Comments welcome.

Costs to Factor Mobility: Implications for Observed Net Trade Flows

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Abstract:

Recent empirical research to test the applicability of international trade theory (for example Davis and Weinstein (2001), Trefler (1993, 1995), and Bowen, Leamer and Sveikauskas (1987)) has used the theoretical construct provided by the Heckscher-Ohlin-Vanek (HOV) model as a null hypothesis. These tests have invariably rejected the theory's predictions: specifically, the theory's predictions of trade flows are found to be an order of magnitude greater than those actually observed. Each of these papers, as well as Davis and Weinstein (1998), has also advanced explanations of this failure based upon country-specific differences in technology and absorption.

In this paper I investigate the possibility that the rejection of the theory is due to the maintained assumption of free internal mobility of factors across sectors. Partial internal immobility is parameterized within the HOV framework, and the implications for estimation derived. Results summarized here indicate that factor specificity is a significant component of the explanation of net trade flows among countries.

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Introduction.

Empirical investigations of international trade patterns and volumes are often couched in terms of the factor content of trade. This is an attractive restatement of the data for analyses linking international trade to outcomes in factor markets. However, research in this area has uncovered a "mystery", to use the term introduced by Trefler (1995): the observed factor content of trade in cross-sectional analysis bears little resemblance to that predicted by the Hechscher-Ohlin-Vanek (HOV) trade theory. Recent empirical research (e.g., Bowen, Leamer and Sveikauskas (1987), Trefler (1993), Trefler (1995), Harrigan (1997), Davis et al. (1997) and Davis and Weinstein (2001)) has explored extensions to the theory necessary to have it more closely fit the observed data. A common thread of the conclusions is the importance of country-specific differences (e.g., varying factor productivity, or home biases in consumption) in explaining the rejection of the HOV theory.

Davis and Weinstein (2001) has been most successful at fitting the theory to the data. The key extension in its case is the inclusion of factor endowments as determinants of the technology choices in each country. This is justified in their analysis through appeal to an equilibrium without factor price equalization (i.e., a "two-cone" world) or through the introduction of less-than-perfect mobility of goods in international trade. In this paper I introduce an alternative explanation for the imprecision of the HOV theory: the existence of costs of factor mobility within countries. The implications of this for observed trade flows are derived and tested for significance in data on endowments and trade flows for 33 countries in 1983 first used in Trefler (1995). Statistical tests provide strong support for this hypothesis in trade among the 33 countries in 1983.

Accounting for factor content.

Much of the reasoning in prior empirical work is embodied in the accounting for factor content. To illustrate this, I restate briefly the accounting framework introduced by Bowen, Leamer and Sveikauskas (1987) in empirical work. When observed production technologies are allowed to differ across trading countries, the mystery of missing trade is revealed to be potentially due to systematic deviations in technological choice across countries.

There are N commodities, and $\mathbf{X}_c$ is the (Nx1) vector of output produced in country c.[1] There are M factors, and $\mathbf{V}_c$ is the (Mx1) vector of factor endowments in that country. $\mathbf{A}_c$ is the (MxN) matrix of unit factor coefficients observed in country c. There are C countries in the trading system, and the world production and endowment vectors are denoted $\mathbf{X}_w$ and $\mathbf{V}_w$, respectively. I will maintain three assumptions throughout this derivation: full employment in each country, the law of one price in individual goods, and identical homothetic consumption preferences. Given those, the steps that follow represent a series of accounting identities for trade and factor content.

With the assumption of full employment, factor endowments and output in country c are linked through the $\mathbf{A}_c$ matrix in (1). Summation of (1) over all C countries yields (2). Use of the fact that the $\mathbf{X}_c$ vectors for each country sum to world output vector $\mathbf{X}_w$ defines in (3) an "average" unit-factor coefficient matrix $\mathbf{A}$ that will serve as a benchmark in what follows.

$$\mathbf{A}_c \mathbf{X}_c \equiv \mathbf{V}_c \qquad (1)$$

$$\Sigma_{c=1}^{C} \mathbf{A}_c \mathbf{X}_c \equiv \Sigma_{c=1}^{C} \mathbf{V}_c \equiv \mathbf{V}_w \qquad (2)$$

[1] I follow the convention of representing multi-element matrices in bold characters.

$$\mathbf{A}\,\mathbf{X_w} \equiv \mathbf{V}_w \tag{3}$$

The elements of **A** will in general differ from the elements of any of the individual $\mathbf{A_c}$.

International trade is represented by a country-specific (Nx1) net export vector $\mathbf{T_c}$ defined in (4), with $\mathbf{E}_c$ the (Nx1) vector of country-c expenditures on goods. If a representative country U is chosen, then the net export vector can without loss of generality be converted to factor units in country U by the identity (5).

$$\mathbf{T}_c \equiv \mathbf{X}_c - \mathbf{E}_c \tag{4}$$

$$\mathbf{A}_U\mathbf{T}_c \equiv \mathbf{A}_U\,\mathbf{X}_c - \mathbf{A}_U\,\mathbf{E}_c \tag{5}$$

Define the country-c share of world expenditure as S_c.[2] With identical and homothetic preferences across countries, and with a given and unique world price vector, the expenditure of country c on each good will be the proportion S_c of the world expenditure (and production) of that good.[3] Substituting this condition into (5) yields (6).

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[2] The (Nx1) vector of international commodity prices is denoted **P**. Individual-country income Y_c evaluated at world prices is defined as the scalar $Y_c = \mathbf{P'X}_c$. World income is defined as the summation of national incomes: $Y_w = \Sigma_{c=1}^{C} Y_c = \mathbf{P'X}_w$. World expenditure is equal to world income, but individual-country expenditures will differ from individual-country income by any trade surplus $B_c = \mathbf{P'T}_c$. Each country's share in world expenditure is denoted by the scalar $S_c = (Y_c - B_c)/Y_w$.

[3] Variations in demand across countries have been studied and found to be significant in explaining trade by Linder (1961), and by Hunter and Markusen (1988), among others. While these are important issues, I abstract from them in this discussion.

$$\mathbf{A}_U\, \mathbf{T}_c \equiv \mathbf{V}_c - \mathbf{A}_U\, S_c\, \mathbf{X}_w \tag{6}$$

Two substitutions make more transparent the various components of this identity. First, the "average" factor-use matrix **A** can be added to and subtracted from the coefficient on $S_c\mathbf{X}_W$. Second, the country-c factor-use matrix can be added to and subtracted from the coefficient on $\mathbf{X}_c$. The identities (1) and (3) can then be substituted into the equation to yield (7).

$$\mathbf{A}_U\, \mathbf{T}_c \equiv (\mathbf{V}_c - S_c\, \mathbf{V}_w) - S_c\, (\mathbf{A}_U - \mathbf{A})\mathbf{X}_w + (\mathbf{A}_U - \mathbf{A}_c)\mathbf{X}_c \tag{7}$$

The left-hand-side term in (7) is a measure of the factor content of country-c trade, and is easily calculated from the unit factor coefficient matrix of representative country U and from the trade vector of country c. The first term on the right-hand side is a many-factor measure of the factor abundance of country c. The second term measures the bias from introducing $\mathbf{A}_U$ due to technological differences of the representative country U from the benchmark world average. The third term measures the bias from introducing $\mathbf{A}_U$ in terms of specialization according to comparative advantage. Goods that can be purchased from suppliers with relatively lower unit cost in country c than that observed in representative country U will presumably be produced in greater quantity in country c.

To illustrate this, consider without loss of generality row i of vector equation (7).

$$\mathbf{A}_{iU}\, \mathbf{T}_c \equiv V_{ic} - S_c\, V_{iw} - S_c(\mathbf{A}_{iU} - \mathbf{A}_i)\mathbf{X}_w + (\mathbf{A}_{iU} - \mathbf{A}_{ic})\, \mathbf{X}_c \tag{8}$$

The right-hand-side expressions can be expanded to:

$$\mathbf{(A_{iU} - A_i)\,X_w} \equiv [(A_{i1U} - A_{i1})/A_{i1}]A_{i1}X_{1w} + [(A_{i2U} - A_{i2})/A_{i2}]A_{i2}X_{2w} + \ldots + [(A_{inU} - A_{in})/A_{in}]A_{in}X_{nw} \tag{9}$$

$$\mathbf{(A_{iU} - A_i)\,X_w} \equiv \Sigma_j\, \beta_{ij}\, A_{ij}X_{jw} \tag{9'}$$

$$\mathbf{(A_{iU} - A_{ic})\,X_c} \equiv [(A_{i1U} - A_{i1c})/A_{i1c}]\, A_{i1c}\, X_{1c} + [(A_{i2U} - A_{i2c})/A_{i2c}]\, A_{i2c}\, X_{2c} + \ldots + [(A_{inU} - A_{inc})/A_{inc}]\, A_{inc}\, X_{nc} \tag{10}$$

$$\mathbf{(A_{iU} - A_{ic})\,X_c} \equiv \Sigma_j\, \gamma_{ijc}A_{ijc}X_{jc} \tag{10'}$$

The coefficient $\beta_{ij} \equiv [(A_{ijU} - A_{ij})/A_{ij}]$ represents the percent by which the factor-use ratios for factor i in production of good j for country U differ from the average world factor-use ratios in production. Note that it is invariant to the country observed. The coefficients $\gamma_{ijc} \equiv [(A_{ijU} - A_{ijc})/A_{ijc}]$ represent the percent by which the factor-use ratio for factor i to produce good j in country c deviates from the same ratio observed in production in country U.

