.68	1.54	−0.34	19.45	−23.82	−1.63
Yugoslavia	−3.15	0.68	0.39	1.59	1.12	2.05	1.15	0.46	0.76	−0.08	2.81	14.24

Note: Numbers in percent. Factor content data are for 1967; endowment data are for 1966.

factor k exceeds the adjusted net exports by country i' of factor k, $(F^A_{ki}/E_{kw})/(Y_i/Y_w) > (F^A_{ki'}/E_{kw})/(Y_{i'}/Y_w)$, if and only if country i is more abundant in factor k than country i', $(E_{ki}/E_{kw})/(Y_i/Y_w) > (E_{ki'}/E_{kw})/(Y_{i'}/Y_w)$. More generally, for each country and factor, the ranking of adjusted net factor exports F^A_{ki}/E_{kw} should conform to the ranking of factors by their abundance. This rank proposition is tested for each country (factor) by computing the Kendall rank correlation between corresponding columns (rows) of the matrix of adjusted factor content and the matrix of factor abundance ratios. In addition, we compute the proportion of correct rankings when the corresponding elements of the columns (rows) of the two matrices are compared two at a time.[6]

Table 1 summarizes the factor content data by listing for each country the ratio of adjusted net exports of each factor in 1967 to the endowment of the corresponding factor in 1966, $100 \times F^A_{ki}/E_{ki}$. According to these data, the United States exports .08 percent of the services of its capital stock, .23 percent of the services of its professional/technical workers but imports labor services amounting to .25 percent of the services of its labor force. Thus, among these resources, U.S. trade reveals the United States to be most abundant in professional and technical workers, capital, and then labor. Among all resources, however, the United States is revealed most abundant in arable land, followed by agricultural workers.

Leamer (1980) computed these factor content ratios using Leontief's 1947 data and found that U.S. trade revealed the United

[6]Subsequent tests of the rank and sign propositions based on the proportion of "successes" do not refer to any specific alternative hypothesis and thus leaves unclear the choice of significance level. Without knowing the proportion of successes expected under a specific alternative hypothesis, judging the relative performance of the H-O-V model is largely impressionistic. The absence of alternative hypotheses when testing the sign and rank propositions is, in large part, the motivation for our subsequent tests of the H-O-V equations in a regression framework.

States to be abundant in capital compared to labor, thus reversing Leontief's paradoxical finding. Likewise, no "Leontief paradox" is evident in Table 1 since the United States exports capital services but imports labor services, and this ordering conforms to the ordering of the U.S. shares of world capital (41 percent) and world labor (22 percent). This result, and others like it, would lead us to accept the H-O theorem on the basis of a rank test.

Although a rank test supports the two-factor version of the H-O theorem for the United States, a contrary finding is that while the United States is a net exporter of capital services, the U.S. share of world income (47 percent) exceeds its share of world capital, which implies that there is a measured scarcity of capital in the United States. This result, and others like it, would lead us to reject the H-O theorem using a sign test.

Some obvious anomalies in Table 1 are that, after adjusting for trade imbalances, Denmark, Finland, Korea, the Netherlands, and Norway export more than 100 percent of the services of their pastureland. These anomalies probably reflect difficulties in applying U.S. input-output coefficients to other countries. For example, Denmark is a substantial exporter of agricultural products and U.S. input coefficients apparently overstate the amount of pastureland used per unit of output in Denmark. The analysis conducted in Section III will formally test the assumption of identical input coefficients, but it is clear from the anomalies in Table 1 that assumption (A3) is not entirely accurate.[7]

Formal tests of the conformity of the adjusted net factor export data (F_{ki}^{A}/E_{kw}) with the factor abundance data $[(E_{ki}/E_{kw})/(Y_i/Y_w)-1]$ are reported in Tables 2 and 3. The first column of Table 2 lists the proportion of sign matches between adjusted net factor exports and the abundance ratios for each factor. The first column of Table 3 lists comparable percentages for each country. For example, the sign of adjusted net capital exports and of excess capital shares matched in 52 percent of the countries.

TABLE 2—SIGN AND RANK TESTS, FACTOR BY FACTOR

Factor	Sign Test[a]	Rank Tests[b]	
Capital	.52	0.140	.45
Labor	.67	0.185	.46
Prof/Tech	.78	0.123	.33
Managerial	.22	−0.254	.34
Clerical	.59	0.134	.48
Sales	.67	0.225	.47
Service	.67	0.282[c]	.44
Agricultural	.63	0.202	.47
Production	.70	0.345[c]	.48
Arable	.70	0.561[c]	.73
Pasture	.52	0.197	.61
Forest	.70	0.356[c]	.65

[a] Proportion of 27 countries for which the sign of net trade in factor matched the sign of the corresponding factor abundance.

[b] The first column is the Kendall rank correlation among 27 countries; the second column is the proportion of correct rankings out of 351 possible pairwise comparisons.

[c] Statistically significant at 5 percent level.

In general, the proposition of conformity in sign between factor contents and excess factor shares receives relatively little support when tested for each factor (Table 2). Although the proportion of sign matches exceeds 50 percent for eleven resources, the proportion of sign matches is 70 percent or greater for only four of the twelve factors with the highest proportion of sign matches for professional and technical workers (78 percent). Moreover, using Fisher's Exact Test, the hypothesis of independence between the sign of the factor contents and of the excess factor shares can be rejected (results not shown) at the 95 percent level for only one resource—arable land.

