International Factor Price Differences: Leontief was Right!

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International Factor Price Differences: Leontief Was Right!

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The factor price equalization hypothesis is widely at odds with the large variation in factor prices across countries. Similarly, the Heckscher-Ohlin-Vanek (HOV) theorem constitutes an incomplete description of trade in factor services: its predictions are always rejected empirically. These two issues are examined using a modification of the HOV model that allows for factor-augmenting international productivity differences. The empirical results are stark: this simple modification of the HOV theorem explains much of the factor content of trade and the cross-country variation in factor prices.

I. Introduction

Persistent differences in wages and other factor prices characterize international trade. Yet a treatment of factor price disparities that is tightly embedded within standard trade theory has eluded empirical researchers. In this paper, I shall provide an integrated treatment of factor price differentials and international trade that is based on international differences in productivity. Understanding factor price differentials is important for several reasons: they are central to the North-South development gap; they are critical to explanations of differing equilibrium growth paths across nations; and they exacer-

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bate trade frictions between the United States and its trading partners, in particular, Canada, Japan, and the European Economic Community.

The model for my analysis is the increasingly forsaken Heckscher-Ohlin-Vanek (HOV) model (Heckscher 1919; Ohlin 1933; Samuelson 1948; Melvin 1968; Vanek 1968). If the HOV model is currently out of fashion, it may seem peculiar to place it center-stage in a modern model. But this suspicion is misplaced. Once international differences in factor prices are properly incorporated, the HOV model performs remarkably well: a simple productivity-related modification of the HOV model explains much of the factor content of trade and the cross-country variation in factor prices.

The focus of criticism of the HOV approach has several elements. One is that the HOV theorem constitutes an incomplete description of trade in factor services: its predictions were rejected in five important studies (Maskus 1985; Bowen, Leamer, and Sveikauskas 1987; Brecher and Choudhri 1988; Staiger 1988; Kohler 1991). An oddity about related empirical work is the invariable wedding of the HOV theorem to the factor price equalization hypothesis. This is done in spite of the common knowledge that factor price equalization is widely at odds with wage data. Another unsatisfactory assumption is the one maintaining that identical technologies are always in place in every country. For example, by assumption, India always has costless access to all U.S. technologies. Conditioning on factor price equalization and identical technologies, the HOV model explains neither factor prices nor trade nor productivity across trading partners.

The basic insight in this paper flows from Leontief (1953). In the original explanation of the Leontief paradox, Leontief maintained that the United States is labor abundant when labor is measured in productivity-equivalent workers: one person year of U.S. labor with the accompanying technology is equivalent to several person years of foreign labor with inferior technology. In this paper, I simply correct for these productivity differences.

An implication of my empirical work is that Leontief was right in maintaining that in 1947 the United States was labor abundant as measured in productivity-equivalent workers. This observation is distinct from the question of whether there is a paradox (see Leamer 1980; Brecher and Choudhri 1982*b*; Casas and Choi 1985). My results leave intact Leamer's conclusion that there is no paradox.

Empirically, this paper is closely related to that of Bowen et al. (1987), who examined the relationship between productivity and departures from the HOV theorem. Their failure to find an economically meaningful relationship is apparently due to their restrictive treatment of productivity and factor price differences. Theoretically, this paper is related to the literature on the HOV theorem without factor price equalization (Bardhan 1965; Deardorff 1979, 1982; Brecher and Choudhri 1982*a*; Woodland 1982, sec. 7.3.2; Helpman 1984). As with Bardhan and Woodland, my treatment is less general in that the failure of factor price equalization is driven solely by international productivity differences.

The paper is organized as follows. The model is developed in Section II. Section III provides the bridge between the theory and its empirical implementation. Sections IV–VIII review the empirical findings. Conclusions appear in Section IX. Before proceeding, I review the literature in detail.

Relation to the Literature

This paper has implications for research into trade, productivity, and development (e.g., Chenery, Robinson, and Syrquin 1986) and international comparisons of living standards (e.g., Summers and Heston 1991). It also suggests a factor endowments footing for the growing literature on convergence and endogenous growth. The paper is more immediately related to (i) tests of the HOV theorem and (ii) research into the Leontief paradox.

i) As Leamer and Bowen (1981) noted, logically complete tests of the HOV theorem must use data on technology, trade, and endowments. Most of the purported tests of the theorem used only two of these three and so are incomplete. They appear as cross-industry studies for a single country (e.g., Baldwin 1971), cross-country studies for a single industry (e.g., Leamer 1984), and factor content studies (e.g., Leontief 1953). Only five papers have reported complete tests of the HOV theorem (Maskus 1985; Bowen et al. 1987; Brecher and Choudhri 1988; Staiger 1988; Kohler 1991). This paper may be viewed as a complete test of the HOV theorem that rejects it in favor of a minor generalization of the theorem.

ii) Considering the attention the so-called Leontief paradox has received, it is surprising that Leontief's original productivity explanation has gone largely unexplored. Previous researchers tackled the paradox by disaggregating labor by skill classification while maintaining the assumption that within classifications no international productivity differences exist. (For examples, see Leontief [1956], Travis [1964], Keesing [1965, 1966], Baldwin [1971], Stern and Maskus [1981], Maskus [1985], and Bowen et al. [1987].) As the literature illustrated, disaggregating at least partly explains the paradox; however, it cannot explain the overall poor performance of the HOV theorem since the five empirical studies reporting complete tests rejected the theorem using disaggregated labor data. In contrast, the conclusions of this paper hold with equal force whether or not labor is disaggregated.

II. The Model

Let $c = 1, \ldots, C$ index countries, let $f = 1, \ldots, F$ index factors, and let $i = 1, \ldots, I$ index industries. Then V_{fc} is the endowment of factor f in country c, w_{fc} is the price of factor f in country c, and $\mathbf{w}_c = (w_{1c}, \ldots, w_{Fc})'$ is the factor price vector. It may differ across countries. The term $\mathbf{A}_c(\mathbf{w}_c)$ is the $F \times I$ technology matrix giving the cost-minimizing input requirements of factor f needed to produce one unit of output i. It may differ across countries. The term $\mathbf{T}_c$ is the $I \times 1$ vector of net exports, with typical element giving the net exports of industry i by country c. The term $\mathbf{F}_c = (F_{1c}, \ldots, F_{Fc})'$ is the vector of factor services embodied in net exports; that is, $\mathbf{F}_c = \mathbf{A}_c\mathbf{T}_c$. The term Y_c is the gross national product of country c, $Y_w = \Sigma_c Y_c$ is world GNP, and B_c is the trade balance of country c so that $s_c = (Y_c - B_c)/Y_w$ is country c's share of world consumption. The HOV model with factor price equalization and identical technologies ($\mathbf{A}_c = \mathbf{A}_{c'}$ for all pairs of countries c and c') implies the following set of equations (e.g., Leamer 1980):

$$F_{fc} = V_{fc} - s_c \sum_{j=1}^{C} V_{fj}, \quad f = 1, \ldots, F, c = 1, \ldots, C, \tag{1}$$

$$w_{fc} = w_{fc'}, \quad f = 1, \ldots, F, c, c' = 1, \ldots, C. \tag{2}$$

Since country c is defined to be abundant in factor f if $V_{fc} - s_c \Sigma_{j=1}^{C} V_{fj} > 0$, equation (1) implies the HOV theorem: a country exports the services of its abundant factors. This prediction has been repeatedly rejected (Maskus 1985; Bowen et al. 1987; Brecher and Choudhri 1988; Staiger 1988; Kohler 1991). Equation (2) is the factor price equalization hypothesis. It is incompatible with the large observed differences in wages across countries (see table 1 below).

The argument of this paper is that empirical departures from equations (1) and (2) are largely eliminated by allowing for productivity differences across countries. For example, Leontief (1953) claimed that the United States is abundant in labor when labor is measured in "productivity-equivalent" units. Let π_{Lc} be a parameter with the interpretation that if V_{Lc} is the labor endowment of country c, then $V^*_{Lc} = \pi_{Lc} V_{Lc}$ is the corresponding labor endowment measured in productivity-equivalent units. In these terms, Leontief claimed that π_{Lc} is larger for the United States than for most countries.

To formalize and generalize Leontief's insight, I proceed as follows. Define V^*_{fc} by $V^*_{fc} = \pi_{fc} V_{fc}$. Let w_{fc} be the price per unit of V_{fc}

and let w_{fc}^* be the price per unit of V_{fc}^*. Since one unit of V_{fc} provides π_{fc} productivity-equivalent units of service, $1/\pi_{fc}$ units of V_{fc} provide one productivity-equivalent unit of service priced at

$$w_{fc}^* = \frac{w_{fc}}{\pi_{fc}}, \quad f = 1, \ldots, F, c = 1, \ldots, C. \tag{3}$$

Let $\mathbf{w}_c^* = (w_{1c}^*, \ldots, w_{Fc}^*)'$. Let $\mathbf{A}_c^*(\mathbf{w}_c^*)$ be country c's technology matrix when its factors are measured in productivity-equivalent units. I assume that all differences in technology across countries are caused by Leontief's factor-augmenting international productivity differences.[1]

ASSUMPTION A. $\mathbf{A}_c^* = \mathbf{A}_{c'}^*$ for all pairs of countries c and c'.