A common implication of all theories of international trade and factor content considered here is that these coefficients do not vary by goods for given i and c. With this simplification, the relation of factor content to factor abundance provided in (8) can be restated as:

$$\mathbf{A_{iU}\, T_c} = (1+\beta_i)(V_{ic} - S_c\, V_{iw}) + (\gamma_{ic} - \beta_i)\, V_{ic} + \chi_{ic} \qquad \text{for all i} \tag{11}$$

This accounting for factor content illuminates three sources of the observed factor content for country c when calculated through use of $\mathbf{A}_{iU}$. First, the observed factor content is a function of the factor abundance of country c in factor i. This is measured by the difference (V_{ic} - $S_c V_{iw}$). The impact of factor abundance on observed factor content will be dependent upon the choice of representative country U. If country U has lower unit factor coefficients than the benchmark world average, then β_i will be negative and the observed factor content will be less than factor abundance will predict. Second, observed factor content for country c is a function of the deviation of country-c unit factor coefficients from those of the benchmark world average as represented by (γ_{ic} - β_i). If country c has larger unit factor coefficients than in the benchmark world average, then the observed factor content will be reduced still further. The third, denoted by χ_{ic}, is the deviation from the identity due measurement error, to violations of the maintained hypotheses, and to the variation in these coefficients by good j. This component is treated as a normally distributed random error in what follows.

Nesting trade theories in explaining factor content.

The message of this accounting exercise is quite straightforward: the mystery in the relationship between the factor content of trade and the relative factor abundance of trading countries may be due to using $\mathbf{A}_{iU}$ to convert trade volumes to "observed" factor content. This insight is not original – in fact, the contributions of Bowen, Leamer and Sveikauskas (1987), Trefler (1993, 1995) and Davis and Weinstein (2001) can be viewed in part as efforts to gauge the degree of imprecision introduced by use of $\mathbf{A}_{iU}$.[4]

[4] All three of these papers advanced hypotheses to improve the factor-abundance explanation for the factor content of trade based upon equation (6) above. All advanced explanations that led to differing $\mathbf{A}_c$ across countries. Bowen, Leamer and Sveikauskas (1987) investigated the implications of country-specific differences in productivity; Trefler (1995) examined productivity differences, both neutral and non-neutral, as well as the introduction of home bias in consumption and production of non-tradeables;

There is extensive empirical evidence of the differences in $\mathbf{A_c}$ across countries, but two recent papers provide systematic cross-country evidence on these differences. Harrigan (1998) provided a unified examination of productive technologies and factor reallocation for 10 OECD countries for the period 1970-1990 and found evidence of significant differences in relative factor use across trading countries. He also found indirect but significant evidence of internal factor immobility in his estimation of product-share equations. Davis and Weinstein (2001) used data on technology for 10 OECD countries and on absorption for 30 countries (10 OECD and 20 outside). It also found systematic differences in technology use across countries and a strong correlation between those differences and the pattern of observed trade. Central to its success was the modeling of the unit factor coefficients in each country as functions of the country's factor abundance. This occurs in the results that follow as well, although the cause of the link is different: in Davis and Weinstein (2001) frictions in goods markets cause the link between technology choice and factor abundance, while here it is costly mobility of factors in internal factor markets

Equation (11) represents the hypothesis that the observed factor content of trade can be explained by the factor abundance of countries adjusted for the fact that $\mathbf{A_c}$ differ across countries. A complete theory will include a specification for the divergence of the $\mathbf{A_c}$ as evident in β_i and γ_{ic}. I will demonstrate in the following sections that the specifications of (11.1) and (11.2) nests the competing hypotheses of $\mathbf{A_c}$ divergence.

Davis and Weinstein (2001) use the Dornbusch, Fischer and Samuelson (1978) model to predict differing capital-labor ratios across countries and introduce separate cones for subsets of countries. All these will imply different $\mathbf{A_c}$ across countries. Bowen, Leamer and Sveikauskas (1987) also introduce the possibility that there are errors in measurement of S_c, but these expenditure-based explanations are not nested here.

$$\beta_i = [(A_{iU} - A_i)/A_i] = b_i \qquad (11.1)$$

$$\gamma_{ic} = [(A_{iU} - A_{ic})/A_{ic}] = g_c - h_i R_{ic} \qquad (11.2)$$

Equation (11.1) indicates that β_i in this model is potentially varying by factor. Equation (11.2) indicates that γ_{ic} will have a country-specific component (g_c) and a component proportional to a measure of the country's factor endowment (R_{ic}). Two such measures will be introduced and discussed below.

Hypothesis: Heckscher-Ohlin-Vanek theorem: With an assumption of costless internal mobility of factors within each economy and under the conditions of incomplete specialization leading to factor-price equalization, all factor-use matrices ($\mathbf{A}$, $\mathbf{A_U}$, and $\mathbf{A_c}$ for each country c) will converge element-by-element to the matrix $\mathbf{A_{HO}}$. Thus, this theory predicts that $b_i = g_c = h_i$ for all i and c. Equation (11) is reduced to (12).

$$\epsilon_{ic} = \chi_{ic} \qquad (12)$$

This is the hypothesis rejected strongly in previous literature, most famously by Trefler (1995).

Hypothesis: Productivity differences across countries: Trefler (1993, 1995) demonstrates that if there is perfect internal factor mobility and country-specific productivity differentials across $\mathbf{A_c}$ in the trading economies, then the model as specified in (11) but with $\mathbf{V_c}$ and $\mathbf{V_w}$ redefined in terms of "effective" (i.e., productivity-adjusted) factor units will be appropriate. Defining the "effective" productivity of factors in country c by ϕ_c and the share of the world endowment of factor i found in country c by σ_{ic}, this hypothesis defines (13).

$$\mathbf{A_{iU}\,T_c} = (\phi_U/\Sigma_c\phi_c\sigma_{ic})[(V_{ic} - S_c\,V_{iw}) + ((\Sigma_c\phi_c\sigma_{ic}/\phi_c)-1)V_{ic}] + \chi_{ic} \qquad \text{for all } i \qquad (13)$$

The coefficients g_c are exogenously determined by productivity differences between country c and country U.[5] The coefficients b_i will differ by factor, and will be larger for a factor if that factor is disproportionately found in low-productivity countries. The coefficients h_i will be zero. **Hypothesis: Costs to Mobility of Factors.** There are costs involved in reallocating factors among industries within an economy, and these costs will differ by factor of production. There are many possible sources of these costs -- costs incurred by the factor in relocating to a new industry, reduced productivity in an expanding industry due to the need for learning-by-doing among new factor entrants, a "lemons" problem among factors available to an expanding industry. Even in the absence of monopoly or monopsony power in these industries, these costs lead to a divergence between the factor price and the marginal value product, and to less reallocation of factors in response to final-good price incentives than would otherwise be expected.

The appendix provides a model of optimal factor re-allocation in response to relative price changes that indicates the economics of these costs to mobility. These implications can be illustrated in the following equations for a small open economy c with factors i and j, with expanding industry z and contracting industry y, and with p the relative price of good z in terms of y.[6]

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[5] If the most productive country is given $\phi = 1$, then ϕ_c is the quantity of the factor in country c necessary to be equally productive to one factor in the most productive country.
Then $g_c = (\phi_U - \phi_c)/\phi_c$ and $b_i = (\phi_U - \phi_{wi})/\phi_{wi}$, where $\phi_{wi} = \Sigma_c\phi_c\sigma_{ic}$ and σ_{ic} is the share of factor i endowment found in country c.

[6] There can also be turnover among expanding industries and among contracting industries. These are neglected in what follows, but could easily be incorporated.

$$A_{iyc} \;/\; pA_{izc} \;=\; \tau_{ic} \qquad (14.1)$$

$$A_{jyc} \;/\; pA_{jzc} \;=\; \tau_{jc} \qquad (14.2)$$

τ_{ic} and τ_{ic} are indices of the costs to factor mobility derived in the appendix. They differ across factors and lie between zero and unity.[7] For countries in which factors move in response to relative-price changes, the existence of these costs leads to less factor allocation than would otherwise occur. Unit factor coefficients in the expanding industry remain higher, and in the contracting industry lower, than would occur with no costs to factor mobility. For countries in which industry y is expanding, the left-hand ratios of (14.1) and (14.2) are set equal to the reciprocals of τ_{ic} and τ_{jc}. It is also possible that country c faces a cost of factor mobility that outweighs the gains from specialization. In that instance, factors are not reallocated to the comparative-advantage industry. Trade occurs, but in the reduced quantities associated with a fixed-endowment economy and at the pre-price-change unit factor coefficients.