Similar results are obtained when the sign proposition is tested for each country (Table 3). The proportion of sign matches exceeds 50 percent for 18 countries, and exceeds 90 percent for five countries (Greece, Hong Kong, Ireland, Mexico, and the UK). However, the proportion of sign matches is below 70 percent for 19 of the 27 countries. In addition, the hypothesis of independence

[7] These anomalous data values may also reflect errors of measurement in either the factor contents or endowments. In particular, Denmark and Norway probably export more than 100 percent of their forestland because these countries export fish and fish products, and fisheries are included in the input-output coefficients for forestland.

TABLE 3—SIGN AND RANK TESTS, COUNTRY BY COUNTRY

Country	Sign Tests[a]	Rank Tests[b]	
Argentina	.33	0.164	.58
Australia	.33	−0.127	.44
Austria	.67	0.091	.56
Belgium-Luxembourg	.50	0.273	.64
Brazil	.17	0.673[c]	.86
Canada	.75	0.236	.64
Denmark	.42	−0.418	.29
Finland	.67	0.164	.60
France	.25	0.418	.71
Germany	.67	0.527[c]	.76
Greece	.92	0.564[c]	.80
Hong Kong	1.00	0.745[c]	.89
Ireland	.92	0.491[c]	.76
Italy	.58	0.345	.69
Japan	.67	0.382	.71
Korea	.75	0.345	.69
Mexico	.92	0.673[c]	.86
Netherlands	.58	−0.236	.38
Norway	.25	−0.236	.38
Philippines	.50	0.527[c]	.78
Portugal	.67	0.091	.56
Spain	.67	0.200	.62
Sweden	.42	0.200	.62
Switzerland	.67	0.382	.69
United Kingdom	.92	0.527[c]	.78
United States	.58	0.309	.67
Yugoslavia	.83	−0.055	.49

[a]Proportion of 12 factors for which the sign of net trade in factor matched the sign of the corresponding excess supply of factor.
[b]The first column is the Kendall rank correlation among 11 factors (total labor excluded); the second column is the proportion of correct rankings out of 55 possible pairwise comparisons.
[c]Statistically significant at the 5 percent level.

between the classification of signs is rejected (95 percent level) for only four countries: Greece, Ireland, Hong Kong, and the United Kingdom.[8] Finally, for the entire sample, the proportion of sign matches out of a possible 324 is only 61 percent.

The sign proposition deals with the abundance of a resource compared with a value-weighted average of other resources (that is, Y_i/Y_w), but we can also compare resources two at a time. For example, the data in Table 1 indicate the United States is more abundant in capital than labor while the U.S. resource share data (not shown) also indicate an abundance in capital compared to labor. The many possible pairwise comparisons are summarized by the rank proposition, which states that the order of adjusted factor contents and the order of the resource abundance ratios conform.

Two formal measures of the conformity between the factor content and factor abundance rankings are shown in Tables 2 and 3. The second column in these tables shows the Kendall rank correlation between the rankings while the third column shows the proportion of correct orderings when the comparisons are made two at a time.[9] For example, the results for capital in Table 2 indicate that we cannot reject (5 percent level) the hypothesis of a zero-rank correlation and that the proportion of correct orderings when the ranking between the net exports of capital services and the capital abundance ratios is compared for all pairs of countries is 45 percent.

In general, the rank proposition receives little support when tested for each factor (Table 2). The hypothesis of a zero-rank correlation is rejected (95 percent level) for only four resources (service workers, production workers, arable land, and forestland) and one of the correlations (managerial workers) is of the wrong sign. Little support is also found for the rank proposition when the comparisons are made among all possible pairs of countries. Specifically, the proportion of correct orderings exceeds 50 percent only for the three land variables.

The rank proposition also receives little support when tested country by country (Table 3). The hypothesis of a zero-rank correlation is rejected for only eight of the 27 correlations (95 percent level) and five of the correlations are of the wrong sign. Somewhat greater support is found for the rank proposition when pairwise comparisons are considered: for 22 of the 27 countries, the proportion of correct orderings exceeds 50 percent. That the rank proposition re-

[8]No variation was observed in the sign of factor abundance for Yugoslavia (each was positive).

[9]These proportions are interpreted as the probability, for a given factor (country), that the ranking of factor contents will match the ranking of factor abundance for a randomly selected pair of countries (factors).

ceives relatively more support when tested country by country suggests that something is affecting all the data similarly, since adding a number that is constant within a country would not affect the country rank test results but would alter the other three tests. A possible source of this kind of problem would be differences in factor input matrices across countries.

Overall, the results for the sign and rank propositions offer little support for the H-O-V model. However, the tests of these propositions do not refer to specific alternative hypotheses and may cast doubt on the H-O-V hypothesis for a variety of reasons, including nonproportional consumption, various kinds of measurement error, and differences in factor input matrices. These alternatives can be studied by regressions of factor contents on endowments as described below.

III. Tests of the H-O-V Equations

The tradition since Leontief's study has been to examine only propositions concerning factor rankings. But as shown in Section I, the H-O-V model actually implies an equality between factor contents and resource supplies. A study of this system of equations has the advantage that it allows explicit consideration of alternative hypotheses—a practice that has generally been absent in empirical tests of trade theory. Here we consider three reasons why the H-O-V equations may be inexact: nonproportional consumption, measurement errors, and technological differences.