It is straightforward to show that under assumption A the factor price equalization hypothesis and the HOV theorem hold, with V_{fc} replaced by $V_{fc}^* = \pi_{fc}V_{fc}$, w_{fc} replaced by $w_{fc}^* = w_{fc}/\pi_{fc}$, and $\mathbf{A}_c(\mathbf{w}_c)$ replaced by $\mathbf{A}_c^*(\mathbf{w}_c^*)$ (Trefler 1992). This observation is expressed as

$$F_{fc}^* = \pi_{fc}V_{fc} - s_c \sum_{j=1}^{C} \pi_{fj}V_{fj}, \quad f = 1, \ldots, F, c = 1, \ldots, C, \tag{4}$$

$$\frac{w_{fc}}{\pi_{fc}} = \frac{w_{fc'}}{\pi_{fc'}}, \quad f = 1, \ldots, F, c, c' = 1, \ldots, C, \tag{5}$$

where F_{fc}^* is a typical element of $\mathbf{F}_c^* = \mathbf{A}_c^*\mathbf{T}_c$. This paper is devoted to examining how closely equations (4) and (5) conform to the international data on trade, endowments, consumption shares, and factor prices.

III. Empirical Implementation

The following data will be used to examine equations (4) and (5). For more details, see the Data Appendix. All data pertain to 1983 unless indicated otherwise. There are 33 countries in the sample, which together account for 76 percent of world exports and 79 percent of world GNP. The choice of countries was largely dictated by the availability of trade data at a detailed industry level (T_{ic}) and, to a lesser extent, by the availability of factor endowment data. The factor content of trade ($\mathbf{F}_c^* = \mathbf{A}_c^*\mathbf{T}_c$) was calculated using the U.S. technology matrix ($\mathbf{A}_c^*$). The usual caveat about using U.S. technology to calculate the factor content of non-U.S. trade applies here, albeit with

[1] Assumption A can also be motivated as follows. Let ϕ_c^i be the production function of industry i in country c and let V_{fc}^i be the input of factor f in industry i. If for all i and c there exist production functions ϕ^i independent of c such that $\phi_c^i(V_{1c}^i, \ldots, V_{Fc}^i) = \phi^i(\pi_{1c}V_{1c}^i, \ldots, \pi_{Fc}V_{Fc}^i)$, then assumption A holds (Trefler 1992).

less force since the technology will be modified in a country-specific, technologically nonneutral fashion by the π_{fc}. There are 10 factors (V_{fc}): capital, cropland, pasture, and seven categories of labor.[2] Since factor price data (w_{fc}) are available only for capital and aggregate labor, the data for these two factors are discussed in detail. Aggregate labor endowment is defined as the economically active population. Wages are average hourly earnings in nonagricultural activities. They were converted into dollars using the Summers and Heston (1991) purchasing power parity (PPP) adjusted exchange rates. Capital endowment is defined as the discounted sum of constant-price investment flows. Capital endowments were converted into dollars using PPP-adjusted exchange rates. The dual price index for capital constructed in this way is the discounted sum of future investment prices with discount factors related to future rates of return on capital (e.g., Christensen, Cummings, and Jorgenson 1981). Given the lack of data on future prices and rates of return, the dual price was proxied by the PPP-adjusted current investment price. In particular, the 1981 price of investment was used in place of the current (1983) price of investment in order to avoid the debt crisis and the bulk of the 1981–82 recession; however, the choice of year had little impact. For reasons discussed in Leamer (1984) and Maskus (1991), the capital stock data should be treated with caution, and, by implication, so should the capital price data. The GNP data used to calculate the s_c are taken from World Bank (1988). Throughout, very similar results obtain with the Summers and Heston (1991) PPP-adjusted data for gross domestic product. The only unknown data are the π_{fc}. In principle, the π_{fc} could be obtained from international productivity studies; however, reliable productivity estimates are always restricted to a very limited number of industrial countries.

When one examines relations (4) and (5), it is tempting to tack on error terms and calculate the likelihood of the π_{fc} given the observed data. However, under the assumption of a normally distributed error process for each equation, there are $2CF$ observations (equations) and $CF + 3$ unknowns (three covariances) so that the ratio of observations to parameters is very low. In addition to the estimation issue is the trickier problem of deciding whether the model is "reasonable": this is often inadequately conveyed by the reporting of a few test statistics.

Proposition 1 below provides the basis for a different approach to

[2] Forests, oil, coal, and minerals have been used in other studies but were not included in this study. Forests were excluded because the forestry and fishing production data are merged at the level of aggregation used. Oil, coal, and minerals were excluded because they are heavily traded internationally, so that, as Leamer (1984, p. 22) detailed, they should not be thought of as internationally immobile factors.

empirical implementation. Fix factor f and introduce notation that stacks equation (4):

$$\mathbf{F}_f^* = \begin{bmatrix} F_{f1}^* \\ F_{f2}^* \\ \vdots \\ F_{fC}^* \end{bmatrix}, \quad \mathbf{X}_f = \begin{bmatrix} (1-s_1)V_{f1} & -s_1 V_{f2} & \cdots & -s_1 V_{fC} \\ -s_2 V_{f1} & (1-s_2)V_{f2} & \cdots & -s_2 V_{fC} \\ \vdots & \vdots & \ddots & \vdots \\ -s_C V_{f1} & -s_C V_{f2} & \cdots & (1-s_C)V_{fC} \end{bmatrix}, \quad \mathbf{\Pi}_f = \begin{bmatrix} \pi_{f1} \\ \pi_{f2} \\ \vdots \\ \pi_{fC} \end{bmatrix}. \tag{6}$$

Then equation (4) can be written as $\mathbf{F}_f^* = \mathbf{X}_f \mathbf{\Pi}_f$, $f = 1, \ldots, F$. By analogy to the linear regression model, $(\mathbf{F}_f^*, \mathbf{X}_f)$ is the data and $\mathbf{\Pi}_f$ is the regression coefficient.

PROPOSITION 1. Fix factor f and assume $V_{fc} > 0$ for all c. Then

i) there exists a solution $\hat{\mathbf{\Pi}}_f = (\hat{\pi}_{f1}, \ldots, \hat{\pi}_{fC})'$ to $\mathbf{F}_f^* = \mathbf{X}_f \mathbf{\Pi}_f$, unique up to the normalization $\hat{\pi}_{f1} = 1$;
ii) there exist values for $(\mathbf{F}_f^*, \mathbf{X}_f)$ such that $\hat{\pi}_{fc} < 0$ for some c; and
iii) for almost all values of $(\mathbf{F}_f^*, \mathbf{X}_f)$ and $(w_{f1}, \ldots, w_{fC})$, the $\hat{\pi}_{fc}$ do not satisfy equation (5).

Proposition 1 may be motivated as follows. Bowen et al. (1987) examined the HOV equation (4) for the case in which the π_{fc} are the same across factors. They were not satisfied by this alteration of the model since estimates of the π_{fc} that produced the best fit were often negative. Part i of proposition 1 shows that if the π_{fc} are allowed to vary across factors, I am able in effect to adjust upward or downward the measured factor supplies in each country so that the HOV equation (4) fits exactly. This is true regardless of the data $(\mathbf{F}_f^*, \mathbf{X}_f)$ on factor contents of trade, consumption shares, and factor endowments. Indeed, the $\hat{\mathbf{\Pi}}_f$ that makes the HOV equation (4) fit exactly is not even unique: it is unique only up to a normalization of one element. Implicit in part i is a useful feature of the $\hat{\mathbf{\Pi}}_f$: they do not depend on data for other factors and so can be calculated one factor at a time without worrying about how other factors are treated. For example, the $\hat{\mathbf{\Pi}}_f$ for labor is not affected by the mismeasurement of capital endowments or by the exclusion of oil endowments.

Since the HOV equation (4) can be made to fit exactly, I cannot assess my productivity modification of the HOV model in terms of how well it fits the trade and endowment data. But I can judge the model in two other ways. First, part ii of proposition 1 indicates that for some data there will be negative $\hat{\pi}_{fc}$. I can therefore follow Bowen et al. in treating negative $\hat{\pi}_{fc}$ as evidence that the model does not fit the data. Second, I can exploit the factor price equation (5), which states that the productivity parameters ought to be proportional to factor price differences. For example, if it is necessary to assume that British labor productivity is only two-thirds of U.S. labor productivity in order to make the HOV equation (4) fit exactly, then British wages ought to be about two-thirds of U.S. wages as well. Part iii of proposition 1 states that when the $\hat{\pi}_{fc}$ are chosen to make the HOV equation (4) fit exactly, it is unlikely that the $\hat{\pi}_{fc}$ will also make the factor price equation (5) fit exactly. Specifically, the $\hat{\pi}_{fc}$ need not satisfy

$$\frac{\hat{\pi}_{fc}}{\hat{\pi}_{f,\mathrm{US}}} = \frac{w_{fc}}{w_{f,\mathrm{US}}}, \quad c = 1, \ldots, C. \tag{7}$$

Equation (7) plays a central role in that it imposes $C - 1$ exact restrictions on the $\hat{\pi}_{fc}$, restrictions that are satisfied with probability zero. Departures from these restrictions will be used to evaluate the plausibility of the model. By analogy to econometrics, equation (7) imposes $C - 1$ overidentifying restrictions that are the basis for hypothesis testing. These overidentifying restrictions are strong in that the $\hat{\pi}_{fc}$ are not functions of the w_{fc}.