The costs-to-mobility hypothesis thus implies that in a set of countries participating in free trade there will be two groups of countries: those that have reallocated factors to comparative-advantage industries and those that have not reallocated factors.[8] The size of the τ_{ic} and τ_{jc} define membership in the two groups and the volume of trade observed. Consider a set C of countries, indexed by c, and consider just the two factors of capital and labor. Each potentially has its own mobility-cost coefficient τ_{Kc} and τ_{Lc}. One source of the cost to mobility can be the regulatory climate and sophistication of institutions supporting

[7] With no costs to factor mobility, $\tau_K = \tau_L = 1$.

[8] Here again, the taxonomy can be expanded to include those that have allocated a subset of factors toward the comparative-advantage industry.

the factor market, and these will be country-specific. Thus the size of the distortionary wedge, and the divergence in $\mathbf{A_c}$, will have a country-specific component. Another potential source of differences in τ_{ic} across countries will be the relative factor abundance of the economy. If the marginal cost of reallocation is increasing in the number of factors reallocated, then τ_{ic} will be dependent upon the quantity reallocated. In this instance, the τ_{ic} will be increasing in the relative factor abundance of the economy and the most abundant economies will (other things equal) have the largest unit factor coefficients. A third case is the one illustrated in the appendix: for marginal costs to mobility constant in any period but decaying over time, the distortion coefficients are the same for all countries. Countries with factor abundance sufficient to trigger positive factor reallocation will converge to the same unit factor coefficient, while those scarce in the factor and with positive factor reallocation will converge to a different, smaller, unit factor coefficient. Those countries with zero reallocation of factors will have unit factor coefficients that differ by country.

The model with costly internal factor mobility but no difference in productivity across countries will have non-zero coefficients b_i and h_i for equations (11.1) and (11.2). The b_i are predicted to be larger for factors in which country U is abundant relative to the world average endowment. With costs to factor mobility the abundant factor will not be reallocated as much as would otherwise be the case toward industries using the abundant factor intensively. By similar reasoning, b_i will be smaller for factors in which the benchmark country is scarce relative to the world average. g_c will be zero for all c. However, if country c is abundant in factor i relative to country U, then h_i will be negative. I consider two measures of relative factor abundance:

$$R_{1ic} = (V_{ic} - S_cV_{iw}) - (V_{iU} - S_cV_{iw}) \tag{15.1}$$

$$R_{2ic} = \begin{cases} 1 & \text{if} \quad (V_{ic} - S_cV_{iw}) > 0 \text{ and } (V_{iU} - S_cV_{iw}) < 0 \\ 0 & \text{if} \quad (V_{ic} - S_cV_{iw}) > 0 \text{ and } (V_{iU} - S_cV_{iw}) > 0 \text{ or} \\ & \qquad (V_{ic} - S_cV_{iw}) < 0 \text{ and } (V_{iU} - S_cV_{iw}) < 0 \\ -1 & \text{if} \quad (V_{ic} - S_cV_{iw}) < 0 \text{ and } (V_{iU} - S_cV_{iw}) > 0 \end{cases} \tag{15.2}$$

The first definition compares both country-c and country-U endowments to the world average to determine relative abundance of country c to country U, while the second identifies relative abundance through a set of inequalities on factor abundance. R_{2ic} is equal to 1 if country c has a factor abundance and country U does not; it is equal to -1 if country U has the factor abundance and country c does not. It is equal to zero if the two countries both are abundant, or both scarce, in that factor.

Although the linkage from costs to trade volume is indirect, introduction of such costs into a model of endowment-based international trade provides testable restrictions upon the estimated coefficients. It has immediate implications as well for the interpretation of the rejection of endowment-based trade theories provided by Bowen et al. (1987), Trefler (1993, 1995), Davis et al. (1997) and Davis and Weinstein (2001). Thus, the following sections investigate the implications of factor-reallocation costs using aggregate trade data.

Hypothesis testing.

Equations (11), (11.1) and (11.2) represent a complete system of equations for testing these hypotheses. The productivity, costs-to-mobility, and HOV hypotheses are embodied in restrictions upon the values of b_i, g_c and h_i as noted above.

Data: The data set employed in Trefler (1993, 1995) is used for this estimation.[9] He collected data on commodity trade, income and factor endowments for the year 1983 for N=33 countries and M=9 productive factors. He used the US unit-labor-coefficient matrix for that year ($\mathbf{A_U}$) to derive the factor-equivalent of the net trade vector. The data are stacked in a M*N-element vector for joint cross-country/cross-factor estimation. I have used the data to replicate the results of Trefler (1995). In contrast to Trefler (1995), I use a Summers/Heston purchasing power parity measure of expenditure share S_c in the results that follow.[10] For comparable scaling, the data are divided by the appropriate world factor endowment. Lower-case letters indicate scalars and vectors whose elements have been divided by the appropriate element of $\mathbf{V_w}$. Thus, the estimation equation (11) will take the form after rescaling:

$$\mathbf{A_{iU}}\,\mathbf{T_c} / V_{iw} = t_{ic} = (1+b_i)(v_{ic} - S_c) + (g_c I_c - h_i R_{kic} - b_i)\, v_{ic} + x_{ic} \qquad \text{for all i, for k=1,2} \qquad (16)$$

b_i and h_i have dimension (1*M). g_c has dimension (1*C_o), while I_c is a (C_o*(M*N)) country-identification matrix of zeros and ones.[11] R_{kic} is the (M*(M*N)) matrix of factor-abundance measures defined in the preceding section. Heteroskedasticity remains, and generalized least squares estimates are obtained by

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[9] Thanks to Professor Trefler for making these available.

[10] In Conway (2001) I also consider an adjusted S_c under the maintained hypothesis that the HOV model predicts well the <u>pattern</u> but not necessarily the volume of trade. The results using this alternative measure are found in the appendix. The results are largely as found with the purchasing-power-parity form of S_c.

[11] The number C_o represents the independent groups of countries in the sample. In the largest specification there are 32 country-specific g_c because by definition $\gamma_{iU} = 0$. In subsequent specifications the number of g_c is reduced to five and eight through testing for equality of estimates of g_c across countries.

a two-stage process of least-squares regression and division by country- and factor-specific standard errors of the regression residual x_{ic}.

There are 50 regression coefficients estimated in the initial regression – nine estimates of b_i, nine estimates of h_i and 32 estimates of g_c. That regression proves to be not significantly different from one in which the countries are aggregated into eight country groups. Table 1 reports the results of estimation of (16) with R_{2ic} used as the proxy for factor abundance in γ_{ic} and with g_c estimated for eight country groups.[12]. The coefficients g_I - g_{VIII} are the country-specific percentage deviations of unit factor coefficients in the country grouping from the unit factor coefficients in the US. Since the US has arguably the highest productivity on average at that time, it is not surprising that the coefficients all have negative signs. Further, the relative magnitudes of the coefficients are reasonable – the least productive grouping of countries had unit factor coefficients over double those of the US on average, while the seventh group (including Belgium, France, UK and Switzerland) had unit factor coefficients only 13 percent larger on average. For all of these groups the g_I - g_{VII} coefficients are significantly less than zero. For the final group, including only Trinidad and Tobago, the g_{VIII} coefficient is insignificantly different from zero.

The b_i coefficients are the estimates of β_i for this sample, and they take the expected signs.[13] The hypothesis of productivity differences predicts that these coefficients will be negative on average, as the US is more productive than the average trading country. With costly factor mobility, these coefficients will be more positive for factors in which the US is abundant relative to the world's average. As anticipated, the

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[12] The eight groups include the 32 countries, as indicated by the assignments at the bottom of Table 1.

[13] The nine factors of production measured in this analysis (with acronyms in parentheses) are capital (K), professional and technical labor (LPT), clerical labor (LCL), sales labor (LSA), service labor (LSE), agricultural labor (LAG), production labor (LPR), cropland (NCR), and pastureland (NPA).

positive coefficients are those on cropland and pastureland (b_{NCR}, b_{NPA}) . Next, though negative, are capital (b_K) and skilled labor (b_{LPT}, b_{LCL}, b_{LPR}) categories. Those most negative are those in which the US is most scarce: agricultural labor (b_{LAG}) and sales labor (b_{LSA}).

Theory provides another test of the productivity hypothesis in the estimated b_i. If productivity alone determined the estimated values of b_i, then it would be the case that $(1+b_i) = (\phi_U/\phi_{wi})$ for each i. Table 4 reports the results of a comparison of these two magnitudes. The benchmark average productivity is calculated from the estimated g_c and the actual shares of the factors in the world total, and is reported in the first two columns for the two regressions. The third and fourth column compare $(1+b_i)$ and (ϕ_U/ϕ_{wi}) for the results of Table 1, while the fifth and sixth columns compare these for the results of Table 2. While there is evidently a similarity, there are also differences captured in b_i not implied by the productivity differences. An F test of the restriction that b_i is due only to productivity differences is rejected for both specifications as indicated in Table 3. Figure 1 illustrates the divergence between productivity-based values and the actual estimates for R_{2ic}. If estimates fall on the diagonal line, then they mirror the predictions based on the productivity hypothesis alone. The cost-to-mobility hypothesis predicts that the estimates will not fall on the diagonal. Points above the line will represent factors in which the US is abundant, while points below the line represent factors in which the US is scarce. The two points above the line are the two land variables, while the points farthest below the line are agricultural labor and sales labor. Thus, these coincide with our prediction.