A. *Alternative Hypotheses*

We first consider an alternative to the assumption of proportional consumption (A2). 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.[10] Instead, we study a specific alternative to assumption A2:

($\tilde{\text{A}}$2) *All individuals have identical preferences with linear Engel curves; within each country, income is equally distributed.*

The modification of (4) implied by ($\tilde{\text{A}}$2) is derived by noting that ($\tilde{\text{A}}$2) implies that 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 and its total expenditure $(Y_i - B_i)$:[11]

$$(7)\quad C_{ij} = \lambda_j L_i + \psi_j\big((Y_i - B_i) - L_i y^0\big),$$

where λ_j = per capita "autonomous" consumption of commodity j,

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

$y^0 = \sum_j \lambda_j$.

Summing (7) over i gives the marginal budget shares ψ_j:

$$(8)\quad \psi_j = (Q_{wj} - \lambda_j L_w)/(Y_w - L_w y^0),$$

where L_w is world population. Inserting (8) into (7) and premultiplying by the kth row of $\mathbf{A}(\mathbf{a}_k)$, the amount of factor k absorbed in consumption $\mathbf{a}_k\mathbf{C}_i$ is

$$(9)\qquad \mathbf{a}_k\mathbf{C}_i = (\varphi_k - \beta_k y^0)L_i + \beta_k Y_i,$$

where

$$\varphi_k = \sum_j a_{kj}\lambda_j,$$

$$\beta_k = \Big(\sum_j a_{kj}Q_{wj} - \sum_j a_{kj}\lambda_j L_w\Big)\Big/(Y_w - L_w y^0),$$

$$\beta_k = (E_{kw} - \varphi_k L_w)/(Y_w - L_w y^0).$$

[10] In the sense that complete information on each country's preferences would be required to determine trade.

[11] Equation (7) is based on the Linear Expenditure System.

Equation (9) implies that equation (4) can be written

$$(10)\qquad \mathbf{F}_i = \mathbf{E}_i - \theta L_i - \beta(Y_i - B_i),$$

where θ and β are $K \times 1$ vectors with elements $\theta_k = (\varphi_k - \beta_k y^0)$ and β_k, respectively. Given (10), assumption (A2) amounts to restricting $\theta = 0$ and $\beta_k = E_{kw}/Y_w$.

Next we allow for measurement errors. We assume measurement of net trade differs from its true value by a constant plus a random error

$$(\tilde{\text{M}}1)\qquad \mathbf{T}_i^m = \omega + \mathbf{T}_i + \mathbf{T}_i^e,$$

where the vector $\mathbf{T}_i^m$ is the measured value of the vector $\mathbf{T}_i$, ω is an $N \times 1$ vector of constants, and $\mathbf{T}_i^e$ is the error vector. The null hypothesis is that there is no measurement error bias

$$(\text{M}1)\qquad \omega = 0.$$

Assumption ($\tilde{\text{M}}1$) implies the factor content vector is also measured with error:

$$(11)\qquad \mathbf{F}_i^m = \mathbf{A}\mathbf{T}_i^m = \mathbf{A}\omega + \mathbf{A}\mathbf{T}_i + \mathbf{A}\mathbf{T}_i^e = \alpha + \mathbf{F}_i + \mathbf{F}_i^e,$$

where $\mathbf{F}_i^m$ is the measured value of $\mathbf{F}_i$, $\alpha = \mathbf{A}\omega$ is a $K \times 1$ vector of unknown constants, and $\mathbf{F}_i^e$ 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:

$$(\tilde{\text{M}}2)\qquad E_{ki} = \gamma_k E_{ki}^m,$$

where E_{ki}^m is the measured value, E_{ki} the true value, and γ_k is a positive error multiplier. The null hypothesis of no measurement errors is

$$(\text{M}2)\qquad \gamma_k = 1 \text{ for all } k.$$

The form of the measurement error contained in ($\tilde{\text{M}}2$) 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

$$(\tilde{\text{M}}3)\qquad E_{kw} = \sigma_{kS} E_{kS}.$$

$$Y_w = \phi_S Y_S.$$

The subscript S refers to the subset of countries in the sample; σ_s is a set of unknown positive elements; and ϕ_s is an unknown positive scalar. The null hypothesis is

$$(\text{M}3)\qquad \sigma_{kS} = 1 \quad \text{for all } k \text{ and } \phi_S = 1.$$

Combining the assumption of nonproportional consumption ($\tilde{\text{A}}2$) with the measurement error assumptions $\tilde{\text{M}}1$–$\tilde{\text{M}}3$, the expression for country i's net trade in factor k becomes

$$(12)\qquad F_{ki} = \alpha_k + \gamma_k E_{ki} - \theta_k L_i - \beta_k (Y_i - B_i) + F_{ik}^e,$$

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

The third source of alternative hypotheses is technological differences. 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.[12]

[12] The specification of neutral technological differences was chosen because of its tractability in estimation.