IV. Cross-Country Results for Capital and Aggregate Labor

Since factor price data are available only for capital and aggregate labor, this section develops the detailed implications of the model for these factors only. Table 1 reports the calculated π_{Lc} and π_{Kc} for the normalization $\pi_{f,\mathrm{US}} = 1$.

Consider aggregate labor. To interpret the wage data, Bangladeshi workers earn 5 percent of the U.S. wage. Although part ii of proposition 1 established that the π_{Lc} can be negative, empirically they are all positive. In contrast, using a very different methodology, Bowen et al. (1987) estimated many negative productivity parameters. Equation (7) states that the $\pi_{Lc}/\pi_{L,\mathrm{US}}$ must equal the $w_{Lc}/w_{L,\mathrm{US}}$. This is a strong restriction in that factor price data are not used to compute the π_{Lc}. It is thus surprising that the correlation between the $\pi_{Lc}/\pi_{L,\mathrm{US}}$ and $w_{Lc}/w_{L,\mathrm{US}}$ series (.90) is extremely high.[3]

The $\pi_{Kc}/\pi_{K,\mathrm{US}}$ for capital are also sensible in that they are nonnegative (part ii of proposition 1) and, in general terms, agree with casual empiricism: the developing countries are at the top of the list and the developed countries are at the bottom. Bangladesh is the only country with a blatantly unusual $\pi_{Kc}/\pi_{K,\mathrm{US}}$. The theory predicts that $\pi_{Kc}/\pi_{K,\mathrm{US}} = w_{Kc}/w_{K,\mathrm{US}}$. Indeed, there is a high correlation between the $\pi_{Kc}/\pi_{K,\mathrm{US}}$ and $w_{Kc}/w_{K,\mathrm{US}}$ series (.68), as predicted.

[3] The only data from country c used to construct the π_{Lc} are data motivated by the HOV theorem: U.S. technology ($\mathbf{A}_{\mathrm{US}}$), consumption shares (s_c), labor endowments (V_{Lc}), and trade ($\mathbf{T}_c$). It is tempting to argue that the high correlation is due to the dependence of π_{Lc} on s_c; however, the correlation between $\pi_{Lc}/\pi_{L,\mathrm{US}}$ and s_c/s_{US} (.39) is less than half the correlation between $\pi_{Lc}/\pi_{L,\mathrm{US}}$ and $w_{Lc}/w_{L,\mathrm{US}}$.

There are two notable differences between the capital and labor results. First, the π_{Kc} are more tightly distributed than the π_{Lc}, perhaps reflecting the greater mobility of capital relative to labor that would likely reduce international capital productivity differences. Second, the correlation is lower for capital, which may reflect the conceptual and data difficulties relating to the construction of capital stock and capital price series.

The theory predicts more than just a high correlation between the $\pi_{fc}/\pi_{f,\mathrm{US}}$ and $w_{fc}/w_{f,\mathrm{US}}$ series: it also predicts that the two series will be equal. Figure 1 is a scatter plot of $w_{Lc}/w_{L,\mathrm{US}}$ against $\pi_{Lc}/\pi_{L,\mathrm{US}}$ that helps to examine this point. The diagonal of the box indicates where observations would lie if the $\pi_{Lc}/\pi_{L,\mathrm{US}}$ exactly equalled the $w_{Lc}/w_{L,\mathrm{US}}$. For example, the model is an almost perfect predictor of Japanese wages relative to U.S. wages (as well as Japanese trade in factor services).[4] The figure reveals a systematic predictive bias in that the $\pi_{Lc}/\pi_{L,\mathrm{US}}$ underpredict wages in the poorest countries and, to a lesser extent, overpredict wages in the wealthy European countries. This is affirmed most clearly by the following regression (standard errors are in parentheses):

$$\log(w_{Lc}) = \underset{(0.061)}{-0.180} + \underset{(0.042)}{0.678}\log(\pi_{Lc}), \quad R^2 = .90.$$

The slope is statistically less than unity. One explanation is that the π_{Lc} are measured with error. Let β be the slope coefficient of the (direct) regression just reported and let $\hat{\beta}^D$ denote its ordinary least squares estimate. Let $\hat{\beta}^R$ be the estimate of the slope coefficient of the following (reverse) regression:

$$\log(\pi_{Lc}) = \underset{(0.094)}{0.142} + \underset{(0.082)}{1.330}\log(w_{Lc}), \quad R^2 = .90.$$

If the error structure of the $\log(w_{Lc})$ and $\log(\pi_{Lc})$ follows that postulated by the normal errors-in-variables model, then the maximum likelihood estimate of β is not unique. In particular, when $0 < \hat{\beta}^D < 1/\hat{\beta}^R$, the set of maximum likelihood estimates is the interval $[\hat{\beta}^D, 1/\hat{\beta}^R] = [0.678, 0.752]$ (Klepper and Leamer 1984, theorem 1).[5] Since this interval excludes unity, the normal errors-in-variables model cannot explain why the slope is less than unity.

Another explanation is that the wage data pertain to nonagricultural activities. Agricultural wages tend to be lower than nonagricul-

[4] A bold conclusion from Saxonhouse's (1989) residual analysis is that Japanese protection has not distorted Japanese wages or trade in labor services.

[5] Even without normality, it is well known that β lies between $\text{plim}(\hat{\beta}^D)$ and $\text{plim}(1/\hat{\beta}^R)$. Notice that the direct and reverse regressions share the same R^2, $1/\hat{\beta}^R = \hat{\beta}^D/R^2$, and the t-statistics for $\hat{\beta}^D$ and $\hat{\beta}^R$ are necessarily identical ($t = 16.23$).

TABLE 1

FACTOR PRICES AND THE π_{fc} FOR CAPITAL AND AGGREGATE LABOR

AGGREGATE LABOR			CAPITAL			
Country	$\pi_{Lc}/\pi_{L,\mathrm{US}}$ (1)	$w_{Lc}/w_{L,\mathrm{US}}$ (2)	Country	$\pi_{Kc}/\pi_{K,\mathrm{US}}$ (3)	$w_{Kc}/w_{K,\mathrm{US}}$ (4)	$\alpha\pi_{Kc}/\pi_{K,\mathrm{US}}$ (5)
Bangladesh	.02	.05	Sri Lanka	.13	.22	.22
Sri Lanka	.04	.07	Indonesia	.26	.39	.43
Pakistan	.04	.11	Portugal	.31	.86	.52
Indonesia	.05	.19	Yugoslavia	.31	.88	.52
Thailand	.05	.14	Panama	.34	.75	.56
Portugal	.20	.29	Singapore	.34	.97	.57
Colombia	.22	.29	Thailand	.41	.67	.68
Yugoslavia	.22	.22	Uruguay	.42	.51	.70
Uruguay	.22		Trinidad	.43	.86	.73
Panama	.25	.26	Greece	.45	.97	.77
Greece	.35	.37	Ireland	.49	1.00	.83
Hong Kong	.42	.26	Colombia	.50	.62	.84
Ireland	.46	.56	Pakistan	.50	.69	.84
Spain	.47	.56	Israel	.52	.90	.88
Trinidad	.51		Italy	.53	.95	.89

Singapore	.54		.34	Spain	.53		.91	.90
New Zealand	.64		.84	Hong Kong	.53		1.18	.90
Austria	.64		.91	Austria	.56		1.06	.94
United Kingdom	.66		.70	Switzerland	.62		1.19	1.05
Japan	.66		.71	France	.63		1.07	1.06
Italy	.66		.80	Norway	.64		1.28	1.07
Israel	.67		.61	New Zealand	.64		1.17	1.07
Finland	.77		.48	Finland	.66		1.10	1.12
Denmark	.78		.76	Belgium	.66		1.11	1.12
Belgium	.81		.74	Japan	.67		1.27	1.12
Sweden	.82		.68	West Germany	.68		1.10	1.15
France	.84		.57	Denmark	.72		1.13	1.22
Canada	.84		1.08	Canada	.75		.98	1.27
Norway	.85		.65	Netherlands	.77		1.15	1.29
West Germany	.86		.72	United Kingdom	.84		1.22	1.41
Netherlands	.88		.86	Bangladesh	.94		.78	1.58
United States	1.00		1.00	Sweden	.97		1.63	1.64
Switzerland	1.04		.94	United States	1.00		1.00	1.68
Mean	.53		.54	Mean	.57		.96	.96
Correlation		.90		Correlation		.68		
Rank correlation		.86		Rank correlation		.71		

NOTE.—Col. 5 is col. 3 multiplied by $\alpha = .96/.57$. This ensures that col. 5 has the same mean as col. 4.