The final set of coefficients are the h_i. With costs to factor mobility, γ_{ic} is predicted to be negative when country c is abundant in a factor relative to country U and positive when country c is scarce in a factor relative to country U. h_i is then positive under this hypothesis, while zero under the productivity or

HOV hypotheses. The coefficient estimates reported in Table 1 indicates the percent by which the unit factor coefficients diverge between country c and country U when the countries differ in factor abundance. For example, the coefficient $h_K = .20$ indicates that the unit capital coefficients of the US will be 20 percent larger on average than in countries with capital scarcity. Similarly, $h_{LAG} = .51$ indicates that the unit coefficients of agricultural labor in the US will be 50 percent smaller on average than those observed in countries with an abundance of agricultural labor. The estimates of these factor-abundance effects are significantly different from zero for capital and for all types of labor. The coefficients h_{NCR} and h_{NPA} indicate unit coefficients in land in the US that are over 100 percent higher than those observed in countries with scarcity of either sort of land, although the point estimates are measured imprecisely.

Table 2 employs R_{1ic} from (14.1) as the specification for factor abundance. It predicts that the difference in unit factor coefficients between country U and country c will be proportional to the relative factor abundance of country c. This coefficient will be increasing in the cost of factor mobility. The b_i for capital and labor categories are quite similar to those of Table 1. The point estimates b_{NCR} and b_{NPA} are negative in this case, but as in Table 1 are less negative than the others and are insignificantly different from zero. The g_c are also quite similar; the countries collect into a smaller number of groups, but their relative sizes indicate a similar relationship to the US. The h_i take the correct sign. Six of the nine (h_{LPT}. h_{LSA}, h_{LSE}, h_{LAG}, h_{LPR}, and h_{NPA}) are significantly different from zero. The point estimates accord well with priors on costs to factor mobility, since the largest values are found on the two types of land, and the next largest in capital. Among labor types the ranking ($h_{LPR} > h_{LPT} > h_{LSE} = h_{LCL} > h_{LAG} > h_{LSA}$) also corresponds to priors about relative costs to labor mobility.

Conclusions and extensions.

Recent empirical tests based on cross-country data have called into question theoretical predictions based upon relative factor abundance. The accounting framework of this paper clarifies that this is due in part to the common convention in the literature of using the US unit factor coefficient matrix as a proxy for the actual technological choices of the trading countries. The validity of this proxy is a prediction of the Heckscher-Ohlin-Vanek model, and rejections of HOV are also rejections of this proxy.

Further examination of the data uncovers two regularities of note. First, there is evidence of the productivity differential across countries found by Trefler (1993, 1995) and those following. Second, there is evidence of a factor-abundance effect – countries abundant in a factor tend to have higher unit factor coefficients than those for whom the factor is scarce. Both make significant contributions in explaining the difference between actual and predicted trade.

There are both descriptive and analytical implications of these results. On the descriptive end, it is clear that cross-country factor-content analyses based on use of a benchmark country should be interpreted carefully. Systematic variation in unit-factor coefficients of the magnitude described here will cause severe bias in results of any effort to explain the factor content of trade. On the analytical end, there is strong evidence that a key explanation of observed factor content of trade will be found in factor-specific differences – both the b_i and the h_i coefficients of the estimation results have that characteristic. The costs-to-mobility hypothesis is consistent with this, and the coefficients estimated are of orders of magnitude consistent with that hypothesis.

The recent literature, including Schott (2001) and Davis and Weinstein (2001), has introduced factor abundance to the analysis of trade volumes through appeal to the existence of multiple cones in production. These theories also predict an impact of factor abundance on unit factor coefficients. At the level of aggregation of trade used in this study, the econometric results reported here have little power against an alternative hypothesis of multiple cones. This is a fascinating direction for future research using more disaggregated data.

It is important to note that this analysis has abstracted from expenditure-side differences across countries in deriving results. In Conway (2001) I have demonstrated the importance of considering expenditure-side variations in interpreting the mysteries of Trefler (1995). Further work in this area as well will be useful.

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Table 1
Regression Results: Equation 15 (R_{2ic})

Source	DF	Sum of Squares	Mean Square	Approx F Value	Pr > F
Regression	26	457535	17597.5	977.89	<.0001
Residual	271	4968.4	18.3337		
Uncorrected Total	297	462504			
Corrected Total	296	453179			

Parameter	Estimate	Approximate Std Error	Approximate 95% Confidence Limits	
b_K	-0.2824	0.0592	-0.3990	-0.1658
b_{LPT}	-0.2795	0.0314	-0.3414	-0.2176
b_{LCL}	-0.2909	0.0390	-0.3676	-0.2142
b_{LSA}	-0.4576	0.0130	-0.4832	-0.4320
b_{LSE}	-0.2724	0.0231	-0.3178	-0.2270
b_{LAG}	-0.7809	0.0265	-0.8331	-0.7287
b_{LPR}	-0.3270	0.0576	-0.4405	-0.2135
b_{NCR}	0.0652	0.5187	-0.9561	1.0865
b_{NPA}	0.2200	0.4845	-0.7338	1.1739
g_I	-0.5256	0.0220	-0.5689	-0.4824
g_{II}	-0.4672	0.0224	-0.5113	-0.4232
g_{III}	-0.3970	0.0238	-0.4438	-0.3502
g_{IV}	-0.3112	0.0190	-0.3486	-0.2737
g_V	-0.2479	0.0281	-0.3032	-0.1926
g_{VI}	-0.1912	0.0359	-0.2619	-0.1205
g_{VII}	-0.1388	0.0241	-0.1863	-0.0913
g_{VIII}	-0.0507	0.0799	-0.2080	0.1066
h_K	0.2004	0.0648	0.0729	0.3279
h_{LPT}	0.2380	0.0321	0.1748	0.3011
h_{LCL}	0.1574	0.0420	0.0747	0.2402
h_{LSA}	0.3644	0.0197	0.3255	0.4032
h_{LSE}	0.2040	0.0233	0.1580	0.2499
h_{LAG}	0.5077	0.0228	0.4628	0.5525
h_{LPR}	0.2535	0.0519	0.1513	0.3558
h_{NCR}	1.0305	1.4913	-1.9055	3.9665
h_{NPA}	1.2424	1.1446	-1.0111	3.4959

Groups:
- I: Bangladesh, Indonesia
- II: Pakistan, Thailand, Uruguay
- III: Sri Lanka, Panama, Greece
- IV: Colombia, Yugoslavia, Spain, Austria
- V: Portugal, New Zealand, Japan, Netherlands, Denmark, Sweden, Norway
- VI: Ireland, Israel, Hong Kong, Singapore, Germany, Canada
- VII: Italy, United Kingdom, Belgium, Finland, France, Switzerland
- VIII: Trinidad/Tobago

Table 2
Regression Results: Equation 11 (R_{1ic})

Source	DF	Sum of Squares	Mean Square	Approx F Value	Pr > F
Regression	23	454395	19756.3	683.59	<.0001
Residual	274	8108.9	29.5946		
Uncorrected Total	297	462504			
Corrected Total	296	453179			

Parameter	Estimate	Approximate Std Error	Approximate 95% Confidence Limits	
b_K	-0.3367	0.0853	-0.5046	-0.1687
b_{LPT}	-0.2914	0.0378	-0.3659	-0.2170
b_{LCL}	-0.2988	0.0524	-0.4020	-0.1956
b_{LSA}	-0.5141	0.0156	-0.5449	-0.4834
b_{LSE}	-0.3281	0.0290	-0.3852	-0.2709
b_{LAG}	-0.7311	0.0334	-0.7969	-0.6652
b_{LPR}	-0.3834	0.0713	-0.5238	-0.2431
b_{NCR}	-0.2098	0.4987	-1.1917	0.7721
b_{NPA}	-0.2795	0.4200	-1.1064	0.5474
g_I	-0.4849	0.0303	-0.5445	-0.4253
g_{II}	-0.4080	0.0781	-0.5617	-0.2544
g_{III}	-0.3541	0.0242	-0.4018	-0.3065
g_{IV}	-0.2199	0.0287	-0.2765	-0.1633
g_V	-0.0697	0.1018	-0.2701	0.1308
h_K	10.2133	5.5311	21.1023	-0.7721
h_{LPT}	5.8668	1.1670	8.1641	3.5694
h_{LCL}	3.8681	2.5207	8.8007	-1.1241
h_{LSA}	1.1844	0.0900	1.3615	1.0073
h_{LSE}	3.8681	0.6421	5.1321	2.6040
h_{LAG}	1.9220	0.1257	2.1695	1.6745
h_{LPR}	7.5787	1.9235	11.3655	3.7920
h_{NCR}	124.7	210.4	538.9	-289.6
h_{NPA}	19.1704	7.8016	34.5292	3.8116