TABLE 4—ALTERNATIVE ASSUMPTIONS AND PARAMETER RESTRICTIONS

	Assumptions[a]						Parameter Restrictions				
Hypothesis	A1	A2	A3	M1	M2	M3	θ_k	δ_i	α_k	γ_k	β_k
HG	*										
H1	*	*	*			*	0	1			E_{ks}/Y_s
H2	*	*		*	*	*	0		0	1	E_{ks}/Y_s
H3	*	*				*	0				E_{ks}/Y_s
H4	*	*	*	*	*		0	1	0	1	
H5	*	*	*				0	1			
H6	*	*		*	*		0		0	1	
H7	*	*					0				
H8	*		*	*	*			1	0	1	
H9	*		*					1			
H10	*			*	*				0	1	

[a]Absence of an asterisk indicates selection of the alternative $\tilde{A}_i$ or $\tilde{M}_i$. Each parameter restriction is listed in the same order as the corresponding assumptions A2–M3.

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; and M3 = complete coverage of 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

$$(\tilde{A}3)\qquad \mathbf{A}_{us} = \delta_i \mathbf{A}_i,$$

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

Assumption ($\tilde{A}$3) implies that the parameters θ_k and β_k, and the values F_{ki}, are now θ_k/δ_i, β_k/δ_i and F_{ki}^{us}/δ_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 (12) gives

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

The γ_k are not scaled by δ_i since the endowments are measured independent of the input matrix. Multiplication of (13) by δ_i yields the bilinear form

$$(14)\qquad F_{ki}^{us} = \alpha_k + (\delta_i \gamma_k) E_{ki} - \theta_k L_i - \beta_k (Y_i - B_i) + F_{ki}^e.$$

Equation (14) identifies our most general model,[13] which we estimate using an iterative maximum likelihood procedure discussed below.

In addition to the general hypothesis contained in (14) (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 4 states each alternative in terms of the restrictions it imposes on the parameters of (14).

Data limitations prevented us from considering more general specifications, such as allowing input requirements to differ across industries and countries.

[13]This specification was selected after testing it against the more general specification

$$F_{ki}^{us} = \pi_k + \delta_i [\alpha_k + \gamma_k E_{ki}] - \theta_k L_i - \beta_k (Y_i - B_i) + F_{ki}^e,$$

where π_k is an unknown constant.

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 (A3), measurement error in trade and the endowments, and incomplete coverage of countries. The hypotheses of special interest are: H4, which leaves only β_k 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).

B. *Measuring Performance and Estimation Issues*

Given estimates of the unrestricted parameters in (14) 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 (14)

$$L = (\text{ESS})^{-(NK/2)}, \tag{15}$$

where ESS is the error sum-of-squares (summed over countries and factors) and NK is the total number of observations. Values of L, like an R^2, necessarily increase 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 G. Schwarz (1978):

$$L^* = L(NK)^{-(p/2)}, \tag{16}$$

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

$$\Lambda = \mathbf{L}_j^*/\mathbf{L}_i^* = (\text{ESS}_i/\text{ESS}_j)^{(NK/2)}(NK)^{(p_i - p_j)/2}. \tag{17}$$

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 Λ is interpreted as the posterior odds in favor of the alternative.

The variances of the residuals in equation (14) are assumed to be different for different factors. Processing of the data would be relatively easy if these variances were all equal. For example, if the endowments were measured without error ($\gamma_k = 1$), then equation (14) 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 sample "world" endowment levels E_{kS}. Furthermore, to eliminate heteroscedasticity associated with country size, we also divide by the adjusted GNP: $Y_i - B_i$. After these adjustments, equation (14) becomes

$$F_{ki}^{us}S_{ki} = \alpha_k S_{ki} + \gamma_k \delta_i (E_{ki}S_{ki}) - \theta_k(L_i S_{ki}) - \beta_k E_{kS}^{-1} + F_{ki}^{e*}, \tag{18}$$

where $S_{ki} = [(Y_i - B_i)E_{ks}]^{-1}$. The errors F_{ki}^{e*} are assumed to be normally distributed with mean zero and variance σ^2.

Given observations on factor contents, resource supplies, and population, the parameters in (18) are estimated using an iterative procedure, which solves the set of first-order conditions for maximizing the likelihood function (15). Given estimates δ_i^0 ($=1$ initially), estimates α_k^0, γ_k^0, θ_k^0, and β_k^0 are obtained from a regression equation for each factor as

$$F_{ki}^{us}S_{ki} = \alpha_k S_{ki} + \gamma_k(\delta_i^0 E_{ki}S_{ki}) - \theta_k(L_i S_{ki}) - \beta_k E_{ks}^{-1} + F_{ki}^{e*}. \tag{19}$$

The estimates α_k^0, γ_k^0, θ_k^0, and β_k^0 are then used to obtain new estimates δ_i^0 from a regression equation for each country as

$$(20) \qquad W_{ki} = \delta_i(\gamma_k E_{ki}/E_{kS}),$$

where $W_{ki} = F_{ki}^{us}S_{ki} - \alpha_k^0 S_{ki} - \theta_k^0(L_i S_{ki}) - \beta_k^0 E_{ks}^{-1}$. Prior to using the new estimates of δ_i obtained from (20) to re-estimate (19), each estimate of δ_i is divided by the estimated value for the United States to maintain the restriction that $\delta_{us} = 1$. The process of iteratively estimating (19) and (20) continues until the value of (15) converges.

The above two-step procedure is used to estimate the parameters in (18) under hypotheses HG, H3, and H7 since each involves the specification that $\gamma_k \neq 1$ and $\delta_i \neq 1$. Estimates of the unrestricted parameters under hypotheses H1, H5, and H9 are estimated using OLS while the parameters under hypotheses H2, H4, H6, H8, and H10, which restrict $\gamma_k = 1$, are estimated using a dummy variables model applied to the data set pooled across countries and factors, and imposing the restriction $\delta_{us} = 1$.