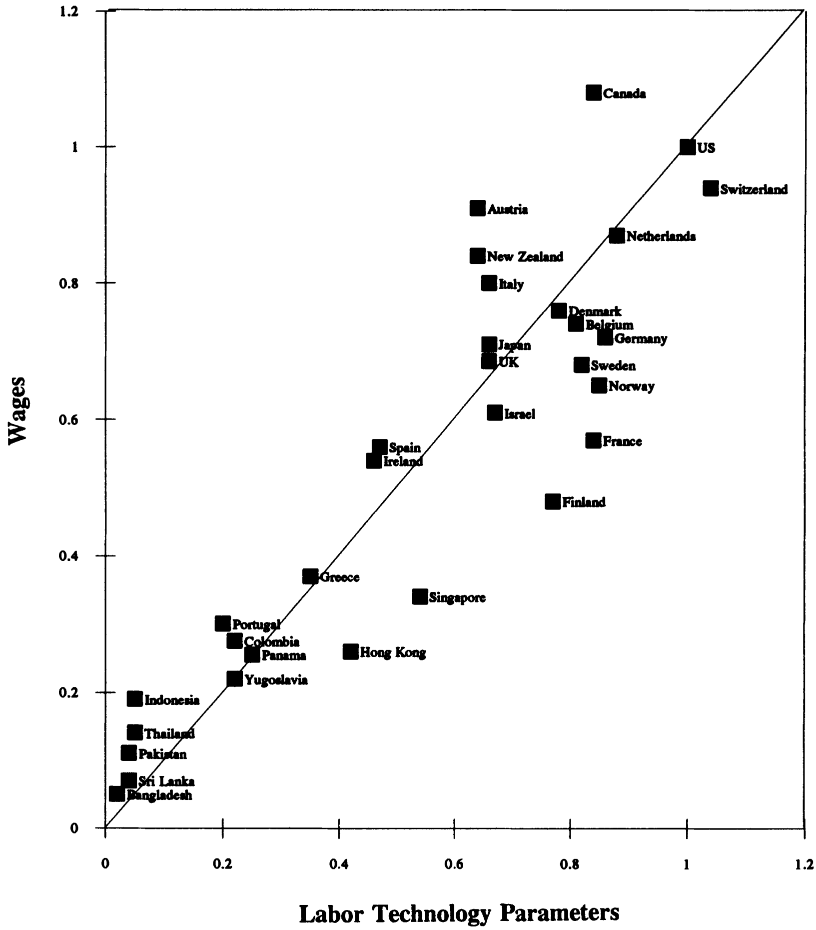

FIG. 1.—Wages and labor technology parameters

tural wages. Also, employment in the agricultural sector is proportionately larger in developing than in developed countries. These two facts bias upward the developing country wage data and bias downward the developed country wage data. A final explanation of the systematic bias is the use of a developed country as the norm ($\pi_{f,\mathrm{US}} = 1$); however, the similarity of the series means reported at the bottom of table 1 implies that any normalization that weights all countries equally will reproduce similar results (i.e., the United States is not an "outlier").

For capital, the United States is an outlier as is confirmed by the very different table 1 means for $\pi_{Kc}/\pi_{K,\mathrm{US}}$ and $w_{Kc}/w_{K,\mathrm{US}}$. For this reason, a more informative normalization is one that weights all countries equally and sets the means of the two series equal. (As the proof of part i of proposition 1 indicates, such a normalization is legitimate.) This is reported in column 5 of table 1, which simply multiplies $\pi_{Kc}/\pi_{K,\mathrm{US}}$ by $\alpha = (\Sigma_c w_{Kc}/w_{K,\mathrm{US}})/(\Sigma_c \pi_{Kc}/\pi_{K,\mathrm{US}})$. It is immediately apparent that Bangladesh and the United States are by far the largest outliers. On the other hand, there is no systematic bias or other anomalies in the way the $\pi_{Kc}/\pi_{K,\mathrm{US}}$ predict the $w_{Kc}/w_{K,\mathrm{US}}$. To see this, omit Bangladesh and the United States, rescale the $\pi_{Kc}/\pi_{K,\mathrm{US}}$ series so that it has the same mean as the $w_{Kc}/w_{K,\mathrm{US}}$ series, and consider the following regressions (standard errors in parentheses):

$$\log(w_{Kc}) = \underset{(0.038)}{-0.004} + \underset{(0.094)}{0.816} \log(\pi_{Kc}), \quad R^2 = .72,$$

$$\log(\pi_{Kc}) = \underset{(0.040)}{-0.016} + \underset{(0.102)}{0.883} \log(w_{Kc}), \quad R^2 = .72.$$

As expected, the intercept is statistically close to zero and the slope is statistically close to unity. Further, the set of maximum likelihood slope estimates, (0.816, 1.133), contains unity.

To conclude, the close correspondence between the π_{fc} and the w_{fc} strongly supports an HOV model that allows for factor-augmenting international technology differences and the implied international factor price differences.

V. Cross-Country Results for Each Factor

For factors other than capital and aggregate labor, the absence of factor price data leads to a search for alternative criteria for evaluating the economic reasonableness of the π_{fc}. This section provides four such criteria. The first is that the π_{fc} must be nonnegative (part ii of proposition 1). Table 2 lists factor-country pairs having negative π_{fc}. Only 10 of the 384 π_{fc} are negative, and they are primarily concentrated among the land factors and the three countries in the sample with the smallest land endowments, namely, Hong Kong, Singapore, and Trinidad and Tobago.

The second criterion is based on casual empiricism: U.S. productivity is among the highest in the world for each factor. Since $\pi_{f,\mathrm{US}} = 1$, this observation suggests that for each factor, the distribution across countries of the π_{fc} will be centered at less than unity. A robust summary statistic is the median. This is easily culled from Appendix tables A1 and A2, which report the π_{fc} sorted by size. For all but administrative workers and pasture, the median is less than unity as expected. The high median for administrative workers may be due to a classification error since the United States has more than half the world

TABLE 2

SUMMARY STATISTICS FOR THE PRODUCTIVITY PARAMETERS π_{fc}

Factor	$\pi_{fc} < 0$ (1)	$(\hat{\beta}_f^D,\ 1/\hat{\beta}_f^R)$ (2)	t (3)	R^2 (4)
Labor:				
Professional and technical	None	(.45, .57)	11.24	.80
Administrative and managerial	None	(.45, 1.33)	4.01	.34
Clerical	None	(.42, .52)	11.69	.82
Sales	None	(.86, .92)	20.34	.93
Service	None	(.66, .73)	15.96	.89
Agricultural and forestry	Hong Kong, Trinidad	(1.38, 1.68)	11.45	.82
Production and transport	None	(.72, .76)	23.51	.95
Land	Hong Kong, Trinidad, Portugal	(.80, 1.71)	4.98	.47
Cropland	Hong Kong, Trinidad, Portugal, Singapore	(.76, 1.23)	6.60	.62
Pasture	Hong Kong	(.66, 3.70)	2.55	.18

NOTE.—$\hat{\beta}_f^D$ and $\hat{\beta}_f^R$ are ordinary least squares estimates of eq. (8). The regressions include only countries with nonnegative π_{fc}. The two estimates, $\hat{\beta}_f^D$ and $\hat{\beta}_f^R$, have the same t-statistic. It appears in col. 3. The two regressions have the same R^2. It appears in col. 4.

endowment of administrative workers whereas France has virtually none. The U.S. productivity edge is known to be most dramatic in agriculture; correspondingly, the median for agricultural workers is the lowest of all factors.

The third criterion is the absence of π_{fc} that are inexplicably small or large, that is, the absence of outliers. From Appendix table A1, there are many outliers for administrative workers, but this is doubtless related to the classification error noted above. Another set of outliers is associated with agricultural workers, where many of the π_{fc} are virtually zero. For this factor, the π_{fc} are forced to zero by the choice of normalization ($\pi_{f,\mathrm{US}} = 1$) and the fact that the United States is so productive in agriculture. The second most productive country is the Netherlands, with a π_{fc} of only 0.61. Finally, for many countries the land factors have unreasonably large values of π_{fc}. The largest value of π_{fc} for aggregate land (101.76 for Singapore) coincides with the fact that by any measure, the Singapore endowment of pasture is the smallest endowment of any factor in any country in the data set. For the other aggregate land parameters in excess of $\pi_{f,\mathrm{US}}$, it appears that the capital-intensiveness of agriculture in rich, geographically small countries is captured by the π_{fc} for land. For example, the largest parameters include those for Japan (15.56), the Netherlands (11.57), Denmark (4.10), Switzerland (3.55), and Belgium (3.53). Thus many of the unusual π_{fc} are not spurious; rather, they can be related to economically interpretable features of the data.

The fourth and final criterion applies only to labor. Consider the developed countries. Occupational wage structures are stable across the developed countries and aggregate wages are correlated with per capita GNP, y_c. Hence, wages for *each* occupation are positively correlated with y_c. If this were also true for the developing countries, then the larger y_c is, the larger w_{fc} should be for each f. Equation (7) then predicts that y_c/y_{US} and $\pi_{fc}/\pi_{f,\mathrm{US}}$ will be positively correlated for each f. This suggests the following regressions, one for each labor occupation:

$$\begin{aligned} \log(\pi_{fc}) &= \alpha_f^D + \beta_f^D \log(y_c) + \epsilon_{fc}, \quad c = 1, \ldots, C, \\ \log(y_c) &= \alpha_f^R + \beta_f^R \log(\pi_{fc}) + u_{fc}, \quad c = 1, \ldots, C. \end{aligned} \tag{8}$$

If any of the β_f^D or β_f^R are negative, then the calculated π_{fc} are questionable. Note that the same argument for the land factors is less compelling.