Groups: I: Bangladesh, Indonesia, Pakistan, Thailand, Uruguay, Sri Lanka, Panama, Greece
II: Ireland, Hong Kong, Singapore
III: Colombia, Yugoslavia, Spain, Austria, Portugal, New Zealand, Japan, Netherlands, Denmark, Sweden, Norway, Germany
IV: Israel, Italy, United Kingdom, Belgium, Finland, France, Switzerland, Canada
V: Trinidad/Tobago

Table 3
F tests of Coefficient Restrictions

	R_{1ic}	R_{2ic}	DF	Critical Value
Country groupings	0.27	0.22	(24,247)	1.52
$b_i = 0$ for all i	192.05	178.86	(9, 271)	1.88
$b_i = b$ for all i	19.26	35.29	(8, 271)	1.94
Test: HOV (b_i=0, g_c=0, h_i=0)	894.12	590.98	(26, 271)	1.55
Test: productivity differences				
$g_c = 0$ for all c	14.38	21.75	(32, 247)	1.45
$g_c = 0$ for all groups	39.23	92.67	(8, 271)	1.94
Test: cost to mobility hypothesis				
$h_i = 0$ for all i	22.61	37.69	(9, 271)	1.88
Test: b_i reflects only g_c differences	30.68	21.59	(9, 271)	1.88

Table 4
Comparison of Estimated b_i and those implied by Productivity Hypothesis

	ϕ_{wi}		Using R_{2ic}		Using R_{1ic}	
Factor	R_{2ic}	R_{1ic}	$(1+b_i)$	ϕ_U/ϕ_{wi}	$(1+b_i)$	ϕ_U/ϕ_{wi}
K	1.22	1.33	0.7176	0.819672	0.6633	0.75188
LPT	1.24	1.32	0.7205	0.806452	0.7086	0.757576
LCL	1.24	1.33	0.7091	0.806452	0.7012	0.75188
LSA	1.44	1.50	0.5424	0.694444	0.4859	0.666667
LSE	1.30	1.37	0.7276	0.769231	0.6719	0.729927
LAG	1.82	1.81	0.2191	0.549451	0.2689	0.552486
LPR	1.34	1.43	0.673	0.746269	0.6166	0.699301
NCR	1.27	1.30	1.0652	0.787402	0.7902	0.769231
NPA	1.19	1.23	1.22	0.840336	0.7205	0.813008

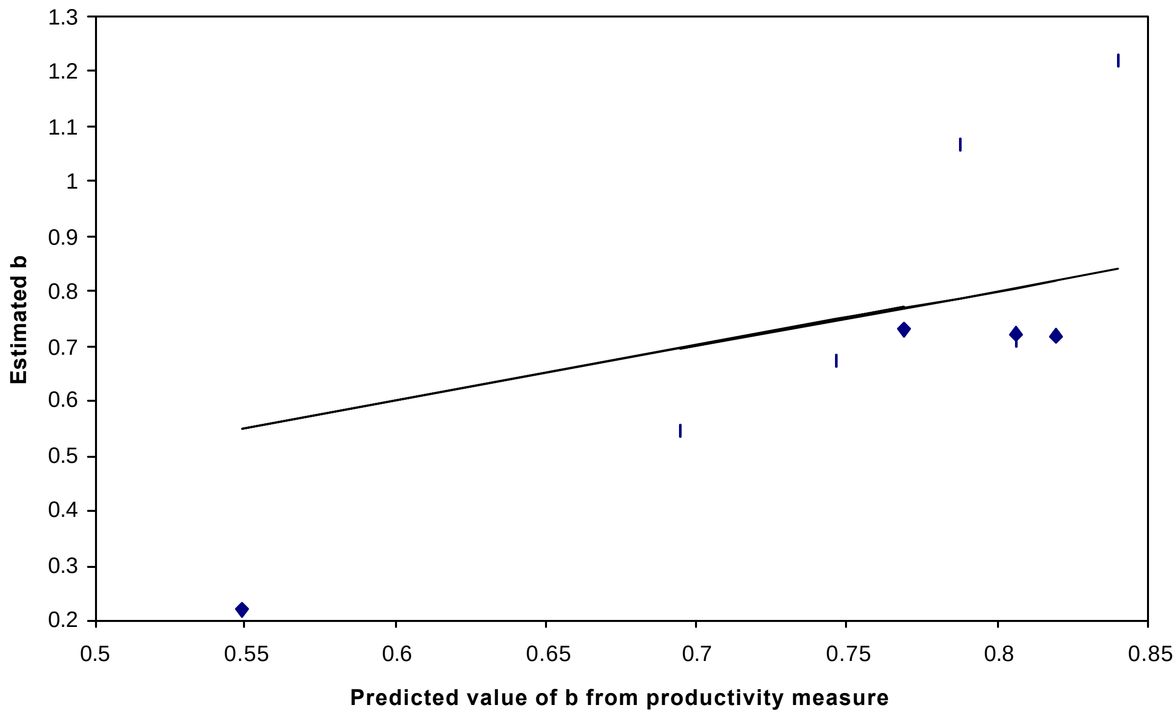


Figure 1: **Factor Abundance in Estimates of b_i**

Appendix
Introduction of costs of factor mobility.

Consider the resource-allocation problem of a profit-maximizing economy with the potential to produce two goods (Z, Y) for the local and world market. Each good is produced with a constant-returns technology using two factors (K, L). Good Y is the numeraire good, with the relative price of Z denoted p. The wage is denoted w, the rent on capital r, and the discount rate for the firm's intertemporal decision-making is ρ. Factors are in fixed supply. In each country, all labor is paid the same wage, and all capital the same rental rate, no matter the productivity in that period.[i] The economy makes its decisions at time 0 with an infinite horizon of payments in mind.

Factors can be moved from production in one sector to production in the other, but are not immediately equally as productive as factors already employed in the sector. The productivity loss in the expanding sector involved in reallocation of factors is modeled by the sequences $\{q_L\}_{t=1}^{\infty}$ and $\{q_K\}_{t=1}^{\infty}$. Each element of $\{q_L\}_{t=1}^{\infty}$ and $\{q_K\}_{t=1}^{\infty}$ measures the percent by which the productivity of the reallocated factor is less than that observed in factors already in the industry.[ii]

The measured factor supplies (L_{Z1}, L_{Y1}, K_{Z1}, K_{Y1}) are given by the quantity of labor or capital in the sector after the reallocation, while the effective factor supplies ($L^e_{zt}, L^e_{yt}, K^e_{zt}, K^e_{yt}$) modify the measured factor supplies by the productivity loss associated with the reallocated factors. includes this reallocation cost. For an economy in which relative price changes cause a once-off increase in production of industry Z, the measured and effective stocks of factors of production for the t^{th} period after the relative price change are:

<u>Z-industry factor use</u>

measured: $L_{Z1} = L - L_{Yo} + \Delta L_Z$

$K_{Z1} = K - K_{Yo} + \Delta K_Z.$

effective: $L^e_{zt} = L - L_{Yo} + (1-q_L(t))\Delta L_Z = L_{Z1} - q_L(t)\Delta L_Z$

$K^e_{zt} = K - K_{Yo} + (1-q_K(t))\Delta K_Z .= K_{Z1} - q_K(t)\, \Delta K_Z$

<u>Y-industry factor use: measured equals effective</u>

$L^e_{yt} = L_{Y1} = L_{Yo} - \Delta L_Z$

$K^e_{yt} = K_{Y1} = K_{Yo} - \Delta K_Z$

---

[i] The results of this analysis are negated if the firm is able to pay each factor its marginal value product in each period. Those reallocating factors would then earn less in the beginning, with factor payments subsequently rising nearly to equal the payment to factors originally in the sector.

[ii] For example, $\{q_L\}_{t=1}^{\infty} = \{.5, .5, 0, 0, 0, 0, ...\}$ indicates that the reallocated labor will be half as productive as labor already in the sector during periods 1 and 2, and will be equally productive thereafter.

with $q_K(t)$ and $q_L(t)$ representing the values of the mobility cost sequence for period t.
In this economy, with expanding Z industry, the shrinking Y industry is assumed to have no productivity loss. If the relative-price shock were reversed, however, the Y industry would be the one with effective factor supplies deviating from measured factor supplies.

Consider the initial allocation of factors to be defined by L_{Yo}, K_{Yo}. The initial wage w_o can be defined $w_o = F_L(K_{Yo},L_{Yo})$ and the initial rental $r_o = F_K(K_{Yo},L_{Yo})$. The initial relative price is p_o.

Optimal factor reallocation.

The asymmetric nature of factor reallocation costs necessitates examination of optimality conditions in two parts – one for the response to a rise in relative commodity price, and one for the response to a fall in the relative commodity price.

Suppose that re-optimization is necessary because of a new value $p_1 > p_o$ that is assumed to be a permanent change. There will be a one-time shift in factors in period zero of ΔL_Z, ΔK_Z. toward production of Z. Define L_{Y1} and K_{Y1} as the post-shock allocation of factors to good-Y production. There is full employment throughout. However, due to the cost of factor mobility, the effective factor allocation to industry Z will be less than the actual allocation during at least a portion of the time horizon..