C. *Analysis*

Table 5 reports information on the performance of each hypothesis. The second column of Table 5 indicates 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 χ^2 values at arbitrarily selected levels of significance. For example, the χ^2 statistic for testing H3 against the unrestricted hypothesis is 58.6 ($= 2[-41.1 - (-70.4)]$), which would be compared against a number like 33.92, the upper 5 percent of a χ^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 it 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 (17), which has a certain arbitrariness in construction, but nonetheless has the effect of lowering the significance level as the sample size grows and thus maintaining 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 (16). 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. The clear winner is hypothesis H3, which allows neutral differences in factor input matrices, biased measurements of factor contents, and multiplicative errors in the endowments,[14] but maintains the assumptions of identical homothetic tastes and complete coverage of countries. Second best (though far behind) is hypothesis H7, which weakens H3 by allowing for incomplete coverage of countries. The third-best hypothesis is HG, the unrestricted model. The other hypotheses are essentially "impossible," given the data evidence. Such extreme values for the Bayes' factors are not uncommon, and should

[14] To examine the potential 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 occurs because the depreciation rates used in computing industry capital stocks were typically lower than the rate used to compute national capital stocks. The discrepancy for managerial workers likely reflects the exclusion of government employees in calculating industry input requirements.

TABLE 5—PERFORMANCE STATISTICS FOR ALTERNATIVE HYPOTHESES

Hypothesis	ESS[a]	ln(L)	Number of Parameters	Adjusted[b] ln(L)	Odds of Hypothesis[c] Relative to H3
HG	1.32	−41.1	71	808.1	3.15E-15
H1	6.63	−280.9	22	707.8	nil
H2	14.56	−397.7	27	576.8	nil
H3	1.61	−70.4	49	841.5	1.0
H4	961.80	−1020.0	11	0.0	nil
H5	6.35	−274.6	33	682.8	nil
H6	11.85	−367.2	38	576.0	nil
H7	1.51	−60.9	60	819.6	32.20E-10
H8	492.39	−920.6	22	68.1	nil
H9	6.25	−272.1	44	653.9	nil
H10	11.58	−363.7	49	548.1	nil

[a] In millions.
[b] Adjusted $\ln(L) = \ln(L) - (p/2)\ln(297) + 1051$, where p = number of parameters and 1051 is the value of equation (16) under hypothesis H4.
[c] Odds = exp[adjusted $\ln(L) - 841.5$]. "Nil" entries indicate a value less than 10^{-50}.

probably be viewed with suspicion since they depend on a number of assumptions, normality being a potentially important example.

Although hypothesis H3 is favored, it does not lead to sensible estimates of many of the parameters. Table 6 reports estimates of the technological differences δ_i. The hypothesis that the technology is the same as that of the United States, $\delta_i = 1$, can be rejected for all but three countries (Australia, Canada, and Mexico),[15] but most of the estimates are wildly different from one, and eight take on implausible negative values. Furthermore, 15 countries have estimated δ's in excess of one, indicating that their factors are more productive than those of the United States.

It is possible that these peculiar estimates are due to one or more "rogue" observations. Table 1 indicates that eight countries with negative estimates all have large imports of the services of one or more of the land factors: arable land, forestland, and pastureland, and accounting for these extreme values

[15] The Bayes' criterion in equation (17) implies a critical t-value of 2.19. The critical value is computed as $[(T-k)(T^{1/T}-1)]^{1/2}$, where T is the number of observations (297) and k is the number of parameters (49). See Leamer (1978, p. 114) for discussion.

TABLE 6—H-O-V REGRESSIONS AND COUNTRY COEFFICIENTS UNDER HYPOTHESIS H3

Country	δ_i[a]	Standard Error	t-Statistics[b]
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

Note: Number of observations = 297.
[a] Values are divided by U.S. estimate ($\delta_{us} = 1.0012$).
[b] Asymptotic t-values for testing δ_i is unity. The critical t-value based on equation (17) is 2.19.

may require a dramatic alteration of the H-O-V model. However, contrary to the suggested importance of these observations, re-estimation of the model for each hypothesis with the land variables excluded produced few changes in the estimated parameters (results not shown). Hypothesis H3 remained most favored, followed by hypothesis H7 and then HG. Under hypothesis H3, seventeen of the estimated technological differences δ_i exceeded unity and the number of countries with negative values of the technological difference parameter increased from eight to ten.[16] We thus remain confused about the exact source of the peculiar estimates.

The estimates reported in Table 7 are also cause for concern. The predicted values of the factor supplies can be found by inserting the observed values into these estimated equations. A negative value of γ_k 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 production workers as the anomaly: the number of production workers embodied in trade is negatively related to the measured number of production workers.[17]

Overall, our results cast doubt on the hypothesis that the H-O-V equations are exact in favor of a model that allows neutral differences in factor input matrices and measurement errors in both trade and national resource supplies. This finding suggests that technological differences and measurement errors are also significant reasons for the relatively poor performance of the sharp hypotheses contained in the rank and sign propositions considered previously. However, our results do support the assumptions of proportional consumption[18] and complete coverage of countries. However, these conclusions are rendered suspect by the peculiar point estimates that are produced by the favored hypothesis.