The estimated regression coefficients and R^2's are reported in table 2. For each labor factor, $0 < \hat{\beta}_f^D < 1/\hat{\beta}_f^R$ so that the estimated coefficients are all positive. The very large $\hat{\beta}_f^D$ and $\hat{\beta}_f^R$ for agricultural workers mirror the very low rural living standards in developing countries relative to developed countries. The surprising feature of the results is the strength of the relationship between the labor parameters and per capita GNP. For all but one type of labor the cross-country R^2 is at least .80 and for production workers it reaches .95.[6]

In the absence of factor price data, alternative criteria must be used to evaluate the π_{fc}. Overall, the π_{fc} are plausible as judged by the four criteria adopted in this section.

VI. An Explanation

Given that the π_{fc} are calculated using data on the deviations from the HOV theorem, it is not immediately obvious why they are so plausible. This section suggests a feature of the data that explains the results. Let $V_{fw} = \Sigma_c V_{fc}$ be the world endowment of factor f. Gross national product at factor prices can be expressed as $Y_c = \Sigma_f w_{fc} V_{fc}$. If trade is balanced so that the consumption share s_c equals Y_c/Y_w, this GNP equation can be rewritten as

$$1 = \sum_f \omega_{fc} \text{FAR}_{fc}, \tag{9}$$

where $\omega_{fc} = w_{fc} V_{fw}/Y_w$ and $\text{FAR}_{fc} = (V_{fc}/V_{fw})/s_c$. The term FAR_{fc} is the factor abundance ratio: by definition, it exceeds unity if and only if country c is abundant in factor f. In the standard HOV model with identical technologies and factor price equalization, $\Sigma_f \omega_{fc} = 1$ so that the weighted average of the factor abundance ratios is unity. In particular, no country can be scarce or abundant in all factors. Yet inspection of Leamer's (1984) resource abundance profiles reveals that each developed country suffers a scarcity of almost all factor endowments and each developing country enjoys an abundance of a large number of factor endowments. Strictly reasoned, this is not inconsistent with equation (9) since no country is scarce or abundant in all factors and since some factors are omitted from Leamer's study; nevertheless, the strength of the pattern is at odds with the spirit of a theory whose cornerstone is factor abundance.

Table 3 illustrates that the same pattern appears in the current data. Column 1 reports that the cross-country correlation between per capita GNP and FAR_{fc} is negative for all factors; that is, developed

[6] The cross-section R^2 of .95 led me to an extensive search for an underlying identity in the construction of the π_{fc}. The search was unsuccessful. For example, the correlations of the π_{fc} with country characteristics (e.g., s_c, y_c, and Y_c/V_{fc}) were never nearly as high as those reported in table 2 and were often quite small. The proof of part ii of proposition 1 provides a simple example that shows there is no such underlying identity.

TABLE 3

CORRELATIONS OF FACTOR ABUNDANCE RATIOS WITH PER CAPITA GNP

	$(V_{fc}/V_{fw})/s_c$ (1)	$(V^*_{fc}/V^*_{fw})/s_c$ (2)
Capital	$-.65^{\dagger}$	$.63^{\dagger}$
Labor	$-.95^{\dagger}$	.32
Land	$-.64^{\dagger}$	$-.16$

NOTE.—Col. 1 is the rank correlation of per capita GNP with the factor abundance ratio $(V_{fc}/V_{fw})/s_c$. Col. 2 is the rank correlation of per capita GNP with the productivity-equivalent factor abundance ratio $(V^*_{fc}/V^*_{fw})/s_c$.

† Statistically significant at the 5 percent level.

countries tend to be scarce in all factors and developing countries tend to be abundant in all factors. This pattern appears for disaggregated factors as well. An obvious explanation is that the developed countries have a more productive relationship between endowments (inputs) and s_c (output) than the developing countries and so need less of all endowments to attain a given s_c. This observation suggests the need for modeling international productivity differences, that is, for modeling the π_{fc}.

Column 2 of table 3 suggests that it is this feature of the data that drives the pattern of the calculated π_{fc}. Let $V^*_{fw} = \Sigma_c V^*_{fc}$ be the world endowment of factor f measured in productivity-equivalent units. By productivity-equivalent factor price equalization the w^*_{fc} are equal across countries so that $w^*_{fc} = w^*_f$. With $V^*_{fc} = \pi_{fc} V_{fc}$ and $w^*_f = w_{fc}/\pi_{fc}$ (eq. [3]), $Y_c = \Sigma_f w_{fc} V_{fc}$ can be written as $Y_c = \Sigma_f w^*_f V^*_{fc}$. Rearranging yields

$$1 = \sum_f \omega^*_f \mathrm{FAR}^*_{fc}, \tag{10}$$

where $\omega^*_f = w^*_f V^*_{fw}/Y_w$ and $\mathrm{FAR}^*_{fc} = (V^*_{fc}/V^*_{fw})/s_c$. The term FAR^*_{fc} is the factor abundance ratio measured in productivity-equivalent units. Since $Y_w = \Sigma_f w^*_f V^*_{fw}$, it follows that $\Sigma_f \omega^*_f = 1$. Hence, measured in productivity-equivalent units, no country can be scarce or abundant in all factors. It follows that the signs of the cross-country correlations of per capita GNP with FAR^*_{fc} must vary across factors; otherwise, countries are scarce or abundant in all factors. Alternatively, the correlations must be statistically insignificant. Table 3 reveals that this is the case. Further, the table reveals that in productivity-equivalent terms, the developed countries are capital abundant, a pattern that accords with the well-known link between capital formation and development. Thus the feature of the data that drives the π_{fc} appears to be productivity differences between the developed and developing countries.

VII. Leontief Was Right!

Using 1947 U.S. data, Leontief (1953) showed that the capital/labor ratio for imports exceeded the capital/labor ratio for exports. I refer to this fact as the Leontief paradox. Note, though, that Leamer (1980) showed that there is nothing paradoxical about it. Table 4 presents several features of the 1983 U.S. data. Column 1 shows that the ratio of capital exports to capital imports (0.84) is almost identical to what it was in 1947 (0.83). However, the ratio of labor exports to labor imports (0.78) fell from its 1947 level (1.07). Hence, the Leontief paradox has disappeared. Stern and Maskus (1981) found that the paradox disappeared sometime between 1958 and 1972. Column 2 illustrates that departures from the HOV theorem as measured by the difference between $\mathbf{F}_{US} = \mathbf{A}_{US}\mathbf{T}_{US}$ and $\hat{\mathbf{F}}_{US} = \mathbf{V}_{US} - s_{US}\mathbf{V}_w$ (and scaled by $\hat{\mathbf{F}}_{US}$) are substantial. Large prediction errors like those in column 2 are the basis for the Bowen et al. (1987) rejection of the HOV theorem.

Since the data set includes the world endowment of factors, factor abundance ratios $\text{FAR}_{f,\text{US}} = (V_{f,\text{US}}/V_{fw})/s_{\text{US}}$ can be calculated (col. 3). If this ratio exceeds unity, then the United States is abundant in factor f. Land is abundant and both capital and labor are scarce. That the United States is labor scarce is to be expected: more surprising is that the United States is capital scarce. This coincides with the general scarcity of factors among the developed countries.

Leontief (1953) conjectured that the reason U.S. exports were more labor intensive than U.S. imports in 1947 was that the United States

TABLE 4

THE LEONTIEF PARADOX AND HIS EXPLANATION

Factor	$\frac{[\mathbf{A}^*\mathbf{X}_{\text{US}}]_f}{[\mathbf{A}^*\mathbf{M}_{\text{US}}]_f}$ (1)	$\frac{F_{f,\text{US}} - \hat{F}_{f,\text{US}}}{\hat{F}_{f,\text{US}}}$ (2)	$\frac{V_{f,\text{US}}/V_{fw}}{s_c}$ (3)	$\frac{V^*_{f,\text{US}}/V^*_{fw}}{s_c}$ (4)
Capital	.84	−.95	.71	.97
Labor	.78	−.98	.54	.96
Land	2.12	−.40	1.28	1.19

NOTE.—Col. 1 reports the factor content of exports relative to the factor content of imports. Col. 2 reports deviations from the HOV theorem: $F_{f,\text{US}} = [\mathbf{A}^*\mathbf{T}_{\text{US}}]_f$ is the factor content of U.S. trade and $\hat{F}_{f,\text{US}} = V_{f,\text{US}} - s_{\text{US}}V_{fw}$ is the endowment-based prediction of $F_{f,\text{US}}$. In the HOV theorem, a factor is defined to be abundant if its factor abundance ratio $(V_{f,\text{US}}/V_{fw})/s_{\text{US}}$ exceeds unity. In the productivity-equivalent version of the HOV theorem (eq. [4]), a factor is defined to be abundant if $(V^*_{f,\text{US}}/V^*_{fw})/s_{\text{US}}$ exceeds unity.

was labor abundant as measured in productivity-equivalent units.[7] Column 4 reports abundance ratios measured in productivity-equivalent units, that is, $FAR^*_{f,US} = (V^*_{f,US}/V^*_{fw})/s_{US}$. (Note that since $\pi_{f,US} = 1$, $V^*_{f,US} = V_{f,US}$; however, $V^*_{fw} \neq V_{fw}$.) It is immediately apparent that there is considerable validity to Leontief's claim: the abundance ratio for labor almost doubles from 0.54 to 0.96. This upward adjustment makes the United States approximately labor neutral. Although this does not satisfy Leontief's claim that in 1947 the United States was labor abundant as measured in productivity-equivalent units, the discrepancy likely reflects the narrowing of the productivity gap between the United States and its major trading partners that has occurred since Leontief wrote. Leontief went on to argue that the productivity adjustment for labor would be much more dramatic than the productivity adjustment for capital.[8] This prediction is also borne out by the data, which show that while the capital abundance ratio rose from 0.71 to 0.97, it did not rise as much as the labor abundance ratio. Overall, these striking results support the view that in the extensive discussions surrounding the so-called Leontief paradox, Leontief's own insight was right!