The maximization problem for the firm is then:

$$\max_{\Delta L_Z,\Delta K_Z} \Sigma_{t=0}^{\infty} (Y_t + p_1 Z_t)/(1+\rho)^t \tag{A1}$$

subject to

$$Y_t = F(K_{Y1}, L_{Y1})$$
$$Z_t = G(K^e_{zt}, L^e_{zt})$$
$$\Delta L_Z \geq 0, \Delta K_Z \geq 0$$

The Kuhn-Tucker conditions for a maximum define a set of inequalities in the value of marginal products in the two industries.

$$\Sigma_{t=0}^{\infty} [-F_K(K_{Y1}, L_{Y1})) + p_1 G_K(K^e_{zt}, L^e_{zt})(1-q_K(t))]/(1+\rho)^t \leq 0 \qquad \Delta K_Z \geq 0 \tag{A2}$$
$$\Sigma_{t=0}^{\infty} [-F_L(K_{Y1}, L_{Y1})+ p_1 G_L(K^e_{zt}, L^e_{zt})(1-q_L(t))]/(1+\rho)^t \leq 0 \qquad \Delta L_Z \geq 0 \tag{A3}$$

With positive factor reallocation, the first inequality in each set becomes an equality.

Define the distortion effect of the cost of mobility for positive factor reallocation as:

$$\tau_K = \Sigma_{t=0}^{\infty} \rho[G_K(K^e_{zt}, L^e_{zt})/G_K(K_{Z1}, L_{Z1})](1-q_K(t))/(1+\rho)^t \tag{A4.1}$$
$$\tau_L = \Sigma_{t=0}^{\infty} \rho[G_L(K^e_{zt}, L^e_{zt})/G_L(K_{Z1}, L_{Z1})](1-q_L(t))/(1+\rho)^t \tag{A4.2}$$

These distortion coefficients will equal unity for costless mobility, and will generally be less than one with positive costs to mobility.[iii] The first-order conditions for positive factor reallocation can then be restated as:

$$-F_K(K_{Y1}, L_{Y1}) + p_1G_K(K_{Z1}, L_{Z1})\tau_K = 0 \qquad \text{(A2.1)}$$
$$-F_L(K_{Y1}, L_{Y1}) + p_1G_L(K_{Z1}, L_{Z1})\tau_L = 0 \qquad \text{(A3.1)}$$

The choice variables remain ΔL_Z, and ΔK_Z, but the distortion affects the optimal allocation. For τ_K and τ_L less than unity, there will be less reallocation of factors to the expanding industry than would have occurred otherwise.

As the Kuhn-Tucker conditions indicate, it is also possible than no factor reallocation will occur. In that case, the discounted present value of the productivity losses through reallocation exceeds the discounted value of future profitability. The inequalities yield the conditions

$$1 > F_K(K_{Y0}, L_{Y0})/p_1G_K(K_{Z0}, L_{Z0}) > \tau_K \qquad \text{(A5.1)}$$
$$1 > F_L(K_{Y0}, L_{Y0})/p_1G_L(K_{Z0}, L_{Z0}) > \tau_L \qquad \text{(A5.2)}$$

with the marginal value products of the two industries diverging in this case as well.[iv] The Z-industry marginal value product exceeds that in the Y industry, indicating the incentive to reallocate in the absence of costs to mobility. However, the second inequality indicates that those incentives are not sufficient to outweigh the costs to mobility.

If $p_1 < p_o$, then the incentive to reallocation of factors will be toward Y. The optimization program is analogous to (A1), but with costs to factor movement in the opposite direction. For non-zero factor flows, the optimality conditions become

$$-F_K(K_{Y1}, L_{Y1})\tau_K + p_1G_K(K_{Z1}, L_{Z1}) = 0 \qquad \text{(A2.2)}$$
$$-F_L(K_{Y1}, L_{Y1})\tau_L + p_1G_L(K_{Z1}, L_{Z1}) = 0 \qquad \text{(A3.2)}$$

These differ only in the roles played by τ_K and τ_L.[v]

[iii] The inclusion of non-negative $q_K(t)$ and $q_L(t)$ will, other things equal, keep the coefficients at or below unity. It is mathematically possible that the term in brackets – the ratios of marginal products with effective and measured factor allocations – will be sufficiently greater than unity in short-run adjustment. This will, in extreme cases, cause the coefficient to rise above unity. I abstract from those cases here.

[iv] It is the case that other variants exist with one factor reallocating and the other factor not. Those cases extend the logic presented here in predictable ways, and so are not presented in detail.

[v] The definitions of τ_K and τ_L will differ as well. For example, in this case

$$\tau_K = \Sigma_{t=0}^{\infty} [F_K(K^e_{yt}, L^e_{yt})/F_K(K_{Y1}, L_{Y1})](1-q_K(t))/(1+\rho)^t$$

Since the factor-reallocation costs are symmetric, I anticipate that these differences will be small and

The existence of this cost to mobility, even though it decays to nothing over time, leads to a factor allocation that in the long run differs from the one observed in the absence of costs to mobility. The coefficients τ_K and τ_L indicate the degree of deviation from the no-cost allocation. Consider two polar extremes. When $q_j = 0$, then $\tau_j = 1$ and the factor market in question has the Heckscher-Ohlin characteristic of costless factor reallocation. It is straightforward in (A2.1) and (A3.1) to check that the resulting allocation of factors will be the textbook equality of the value of marginal product in each period. When $q_j = 1$, then $\tau_j = 0$ and factor j is a specific factor. Reallocation is so costly that no factor movement will occur; there will be a corner solution with (A2) and (A3) becoming inequalities. The reallocation-cost parameters thus divide countries into two groups in their responses to relative price movements: those with unchanged productive factor allocations and those with expanding production in the industry with increased relative price. The appendix provides an illustration of this division using a Cobb-Douglas technology.

Much of the recent empirical research on the determinants of international trade patterns and volumes has employed unit factor coefficients as indicators of technological choice rather than quantities of factors reallocated. Define the unit labor coefficients a_{LZ} and a_{LY} as the ratios of labor used in production to the quantity produced in the Z and Y industries, respectively. The unit capital coefficients a_{KZ} and a_{KY} are defined similarly. For production technologies for which the marginal product and average product are identical, the optimality conditions for expanding-Z economies can then be rewritten:

$$a_{KY} / a_{KZ} = \tau_K \tag{A6.1}$$
$$a_{LY} / a_{LZ} = \tau_L \tag{A6.2}$$

and similar conditions result for expanding-Y economies and for non-specializing economies. The value of the unit factor coefficients are clearly dependent upon the distortion coefficients in this case, and will be for more general technologies as well.

There are many testable hypotheses that can be drawn from this model. One set of these concerns the dynamic of factor reallocation and productivity after relative-price shocks in open economies. This is a fertile area for future research, but one which I do not enter here. A second set concerns the steady-state pattern and volume of international trade. In this area, the consideration of costs to factor mobility sheds light on a number of empirical mysteries.

A Cobb-Douglas example.

A Cobb-Douglas technology with coefficients μ and ν is chosen for simplicity. In the case of $p_1 > p_o$:

$$Y_t = (K_{Yo} - \Delta K_Z)^{\nu} (L_{Yo} - \Delta L_Z)^{1-\nu} \tag{A7}$$
$$Z_t = (K - K_{Yo} + (1-q_K{}^t)\Delta K_Z)^{\mu} (L - L_{Yo} + (1-q_L{}^t)\Delta L_Z)^{1-\mu} \tag{A8}$$

---

abstract from them in the analytics. The simulation results reported below incorporate the differences in τ_K across sectors.

The Kuhn-Tucker conditions then take the form:

$$(\nu/\mu)(a_{KZ}/a_{KY}) \leq p\,\tau_K \qquad \Delta K_Z \geq 0 \qquad \text{(A2.3)}$$
$$((1-\nu)/(1-\mu))(a_{LZ}/a_{LY}) \leq p\,\tau_L \qquad \Delta L_Z \geq 0 \qquad \text{(A3.3)}$$

and for non-zero factor movement, $[(1-\nu)\mu/(\nu(1-\mu))]\,(\tau_K/\tau_L) = [(a_{LY}/a_{KY})/(a_{LZ}/a_{KZ})]$.

There is an analogous set of equations for an economy with Y expanding:

$$(\nu/\mu)(a_{KZ}/a_{KY})\tau_K \leq p \qquad \Delta K_Y \geq 0 \qquad \text{(A2.4)}$$
$$((1-\nu)/(1-\mu))(a_{LZ}/a_{LY})\tau_L \leq p \qquad \Delta L_Y \geq 0 \qquad \text{(A3.4)}$$

and for non-zero factor movements, $[(1-\nu)\mu/(\nu(1-\mu))]\,(\tau_L/\tau_K) = [(a_{LY}/a_{KY})/(a_{LZ}/a_{KZ})]$.