TABLE 7—H-O-V REGRESSIONS AND FACTOR COEFFICIENTS UNDER HYPOTHESIS H3

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

[a]Asymptotic t-values in parentheses. The critical t-value based on equation (17) is 2.19.
[b]Values of γ_k scaled by 10^3.

IV. Concluding Remarks

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

[16]The estimate for Belgium-Luxembourg switched from negative to positive, while the estimates for the Netherlands, Norway, and Spain switched from positive to negative.

[17]Parameter estimates for the unrestricted model HG were very similar to those reported for hypothesis H3. In particular, of the eight countries with negative values of δ_i in Table 6, only the value for France was positive. In addition, the signs and levels of significance of the parameters γ_k paralleled those shown in Table 7.

[18]This contrasts with Yutaka Horiba's (1979) test of the proportional consumption assumption using data on U.S. regional trade. Using a specification similar to ours, he rejected the assumption in terms of the value of β_k but not its sign.

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. The H-O-V theorem was weakened to allow nonproportional consumption and technological differences and was supplemented with various assumptions about measurement errors. Using 1967 trade and input requirements, we tested the null hypothesis that the H-O-V equations are exact against several of these weaker alternatives. In addition, we examined sign and rank corollaries of the H-O-V theorem analogous to those implicitly studied by Leontief.

The Leontief-type sign and rank propositions, whether examined across countries or across factors, were generally not supported. The sign of net factor exports infrequently predicted the sign of excess factor supplies and therefore does not reliably reveal factor abundance. The ranking of factor contents infrequently conforms to the ranking of factor abundance ratios, as examined through either rank correlations or pairwise rankings.

The hypothesis that the H-O-V equations are exact was also not supported. The data suggest errors in measurement in both trade and national factor supplies, and favor the hypothesis of neutral technological differences across countries. However, the form of the technological differences favored by the data involves a number of implausible estimates, including some in which factors yield strictly negative outputs.[19] Thus, to a considerable extent, the conclusions that come from a study of the sign and rank propositions apply to the more promising regression study: The Heckscher-Ohlin model does poorly, but we do not have anything that does better. It is easy to find hypotheses that do as well or better in a statistical sense, but these alternatives yield economically unsatisfying parameter estimates.

These generally negative conclusions concerning the empirical validity of the H-O-V model appear to contrast sharply with Leamer's (1984) conclusion that "the main currents of international trade are well understood in terms of the abundance of a remarkably limited list of resources. In that sense the Heckscher-Ohlin theory comes out looking rather well." However, the present paper tests a different set of hypotheses. Leamer (1984) studies the weakened hypothesis that the structure of trade can be explained by the availability of resources. This paper examines the stricter H-O-V hypothesis that factor supplies, factor input requirements, and trade interact in a particular way. In addition, the present results suggest that there are important differences in selected input intensities between the United States and the other countries. Leamer's (1984) study may come to a more optimistic conclusion because he makes no commitment to the U.S. input intensities.[20]

DATA APPENDIX

Data on 1966 factor and 1967 trade endowments were collected for 27 countries. The twelve resources are capital, total labor, professional/technical workers, managerial workers, clerical workers, sales workers, service workers, agricultural workers, production workers, arable land, pastureland, and forestland. In accordance with this *Review's* policy of ensuring clear documentation of data, Table A1 lists the data on countries' population, GNP, and trade balance, as well as their trade and endowment of each factor. The following provides a concise discussion of data sources and methods, and includes citation to previously published work which contains further information on these data.

Factor endowment data were obtained from Bowen (1980, 1983). Net capital stocks for each country were

[19]Although the assumption of factor price equalization is not explicit in our analysis, the performance of hypothesis H3 together with the results shown in Table 6 could be taken as evidence against the assumption of factor price equalization. Factor price differences might help explain the variability in the estimates of δ_i since such differences would imply nonneutral differences in factor input matrices. We intend to examine the possibility of nonneutral technological differences in later research.

[20]See also Anderson's (1987) review of Leamer (1984).

TABLE A1—DATA BASE

(1)	(2)	(3)	Country		(4)	(5)	(6)	(7)
22.0	2.17431E10	4.68938E8	Argentina	E	2.40180E10	8496000	1342368	953251
				T	8.67853E8	77647	79417	1701
11.6	2.27360E10	−1.16039E8	Australia	E	3.50530E10	4727000	461828	702905
				T	−1.45799E9	−44830	78226	−14787
7.3	1.01688E10	−6.44060E8	Austria	E	1.56530E10	3363000	605340	393135
				T	−1.07484E9	−40112	−10955	−4982
9.8	1.89645E10	−3.45010E8	Bene-Lux	E	2.25630E10	3764000	236379	477652
				T	−9.38096E8	−7454	−26037	293
83.9	2.90170E10	2.45233E8	Brazil	E	3.04760E10	26463000	12696947	1267578
				T	−1.39899E9	−18704	6813	−4128
20.0	5.68412E10	4.24574E8	Canada	E	7.65370E10	7232000	690656	984998
				T	1.88821E9	−158932	47260	−28570
4.8	1.11664E10	−5.88141E8	Denmark	E	1.30180E10	2230000	304618	249760
				T	−1.32815E9	805	47564	−4358
4.6	8.64730E9	−2.20552E8	Finland	E	1.39290E10	2176000	574029	173862
				T	3.94420E8	−1796	−3009	−2530
49.2	1.08118E11	−9.53400E8	France	E	1.46052E11	21233000	3709405	2299534
				T	−7.06224E8	−34336	−38160	−736
59.7	1.22675E11	2.11160E9	Germany	E	1.81079E11	26576000	2854262	4217611
				T	5.72919E7	349286	−240808	75288
8.6	6.72160E9	−8.16871E8	Greece	E	7.22300E9	4314000	2065975	250212
				T	−1.35709E9	−52749	7616	−7373
3.6	1.97080E9	−4.43437E8	Hong Kong	E	2.08700E9	1525000	78842	104462
				T	−1.48229E9	−28429	−31726	−2834
2.9	2.93960E9	−3.84555E8	Ireland	E	3.37000E9	1109000	346895	90273
				T	−5.16958E8	−9731	18912	−3303