VIII. Interpretation of the π_{fc}

The interpretation that properly attaches to the π_{fc} is not crystal clear. Consider the π_{fc} of 0.66 for British workers. One possibility is that British workers simply work two-thirds as hard as U.S. workers. Another possibility is that British workers are just as industrious, but they have access to a technology that makes them only two-thirds as efficient. A final possibility is that both industriousness and technology are the same globally, but the United States and Britain lie in different cones of diversification: Britain uses labor-intensive techniques to produce a labor-intensive mix of products and the United States uses capital-intensive techniques to produce a capital-intensive mix of products. This third possibility has some intellectual appeal

[7] "Let us, however, reject the simple but tenuous postulate of comparative *technological parity* and make the plausible alternative assumption that in any combination with a given quantity of capital, *one man year of American labor is equivalent to, say, three man years of foreign labor*. . . . Spread thrice as thinly as the unadjusted figures suggest the American *capital supply per 'equivalent worker' turns out to be comparatively smaller*, rather than larger, than that of many other countries. This, I submit, is the analytical explanation of the results of our empirical findings" (Leontief [1953] 1968, pp. 523–24; italics added).

[8] United States technology factors "must have increased—in comparison with other countries—the productivity of American labor much more than they have raised the efficiency of American capital" (Leontief 1968, p. 526).

since it fits squarely within traditional HOV concerns. Indeed, cones of diversification creep into proposition 1 via the assumption that all the V_{fc} are strictly positive. However, it is not transparent how to create a multicone HOV model that allows the HOV factor content prediction to be couched in terms of factor earnings $\pi_{fc}V_{fc}$ rather than factor supplies V_{fc}. This pushes me strongly toward the other two possibilities: industriousness and technology.

It is formally impossible to distinguish between these two possibilities. To see this let ϕ_c^i be the production function for industry i in country c and let V_{fc}^i be the input of factor f in industry i. Assumption A is satisfied if for all i and c there exist internationally identical production functions ϕ^i such that $\phi_c^i(V_{1c}^i, \ldots, V_{Fc}^i) = \phi^i(\pi_{1c}V_{1c}^i, \ldots, \pi_{Fc}V_{Fc}^i)$. Hence, the component of π_{fc} interacting with V_{fc} (call it industriousness or factor quality) is indistinguishable from the component of π_{fc} interacting with ϕ_c^i (call it technology). This feature is shared with much of the productivity literature, a point highlighted by the fact that the π_{fc} are closely related to Malmquist indices of productivity differences (Caves, Christensen, and Diewert 1982). My view, necessarily informal in light of this, is that the productivity parameters reflect national differences that strike at the heart of the imperfectly understood development process. One facet of national differences that I have discussed elsewhere is the ability to commercialize technology (Trefler 1993*a*). While basic research is internationally available through publications of the scientific community, the translation of basic research into low-cost production processes is both a guarded secret of firms and the comparative advantage of the developed countries.

Given that for expositional purposes I am interpreting the π_{fc} as productivity parameters, it is of some interest to compare my calculated π_{fc} with existing productivity estimates. For the small subset of developed countries for which reliable productivity indices have been computed, it is possible to compare them with my π_{fc}. Denny and Fuss (1983) found that in 1973, Japan was 8 percent more productive than the United States, a figure that is much higher than the table 2 values for Japan of $\pi_{Lc} = 0.66$ and $\pi_{Kc} = 0.67$. On the other hand, Christensen, Cummings, and Jorgenson (1981) found that in 1973, Japan was only 77 percent as productive as the United States, a figure similar to my own. The Christensen et al. study is by far the most comprehensive in terms of country coverage. It covers Korea (which is not in my sample) and eight OECD countries in 1973. Christensen et al. found that across the OECD countries in their sample, productivity relative to the United States varied between 0.77 and 0.91. The corresponding ranges of the π_{fc} for these countries are (0.66, 0.88) for labor and (0.53, 0.84) for capital. Thus my π_{fc} have a downward bias but are otherwise close to the carefully constructed Christensen et al. figures. This suggests that the π_{fc} at least partly capture what is commonly termed "productivity."

IX. Conclusions

The factor price equalization hypothesis and the Heckscher-Ohlin-Vanek theorem are widely at variance with observed international differences in factor prices and international trade in factor services. Departures from the factor price equalization hypothesis and the HOV theorem were examined theoretically and empirically using a generalization of the HOV model. The generalization was motivated by Leontief's original explanation of his so-called paradox: factor-augmenting international technology differences imply that endowments must be adjusted to reflect international productivity differences.

My method was to calculate international productivity differences that make the HOV theorem perfectly fit the data on trade and endowments. I then showed that these international productivity differences are consistent with observed international factor price differences. For example, it was necessary to assume that British labor productivity is only two-thirds of U.S. labor productivity in order to make the modified HOV theorem fit exactly. Correspondingly, British wages were found to be about two-thirds of U.S. wages.

An alternative method is to work in the opposite direction from factor prices to the HOV theorem. I could have inferred international productivity differences from international factor price differences and shown that the inferred productivities make the modified HOV theorem fit remarkably well. The modification of the HOV theorem under consideration would have been to replace factor endowments with factor endowment earnings. No matter what the method of investigation, the conclusion remains: There is a simple modification of the HOV model that explains most of the factor content of trade and the cross-country variation in factor prices.

Appendix

A. *Mathematics*

Proof of Proposition 1

Part i: $\hat{\mathbf{\Pi}}_f$ is defined as a solution to the system $\mathbf{F}_f^* = \mathbf{X}_f\mathbf{\Pi}_f$, where $\mathbf{X}_f$ is given in equation (6). Consider the rank of $\mathbf{X}_f$. The sum of column c is $(1 - \Sigma_j s_j)V_{fc} = 0$. Deleting row c and taking α_j-weighted linear combinations of the remaining rows yield a c element equal to $-V_{fc}\Sigma_{j\neq c}\alpha_j s_j$, which is nonzero when at least one α_j is nonzero. Thus $\text{rank}(\mathbf{X}_f) = C - 1$. Consider the rank of the augmented matrix $[\mathbf{X}_f, \mathbf{F}_f^*]$. Since $\Sigma_c \mathbf{T}_c = \mathbf{0}$ implies $\Sigma_c F_{fc}^* = 0$, $\text{rank}[\mathbf{X}_f, \mathbf{F}_f^*] = C - 1$. Hence, a solution exists that is unique up to a single normalization (Theil 1971, sec. 1.3).

Part ii: Consider an example with two countries and two goods. Without loss of generality, let $\pi_{f1} = 1$ and assume that country 2 imports the services of factor f so that $F^*_{f2} < 0$. Solving for π_{f2} yields $\pi_{f2} = (F^*_{f2} + s_2 V_{f1})/(1 - s_2)V_{f2}$. A simple numerical example shows that π_{f2} can be negative.

Part iii: By part i, $\hat{\mathbf{\Pi}}_f$ has only one degree of freedom. But equation (5) (or see eq. [7]) imposes an additional $C - 1 > 1$ linearly independent restrictions so that $\hat{\mathbf{\Pi}}_f$ cannot also satisfy equation (5). Q.E.D.

A Note on Computations

The $\hat{\mathbf{\Pi}}_f$ were calculated by setting $\pi_{f,\text{US}}$ to unity and omitting the equation corresponding to the United States. This results in a full-rank, $C - 1$ dimensional linear system that is easily solved. In theory, the choice of omitted country does not matter unless $\Sigma_c \mathbf{T}_c$ is nonzero, as is the case in the data set. In practice, the small size of $\Sigma_c \mathbf{T}_c$ means that the choice of omitted country makes little difference.

That $\Sigma_c \mathbf{T}_c$ is nonzero is partly due to omitted countries. Suppose that there are data for countries $c = 1, \ldots, C$ and no data for countries $c = C + 1, \ldots, C'$. Then equation (4) can be written as $\mathbf{F}^*_f = \mathbf{X}_f \mathbf{\Pi}_f + \alpha_f \boldsymbol{\iota}$, where $\boldsymbol{\iota}$ is a $C \times 1$ vector of ones and $\alpha_f = \Sigma_{j=C+1}^{C'} \pi_{fj} V_{fj}$. In this case, it is trivial to show that proposition 1 remains the same with $\mathbf{X}_f \hat{\mathbf{\Pi}}_f$ replaced by $\mathbf{X}_f \hat{\mathbf{\Pi}}_f + \hat{\alpha}_f \boldsymbol{\iota}$ and $\hat{\mathbf{\Pi}}_f$ replaced by $(\hat{\mathbf{\Pi}}_f, \hat{\alpha}_f)$. In light of this, it is not surprising that the reported $\hat{\mathbf{\Pi}}_f$ are very similar to those calculated under the assumption of incomplete country coverage.