Note: See notes at end of table for column definitions.

Country		(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Argentina	E	588773	161424	2948112	927763	956650	30248000	60130000	145802000
	T	−998	−12	−6990	2886	1645	6561280	−3745350	3835996
Australia	E	443865	300164	2018429	369651	355470	39614000	35151000	447208000
	T	−15213	−6415	−82554	−1348	−2767	6762249	−4913655	3498840
Austria	E	260969	68941	1362688	261978	357487	1686000	3203000	2249000
	T	−4728	−1852	−14008	−1885	−1710	−1546894	−156822	87684
Bene-Lux	E	426461	145290	1778490	409900	275148	981000	687000	818000
	T	−2621	−436	22601	−805	−451	−3672691	−6653807	189337
Brazil	E	1098214	727732	5440793	1595719	2344622	31910000	522600000	141400000
	T	−4805	−1407	−14172	−646	−363	741997	15142	152291
Canada	E	868563	625568	2438630	496115	770208	43404000	322271000	20957000
	T	−21686	−10161	−134350	−5712	−5798	5389052	20253445	899259
Denmark	E	231474	35680	861226	224784	247530	2701000	472000	326000
	T	−5349	−2138	−34661	570	−824	737315	3254944	5328684
Finland	E	224998	32640	797286	165811	207590	2753000	21930000	110000
	T	−2960	−587	8710	−846	−579	−736283	6481551	320649
France	E	2344123	626373	7905046	1751722	1783572	20214000	12714000	13632000
	T	−1197	−1145	9304	−1872	−527	−4585442	−26133156	−437494
Germany	E	2479541	728182	11153947	2320085	2551296	8228000	7184000	5802000
	T	64071	28574	392143	13849	16244	−26018409	−25195922	−5730951
Greece	E	198444	29335	1134582	289901	309314	3851000	2608000	5239000
	T	−6174	−2893	−39697	−2046	−2187	1571541	−2343192	−526643
Hong Kong	E	77927	76097	755180	180102	247660	13000	10000	1
	T	−4095	−1153	14839	−1916	−1547	−2931651	−3459434	−1232976
Ireland	E	87278	14417	370739	109569	87611	1199000	208000	3554000
	T	−3175	−1431	−19559	−407	−769	96740	−622571	2308561

TABLE A1—CONTINUED

(1)	(2)	(3)	Country		(4)	(5)	(6)	(7)
52.0	7.96580E10	-5.39406E8	Italy	E	9.04360E10	19998000	4527547	1763824
				T	-6.98937E9	28922	-103119	11262
98.9	1.10388E11	2.53711E8	Japan	E	1.65976E11	49419000	11905037	6478831
				T	-8.78167E9	107388	-172142	27674
29.1	4.13000E9	-4.87021E8	Korea	E	3.02500E9	9440000	4936176	370048
				T	-1.49530E9	-49392	-9346	-5712
44.1	2.21625E10	-5.61792E8	Mexico	E	2.16390E10	12844000	5878699	910640
				T	-8.28121E8	-50163	25306	-9625
12.5	2.08090E10	-1.26535E9	Netherlands	E	2.99410E10	4699000	388607	657390
				T	-2.85259E9	-60964	29917	-8221
3.8	7.65510E9	-8.39611E8	Norway	E	1.28830E10	1464000	223699	125758
				T	-1.70045E9	-102657	-6254	-11350
32.7	6.18600E9	-1.04685E8	Philippines	E	6.59700E9	12470000	6660227	379088
				T	-1.04236E9	-35637	4721	-5728
9.3	4.26650E9	-4.03294E8	Portugal	E	3.75700E9	3381000	1166445	196436
				T	-8.61326E8	-23677	-11321	-2897
32.0	2.82285E10	-2.31879E9	Spain	E	3.47920E10	11849000	3673190	940811
				T	-4.87847E9	-148941	-17365	-17993
7.8	2.35715E10	-3.01150E8	Sweden	E	3.15550E10	3450000	368805	375705
				T	-1.03381E8	-19339	-16365	-3741
6.0	1.50576E10	-6.65988E8	Switzerland	E	2.33150E10	2843000	263546	457723
				T	-2.11706E9	-48845	-32919	-870
54.7	1.06534E11	-2.55290E9	United Kingdom	E	1.10717E11	25396000	891400	3512267
				T	-1.72415E10	-400012	-283790	-16862
196.5	7.62700E11	4.34870E9	United States	E	7.85933E11	76595000	3707198	2515623
				T	5.76114E9	764413	258625	87377
19.7	8.60700E9	-3.55350E8	Yugoslavia	E	1.40230E10	8837000	4539567	451571
				T	-8.59292E8	-17986	4413	-4003

Country		(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Italy	E	1181882	185981	8233177	2225777	897910	15258000	6099000	5147000
	T	4838	3877	112909	-1250	435	-62445355	-26821582	-7174026
Japan	E	2826767	1433151	16940833	5757313	3553226	5839000	25400000	157000
	T	16998	9108	220165	1543	4057	-19862383	-67987781	-2956563
Korea	E	244496	75520	1666160	927008	465392	2293000	6656000	18000
	T	-5232	-2186	-23143	-1903	-1873	-1111149	-2404532	-130644
Mexico	E	624218	245320	2766598	1075043	1344767	26000000	78000000	72100000
	T	-9184	-3865	-48936	-1760	-2103	3061733	3920090	297403
Netherlands	E	535686	123114	1823682	467550	429019	946000	292000	1299000
	T	-4618	-3443	-71238	-1260	-2084	417979	-3260982	3394099
Norway	E	158551	50508	653676	122390	129271	841000	7300000	158000
	T	-9529	-4377	-64732	-2976	-3447	-1297301	6966388	443706
Philippines	E	448920	342925	2035104	746953	872900	8330000	14100000	830000
	T	-4561	-2158	-24600	-1722	-1595	842059	-1283864	-216082
Portugal	E	109206	24005	1103220	225513	273185	4070000	3400000	530000
	T	-3159	-990	-3460	-1060	-791	-1274623	473446	-224250
Spain	E	596005	98347	4397164	893415	1071150	20156000	13600000	12000000
	T	-15604	-7010	-79483	-5828	-5650	-1221046	-3755719	-1066016
Sweden	E	566835	77625	1390350	317745	334305	3158000	22794000	525000
	T	-2183	-926	7287	-2105	-1317	-2210020	6774374	36931
Switzerland	E	307613	48900	1205432	209245	307897	401000	981000	1778000
	T	1446	-278	-14405	-948	-876	-3652367	-4066582	-692250
United Kingdom	E	2450714	789816	12027546	2460872	3088154	7480000	1829000	12107000
	T	-3730	-6651	-62500	-15201	-11232	-24179333	-49416509	-12948250
United States	E	9911393	7284184	28799720	5108886	9275654	177550000	306850000	258000000
	T	102628	30444	235781	24053	25598	35789032	-69100970	-1108796
Yugoslavia	E	609753	98974	2212785	269528	534638	8266000	8812000	6450000
	T	-4187	-1595	-10469	-1032	-1117	-108893	-78267	664739

Notes: E = 1966 endowment. T = 1967 net trade in factor. Units of T are those of the corresponding endowment. Columns are: 1) Population (mil.); 2) GNP (1966, $US); 3) Trade Balance (1966, $US); 4) Capital (1966, $US); Labor: 5) Total; 6) Agricultural; 7) Clerical; 8) Professional/Technical; 9) Managerial; 10) Production; 11) Sales; 12) Services; Land (hectares): 13) Arable; 14) Forest; 15) Pasture.

computed by summing annual real gross domestic investment flows starting in 1949 with annual depreciation assumed to be 13.33 percent. The underlying investment data were derived from the World Bank's Economic and Social Data Bank tape and appear in the World Bank publication *World Tables*. Detailed discussion of the methods used to construct net capital stocks appears in Bowen (1982).

Labor endowments were derived from issues of the International Labour Office (ILO) publication *Yearbook of Labor Statistics*. The labor categories are those defined at the one-digit level of the ILO's International Standard Classification of Occupations (ISCO). Total labor is defined as a country's total economically active population. For each country, the number of workers in each ISCO category was computed by multiplying the share of a country's total labor belonging to a category times its total labor. Since occupational data are not regularly collected, the share of each labor type in each country in 1966 was derived from a time-series regression of the available share data against time. Bowen (1982) provides discussion of this method and presents the years for which occupational data were available for each country.

Land endowments were taken from issues of the Food and Agricultural Organization (FAO) publication *Production Yearbook*. The definitions of arable land, pastureland, and forestland are those used by the FAO.

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 indirect 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 obtained from the U.N. Trade Data Tapes at the four- and five-digit level of the SITC and concorded to the input-output sectors to perform the required vector multiplications. The concordances are available from the authors upon request.

On the production side, capital (plant, equipment, and inventories) input requirements were constructed from data prepared by the Bureau of Labor Statistics Economic Growth Project, which provided industry capital stock figures measured in 1958 dollars. Industry occupation requirements, measured in number of persons, were based upon 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 one-digit occupational categories defined by ISCO. (It was often not feasible to translate industry skill requirements into the ILO definitions; white-collar employment in certain nontraded sectors was a particular difficulty.) Sveikauskas (1983, Appendix) and especially Sveikauskas (1984) provide a complete description of the factor requirements data and a detailed table listing the input requirements data that can be made available.

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; pastureland as proportional to total purchases from I/O sector 1 and forestland 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.

Land input coefficients are measured in dollars, whereas land endowments are measured in hectares. To adjust for this difference in units of measurement, the net trade in each land type was deflated using an imputed price. The prices were derived 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; pastureland, \$108.942 per hectare; forestland, \$5.688 per hectare.

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