B. Data

All data pertain to 1983 unless otherwise stated.

International Factor Endowment and Factor Price Data

Labor.—International labor endowments are defined as the economically active population as reported in the International Labour Office *Yearbook of Labour Statistics* (1945–89). Labor is disaggregated into the seven one-digit International Standard Classification of Occupations categories. These data are taken from national censuses that were often conducted in years other than 1983 and so were adjusted by multiplying the data by the ratio of population in 1983 to population in the census year. Population data are taken from World Bank (1988). International wage data are earnings per hour in nonagricultural activities as reported in the International Labour Office *Yearbook of Labour Statistics* (1989–90).[9] Wages were converted into U.S. dollars using a consumption-based PPP adjustment for exchange rates

[9] Details of the construction of the wage series are as follows. (i) For most countries, weekly or monthly earnings and hours worked were used to compute hourly wages. Where wages were reported per month and hours per week (nine middle-income countries), I converted by the factor 52/12. Where wages were reported per day and hours per week (Bangladesh, Hong Kong, and Indonesia), I assumed 5.5 working days per week. (ii) Where only manufacturing wages were available, they were adjusted using the U.S. ratio of manufacturing wages to nonagricultural wages. (iii) On the basis of similar per capita incomes, wages in Colombia and Indonesia were proxied by wages in Paraguay and the Philippines, respectively, and hours per week in Pakistan were proxied by Sri Lankan hours per week. (iv) For Bangladesh, unskilled wages were used rather than skilled wages. (v) For Switzerland, wages for males only were used. (vi) For Singapore, 1986 wages deflated by the consumer price index were used. Errors introduced by points i–vi seem small relative to national differences in the collection of the underlying data on earnings and hours worked.

taken from the Penn World Table (Mark 5) as documented in Summers and Heston (1991).

Capital.—International capital stock data were constructed using the most common method, namely, the double declining balance method (e.g., Leamer 1984). The investment flows, domestic investment price indexes, and investment-based PPP adjustments needed to construct dollar-denominated capital stock data are taken from the Penn World Table. The assumed asset life is 15 years, though longer lives of 20 and 25 years made no difference to the results. The price of capital is the 1981 (PPP-adjusted) investment price index from the Penn World Table. See Section III above for further details.

Land.—International land endowment data are taken from the United Nations Food and Agricultural Organization's *Production Yearbook* (1984) and are measured in hectares.

Consumption shares.—Consumption shares ($s_c = [Y_c - B_c]/Y_w$) were computed using data on GNP, imports, and exports from World Bank (1988).

Technology Data

The technology matrix $\mathbf{A}_c^*$ was constructed from the U.S. input-output table (U.S. Department of Commerce 1989) and from data on U.S. factor usage by industry. Data on factor usage are detailed in Trefler (1993*b*) and were computed from the Current Population Survey, March 1984, and various U.S. Department of Commerce industry censuses. Note that the occupation data have been updated using 1983 data contained in the March 1984 Current Population Survey. Further, for the very few industries for which disaggregated capital stock data were not available from industry censuses, the aggregated data were prorated on the basis of the value of fixed assets as reported in U.S. Internal Revenue Service (1986). Land is treated differently than in most factor content studies in that land is measured in hectares and is taken from the *Census of Agriculture* rather than imputed from the U.S. input-output table. This means that input-output table industries 1 and 2 are not treated as the sole users of pasture and cropland, respectively; rather, land use by type and industry is more sensibly based on *Census of Agriculture* data. It also means that land endowments in the United States are calculated on a consistent basis with land endowments in other countries.

International Trade Data

Trade data are taken from the United Nations Statistical Office Trade Tape (1988). They were converted from the four-digit Standard Industrial Trade Classification (SITC) (revision 1) industry classification into the 79-sector, input-output industry classification. While finer input-output industry classifications are available, they were not used because it was felt that commodity conversion at finer levels of disaggregation is not reliable (see U.S. Department of Commerce 1985; Maskus 1991). Conversion was based on an SITC(R1)-SITC(R2) converter supplied by the World Bank, the SITC(R2)-SIC converter in the *1983 Imports Extract Master (Concordance)* (U.S. Department of Commerce), and appendix B of U.S. Department of Commerce (1984). In the conversion process, classifications "stepped down" from four digits to two digits.

C. *Productivity Parameters*

Table A1 reports the π_{fc} for each labor classification. Table A2 reports the π_{fc} for each land classification.

TABLE A1

PRODUCTIVITY PARAMETERS π_{fc} BY DISAGGREGATED LABOR CLASSIFICATION

Professional and Technical		Administrative and Managerial		Clerical		Sales		Service		Agricultural		Production and Transport	
Sri	.10	Ban	.29	Sri	.10	Ban	.02	Ban	.03	HK	−.40	Ban	.04
Ban	.12	Tha	.29	Ban	.13	Ind	.04	Sri	.09	Tri	−.04	Sri	.04
Pak	.17	Pak	.33	Ind	.24	Sri	.05	Pak	.13	Ban	.00	Pak	.05
Ind	.26	Sri	.47	Pak	.24	Pak	.05	Ind	.15	Sri	.00	Ind	.08
Tha	.27	Pan	.52	Por	.25	Tha	.08	Uru	.16	Ind	.00	Tha	.14
Yug	.31	UK	.70	Uru	.28	Uru	.18	Col	.22	Pak	.00	Por	.18
Uru	.33	Uru	.86	Yug	.36	Col	.23	Pan	.22	Por	.00	Yug	.21
Pan	.38	US	1.00	Pan	.40	Por	.24	Por	.24	Tha	.01	Uru	.23
Por	.40	Sin	1.10	Col	.48	Yug	.38	Tha	.24	Col	.02	Col	.25
Isr	.43	Yug	1.26	Tha	.54	HK	.39	HK	.33	Yug	.02	Pan	.28
Swe	.47	Isr	1.34	HK	.58	Pan	.40	Yug	.45	Grc	.03	Tri	.31
Col	.56	Jap	1.48	Sin	.59	Ire	.41	Grc	.58	Pan	.05	HK	.32
Grc	.56	Por	1.49	Grc	.62	Grc	.42	Dnk	.59	Spa	.05	Grc	.33
Ire	.57	Can	1.60	Isr	.62	Jap	.44	Spa	.59	Jap	.06	Sin	.34
UK	.57	HK	1.63	Aus	.64	Sin	.48	Aus	.64	Ita	.07	Ire	.36
Fin	.65	Ire	1.67	NZ	.64	Spa	.49	Tri	.64	Uru	.09	Spa	.37
NZ	.66	NZ	1.77	Spa	.66	NZ	.60	UK	.66	Ger	.12	NZ	.53
Nld	.68	Nor	1.78	Tri	.66	Aus	.67	Sin	.71	Aus	.14	Aus	.55
Nor	.68	Grc	2.01	UK	.68	Ita	.77	Ire	.77	Ire	.14	Ita	.57
Bel	.69	Dnk	2.13	Ire	.69	Tri	.77	Isr	.79	Fin	.16	UK	.60
Dnk	.71	Fin	2.55	Bel	.70	Can	.80	Fin	.80	Swz	.19	Jap	.61
Spa	.75	Col	2.60	Jap	.70	Nld	.80	Swe	.80	Bel	.23	Isr	.71
Can	.76	Spa	2.98	Ita	.71	Ger	.86	Can	.81	Fra	.23	Bel	.72
Ita	.77	Tri	3.25	Can	.73	Nor	.87	Ita	.82	Swe	.29	Ger	.73
Fra	.80	Swe	3.35	Fra	.75	Bel	.90	Nor	.85	Isr	.33	Fin	.74
Tri	.81	Nld	3.37	Dnk	.76	Isr	.91	Fra	.90	Nor	.36	Nor	.75
Aus	.85	Ger	3.78	Ger	.79	Fra	.94	NZ	.95	NZ	.43	Fra	.77
Sin	.93	Ita	3.85	Nld	.80	Swe	.95	Nld	.98	Dnk	.49	Dnk	.79
US	1.00	Bel	3.90	Swz	.89	Dnk	.96	US	1.00	Sin	.50	Nld	.90
HK	1.02	Aus	4.56	Swe	.97	Fin	.97	Jap	1.01	Can	.57	Can	.91
Swz	1.06	Swz	4.57	US	1.00	US	1.00	Ger	1.06	UK	.60	Swe	.91
Jap	1.17	Ind	4.95	Fin	1.08	UK	1.11	Bel	1.11	Nld	.61	Swz	.94
Ger	1.23	Fra	31.50	Nor	1.44	Swz	1.27	Swz	1.19	US	1.00	US	1.00

TABLE A2

PRODUCTIVITY PARAMETERS π_{fc} BY DISAGGREGATED LAND CLASSIFICATION

All Land		Cropland		Pasture	
HK	−289.97	HK	−224.07	HK	−817.18
Tri	−.41	Sin	−20.92	Uru	.10
Por	−.10	Tri	−.85	Col	.13
Ban	.10	Por	−.37	Pan	.31
Uru	.15	Ban	.03	NZ	.37
Pak	.18	Pak	.10	Ind	.47
Col	.21	Ind	.17	Pak	.49
Ind	.28	Sri	.23	Grc	.52
Sri	.33	Spa	.25	Ire	.62
Pan	.40	Tha	.30	Yug	.66
Yug	.48	Yug	.33	Sri	.82
Spa	.52	Can	.48	Can	.98
Grc	.56	Uru	.58	US	1.00
Tha	.57	Bel	.59	Spa	1.05
NZ	.59	Pan	.59	Ban	1.30
Can	.65	Col	.60	Por	1.73
Ire	.77	Grc	.62	Aus	2.04
US	1.00	Ita	.68	Isr	2.22
Ita	1.44	Fin	.71	UK	2.33
Aus	1.67	Swe	.95	Fra	3.25
UK	2.04	US	1.00	Ita	3.29
Fin	2.12	Ger	1.16	Swz	3.44
Fra	2.27	Aus	1.21	Tri	5.88
Swe	2.30	Ire	1.50	Ger	7.13
Isr	2.35	UK	1.57	Bel	7.14
Ger	3.46	Fra	1.60	Swe	7.95
Bel	3.53	Dnk	1.79	Nld	13.31
Swz	3.55	Nor	1.89	Tha	17.20
Dnk	4.10	Isr	2.60	Fin	22.90
Nor	5.50	Swz	4.00	Dnk	29.16
Nld	11.57	Jap	4.59	Nor	35.56
Jap	15.56	NZ	7.58	Jap	104.33
Sin	101.76	Nld	9.27	Sin	837.81

References

Baldwin, Robert. "Determinants of the Commodity Structure of U.S. Trade." *A.E.R.* 61 (March 1971): 126–46.

Bardhan, Pranab K. "International Differences in Production Functions, Trade and Factor Prices." *Econ. J.* 75 (March 1965): 81–87.

Bowen, Harry P.; Leamer, Edward E.; and Sveikauskas, Leo. "Multicountry, Multifactor Tests of the Factor Abundance Theory." *A.E.R.* 77 (December 1987): 791–809.

Brecher, Richard A., and Choudhri, Ehsan U. "The Factor Content of International Trade without Factor-Price Equalization." *J. Internat. Econ.* 12 (May 1982): 277–83. (*a*)

———. "The Leontief Paradox, Continued." *J.P.E.* 90 (August 1982): 820–23. (*b*)

———. "The Factor Content of Consumption in Canada and the United States: A Two-Country Test of the Heckscher-Ohlin-Vanek Model." In

Empirical Methods for International Trade, edited by Robert C. Feenstra. Cambridge, Mass.: MIT Press, 1988.

Casas, François R., and Choi, E. Kwan. "The Leontief Paradox: Continued or Resolved?" *J.P.E.* 93 (June 1985): 610–15.

Caves, Douglas W.; Christensen, Laurits R.; and Diewert, W. Erwin. "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity." *Econometrica* 50 (November 1982): 1393–1414.

Chenery, Hollis; Robinson, Sherman; and Syrquin, Moshe. *Industrialization and Growth: A Comparative Study.* New York: Oxford Univ. Press (for World Bank), 1986.

Christensen, Laurits R.; Cummings, Dianne; and Jorgenson, Dale W. "Relative Productivity Levels, 1947–1973: An International Comparison." *European Econ. Rev.* 16 (May 1981): 61–94.

Deardorff, Alan V. "Weak Links in the Chain of Comparative Advantage." *J. Internat. Econ.* 9 (May 1979): 197–209.

———. "The General Validity of the Heckscher-Ohlin Theorem." *A.E.R.* 72 (September 1982): 683–94.

Denny, Michael G. S., and Fuss, Melvyn A. "A General Approach to Intertemporal and Interspatial Productivity Comparisons." *J. Econometrics* 23 (December 1983): 315–30.

Heckscher, Eli F. "The Effect of Foreign Trade on the Distribution of Income" (in Swedish). *Ekonomisk Tidskrift* 21, no. 2 (1919): 1–32. Reprinted in *Readings in the Theory of International Trade.* Homewood, Ill.: Irwin (for American Econ. Assoc.), 1950.

Helpman, Elhanan. "The Factor Content of Foreign Trade." *Econ. J.* 94 (March 1984): 84–94.

Keesing, Donald B. "Labor Skills and International Trade: Evaluating Many Trade Flows with a Single Measuring Device." *Rev. Econ. and Statis.* 47 (August 1965): 287–94.

———. "Labor Skills and Comparative Advantage." *A.E.R. Papers and Proc.* 56 (May 1966): 249–58.

Klepper, Steven, and Leamer, Edward E. "Consistent Sets of Estimates for Regressions with Errors in All Variables." *Econometrica* 52 (January 1984): 163–83.

Kohler, Wilhelm. "How Robust Are Sign and Rank Order Tests of the Heckscher-Ohlin-Vanek Theorem?" *Oxford Econ. Papers* 43 (January 1991): 158–71.

Leamer, Edward E. "The Leontief Paradox, Reconsidered." *J.P.E.* 88 (June 1980): 495–503.

———. *Sources of International Comparative Advantage: Theory and Evidence.* Cambridge, Mass.: MIT Press, 1984.

Leamer, Edward E., and Bowen, Harry P. "Cross-Section Tests of the Heckscher-Ohlin Theorem: Comment." *A.E.R.* 71 (December 1981): 1040–43.

Leontief, Wassily W. "Domestic Production and Foreign Trade: The American Capital Position Re-examined." *Proc. American Philosophical Soc.* 97 (September 1953): 332–49. Reprinted in *Readings in International Economics,* edited by Richard E. Caves and Harry G. Johnson. Homewood, Ill.: Irwin, 1968.

———. "Factor Proportions and the Structure of American Trade: Further Theoretical and Empirical Analysis." *Rev. Econ. and Statis.* 38 (November 1956): 386–407.

Maskus, Keith E. "A Test of the Heckscher-Ohlin-Vanek Theorem: The Leontief Commonplace." *J. Internat. Econ.* 19 (November 1985): 201–12.

———. "Comparing International Trade Data and Product and National Characteristics Data for the Analysis of Trade Models." In *International Economic Transactions: Issues in Measurement and Empirical Research,* edited by Peter Hooper and J. David Richardson. Chicago: Univ. Chicago Press (for NBER), 1991.

Melvin, James R. "Production and Trade with Two Factors and Three Goods." *A.E.R.* 58 (December 1968): 1249–68.

Ohlin, Bertil G. *Interregional and International Trade.* Cambridge, Mass.: Harvard Univ. Press, 1933.

Samuelson, Paul A. "International Trade and the Equalisation of Factor Prices." *Econ. J.* 58 (June 1948): 163–84.

Saxonhouse, Gary R. "Differentiated Products, Economies of Scale, and Access to the Japanese Market." In *Trade Policies for International Competitiveness,* edited by Robert C. Feenstra. Chicago: Univ. Chicago Press (for NBER), 1989.

Staiger, Robert W. "A Specification Test of the Heckscher-Ohlin Theory." *J. Internat. Econ.* 25 (August 1988): 129–41.

Stern, Robert M., and Maskus, Keith E. "Determinants of the Structure of U.S. Foreign Trade, 1958–76." *J. Internat. Econ.* 11 (May 1981): 207–24.

Summers, Robert, and Heston, Alan. "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950–1988." *Q.J.E.* 106 (May 1991): 327–68.

Theil, Henri. *Principles of Econometrics.* New York: Wiley, 1971.

Travis, William P. *The Theory of Trade and Protection.* Cambridge, Mass.: Harvard Univ. Press, 1964.

Trefler, Daniel. "International Factor Price Differences: Leontief Was Right!" Manuscript. Toronto: Univ. Toronto, Dept. Econ., 1992.

———. Review of *Technology and the Wealth of Nations,* edited by Nathan Rosenberg, Ralph Landau, and David C. Mowery. *Rev. Internat. Econ.* (1993), in press. (*a*)

———. "Trade Liberalization and the Theory of Endogenous Protection: An Econometric Study of U.S. Import Policy." *J.P.E.* 101 (February 1993): 138–60. (*b*)

U.S. Department of Commerce. "The Input-Output Structure of the U.S. Economy, 1977." *Survey Current Bus.* 64 (May 1984): 42–84.

———. *Understanding United States Foreign Trade Data.* Washington: U.S. Dept. Commerce, Internat. Trade Admin., 1985.

U.S. Internal Revenue Service. *Source Book, Statistics of Income, Active Corporation Income Tax Returns, July 1983–June 1984.* Washington: Internal Revenue Service, 1986.

Vanek, Jaroslav. "The Factor Proportions Theory: The *N*-Factor Case." *Kyklos* 21, no. 4 (1968): 749–56.

Woodland, A. D. *International Trade and Resource Allocation.* Amsterdam: North-Holland, 1982.

World Bank. International Economics Department. *World Tables of Economic and Social Indicators, 1950–1987.* Washington: World Bank, Internat. Econ. Dept., 1988.