In the absence of costs to mobility, the assumption $\nu > \mu$ is sufficient to ensure that cost-minimizing ratios of capital to labor will be larger in Y than in Z: i.e., that Z is labor-intensive in production. With extreme costs of mobility there can be factor intensity reversals relative to the Heckscher-Ohlin case.

Two types of distortions are introduced by costs to mobility. First, as is evident in equations (A2.3), (A3.3), (A2.4) and (A3.4), the existence of τ_K and τ_L below unity leads to less than complete convergence of the value of marginal product in that factor in the two sectors. This introduces a wedge in the ratios of unit factor coefficients chosen by the firms. With costless factor movement the equilibrium allocation of the labor force will be defined by the intersection of value-of-marginal-product curves. With costs to factor movement the equilibrium allocation involves less factor reallocation than would otherwise occur.

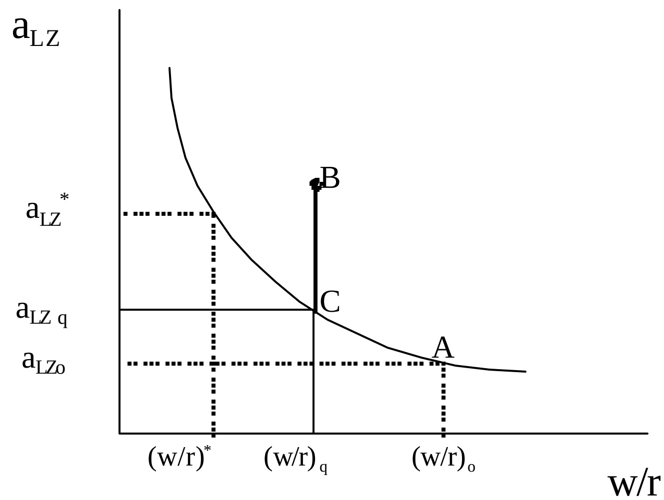
To illustrate:

$$a_{LZ} = [(L_{Z1}/K_{Z1})\{(L^e_{zt}/L_{Z1})/(K^e_{zt}/K_{Z1})\}]^{\mu} = (L_{Z1}/K_{Z1})^{\mu}\ \{(L^e_{zt}/L_{Z1})/(K^e_{zt}/K_{Z1})\}^{\mu} \qquad \text{(A9)}$$

The Cobb-Douglas technology is characterized by unit elasticity of substitution of capital for labor with respect to the relative factor price (w/r). The optimal long-run demands, represented by the ratio (L_{Z1}/K_{Z1}) in (A9), trace out the curve in Figure A1.

If the economy begins at $(w/r)_o$, the increase to p_1 will induce an increase in the production of Z. It will also induce an increase in a_{LZ} since the w/r ratio will fall. The long-run cost-minimizing use of labor in production is modeled by the curve in the diagram. Point A was the initial coefficient/factor price combination. In the absence of costs to mobility the firm would shift immediately to a_{LZ}^*. With costs to mobility the long-run allocation of labor will yield a_{LZ} and w/r at point C. In the initial period after reallocation, however, the observed unit factor coefficient will diverge from C due to the term in brackets in (A9). If, for example, the mobility cost is larger in labor markets, then the initial coefficient will be B; over time, the coefficient will fall until it converges to point C.

This response of the firm to opening trade at a higher final-good price is illustrated in Figure A2 for labor in a numerical simulation that illustrates the dynamic evolution of the unit labor coefficient. The a_{L2o} is the lowest horizontal line, implying a ratio of .96. In the world of costless labor mobility the new labor-output ratio $a_{LZ}(0)$ is 1.2.[vi] With costs to mobility, as modeled here with $q_L = .5$ and $q_K=0$, $a_{LZ}(.5)$ is lower at 1.1. However, for the first few years of adjustment the ratio is in fact much higher. It begins at 1.22 and



declines over time as the loss in productivity of relocating workers is dissipated over time. After about 8 periods, the labor-output ratio has converged nearly to its long-run level.

Figure A1

Implication for unit factor coefficients.

A difference in value between τ_K and τ_L leads to a deviation in observed capital-labor ratios in production in the two sectors between Y expanding and Z expanding economies. The observed unit factor coefficients in the three sets of countries will diverge, with the divergence depending upon the country's comparative advantage and upon the factor in question.

With costless mobility of factors internally, the unit factor shares simplify to the matrix

$$\begin{bmatrix} wa_{LY} & wa_{LZ} \\ ra_{KY} & ra_{KZ} \end{bmatrix} = \begin{bmatrix} (1-\nu) & p(1-\mu) \\ \nu & p\mu \end{bmatrix} \tag{A10}$$

[vi] Note that the wage is held constant across these outcomes for illustrative purposes. Thus, the real wage to this firm has fallen and the desired labor-output ratio rises.

but with costly mobility of factors the unit factor shares diverge from these values. Table A1 presents the values of these unit factor shares for τ_K and τ_L less than unity. Straightforward application of comparative statics to (A6) - (A7) indicates that for the Z- expansion economy the values of the unit labor shares in both sectors will lie below (1-μ) and (1-ν), respectively, for values of either τ_L or τ_K (or both) less than unity. The values of the unit capital shares in both sectors will lie above μ and ν, respectively, for values of either τ_K or τ_L that fall below unity.[vii] The effects of costly mobility on unit factor shares are reversed for countries with Y expansion.

The existence of costs to mobility will discourage the movement of factors. The countries with Z

Table A1: **Unit Factor Shares Derived from Optimization and Perfect Competition**

For the Z-expanding economies:

$$(1-\nu)[\nu-\rho\tau_K\mu]/\Delta_1 = a_{LY}\, w \tag{A8}$$
$$\nu[\tau_L(1-\mu)\rho-(1-\nu)]/\Delta_1 = a_{KY}\, r \tag{A9}$$
$$p\tau_L(1-\mu)[\nu-\rho\tau_K\mu]/\Delta_1 = a_{LZ}\, w \tag{A10}$$
$$p\mu\tau_K[(1-\mu)\rho\tau_L-(1-\nu)]/\Delta_1 = a_{KZ}\, r \tag{A11}$$

$$\Delta_1 = (\tau_L\, \nu(1-\mu)-\mu(1-\nu)\tau_K) > 0$$

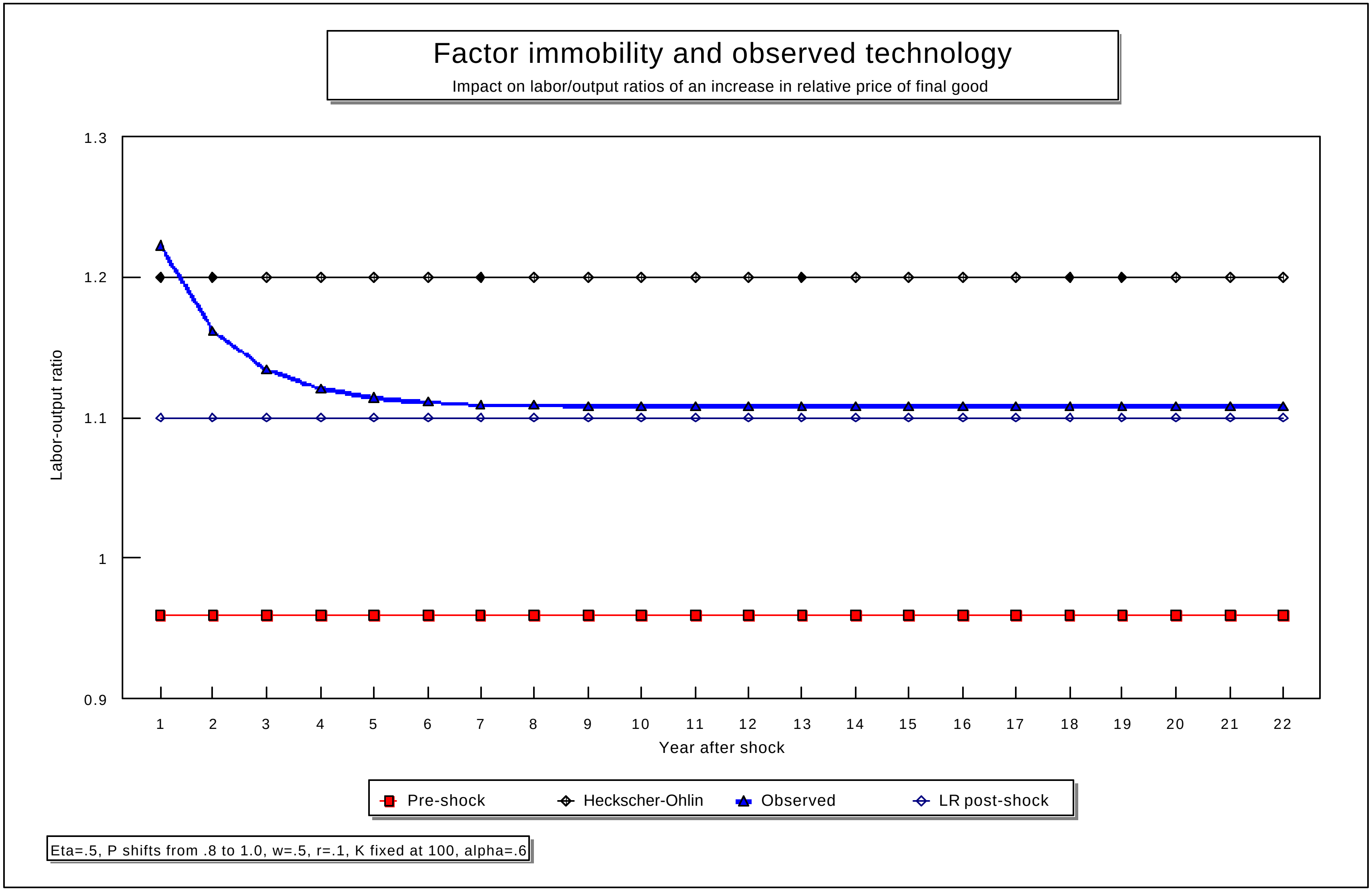
For the Y-expanding economies:

$$(1-\nu)\tau_L[\mu-\rho\tau_K\nu]/\Delta_2 = a_{LY}\, w \tag{A8.1}$$
$$\nu\tau_K[(1-\nu)\tau_L\rho-(1-\mu)]/\Delta_2 = a_{KY}\, r \tag{A9.1}$$
$$p(1-\mu)[\mu-\rho\tau_K\nu]/\Delta_2 = a_{LZ}\, w \tag{A10.1}$$
$$\mu p[(1-\nu)\tau_L\rho-(1-\mu)]/\Delta_2 = a_{KZ}\, r \tag{A11.1}$$

expansion are those that are abundant in capital, the factor used intensively in producing Z. With less movement of factors than predicted in the costless-mobility case, the production of both goods will be more capital-using and labor-conserving. This is possible because the economy specializes less in its comparative-advantage good than would be observed in the costless-mobility case.

[vii] Further calculations reveal that for this Z expansion economy with mobility costs the capital/labor ratio in Y production will always lie above that observed in the costless-mobility case. In Z, the capital/labor ratio may fall either above or below the costless-mobility ratio; it will fall below (μ/(1-μ)) unless the ratio (τ_K/τ_L) is substantially greater than unity.

Table A2


Factor immobility and observed technology
Impact on labor/output ratios of an increase in relative price of final good
1.3
1.2
1.1
1
0.9
Labor-output ratio
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Year after shock
Pre-shock
Heckscher-Ohlin
Observed
LR post-shock
Eta=.5, P shifts from .8 to 1.0, w=.5, r=.1, K fixed at 100, alpha=.6

If country 2 is taken as the benchmark country and the Heckscher-Ohlin outcome as the world average, then the coefficients β_{ijc} and γ_{ijc} can be defined:

Table A2: **Estimation Coefficients**

$\beta_{KY} = \tau_K \beta_{KZ}$	$\gamma_{KY1} = [(1-\mu)\tau_L(\rho-\nu)-(1-\nu)(1-\mu\tau_K)]/\Delta_1$
$\beta_{LY} = \tau_L \beta_{LZ}$	$\gamma_{LY1} = [(1-\nu-\rho)\tau_K\mu + \nu(1-\tau_L(1-\mu))]/\Delta_1$
$\beta_{KZ} = [(1-\nu)\tau_L(\rho-\mu)-(1-\mu)(1-\tau_K\nu)]/\Delta_2$	$\gamma_{KZ1} = \tau_K \gamma_{KY1}$
$\beta_{LZ} = [\tau_K\nu(1-\mu-\rho)+\mu(1-\tau_L(1-\nu)_)]/\Delta_2$	$\gamma_{LZ1} = \tau_L \gamma_{LY1}$

Country 1: Z expanding.
Country 2: Y expanding, benchmark
World average: no change in factor allocation

Consider an economy with scarce labor in autarky. In that economy, the first-order conditions of (A4) and (A5) will define the wage/rental ratio; however, due to the relative labor scarcity, the wage/rental ratio will be higher than in free trade for any given ratio $\tau = (\tau_K/\tau_L)$. Figure A3 illustrates the impact of introducing free trade for any τ. In the case pictured ($\tau > 1$ and the country relatively labor-scarce) the costs of mobility cause an adjustment in wage/rental and labor/capital ratios toward but not up to the equilibrium levels in the Heckscher-Ohlin world. As q_L rises, other things equal, τ falls. This leads to rising (L_Y/K_Y) and falling (L_Z/K_Z) ratios as labor movement to the comparative-advantage sector is relatively discouraged. a_{LY} will be rising for rising q_L, while a_{LZ} will be falling for rising q_L. Increasing q_K, other things equal, has the opposite effect.

Simulation 1: illustrating the violation of factor price equalization and divergent unit factor coefficients.

Consider a world of 99 countries characterized by identical Cobb-Douglas technology for production of goods Y and Z. Factor allocation is assumed governed by the optimization program defined in equations (A1) through (A7). There is, specifically, the productivity loss associated with reallocation of factors with values $q_K = .55$ and $q_L = .66$ taken as parametric and identical for all countries.

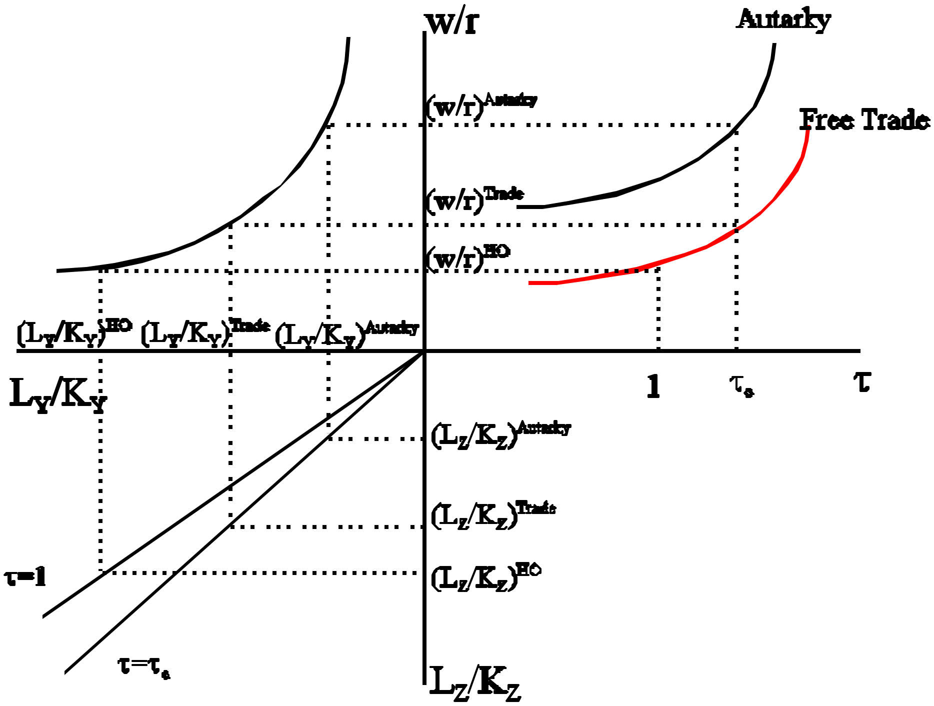


Figure A3

Each country is assumed to begin from its welfare-maximizing autarkic allocation of factors of production. Each country then has the opportunity to trade with the rest of the world at relative price p^* = .8 of good Z. All but one country chooses to trade, as p^* differs from the opportunity cost of Z in production. However, four groups of countries emerge. The first group, those with highest capital/labor endowment ratios, reallocate factors toward Y production. The fourth group, those with the lowest capital/labor endowment ratios, specialize completely in Z production. The third group, with relatively low capital/labor endowment ratios, reallocate productive factors toward Z production and specialize incompletely. The second group, with intermediate values of the capital/labor endowment ratio, trade in the two products but leave productive allocations unchanged. Table A1 provides relevant statistics on the factor allocation and trade patterns of a selection of these countries.

The degree of distortion introduced by the cost to factor mobility is represented by the divergence of τ_K and τ_L from unity. It is evident from Table A3 that τ_K does not differ that greatly from unity and does not vary that extensively from country to country, while τ_L evidences a larger distortionary effect and also varies more widely across countries. The optimal reallocation of factors is derived numerically to satisfy equations (2.3), (2.4), (3.3) and (3.4), depending upon the country's comparative advantage. As is implied by the reported factor reallocations, countries with capital endowments of 1 through 32 have the comparative advantage in Z production while those with capital endowments of 33 through 99 have comparative advantage in Y production.[viii]

Comparative advantage will lead to trade in this equilibrium, but not necessarily to factor reallocation. The cost of factor mobility leads to losses in discounted present value from reallocating factors, and these losses must be weighed against the gains from trade. In the three columns entitled "National Income", the discounted present value is reported for three variants. The first variant is the optimal reallocation and with no costs of mobility. The second variant (CostMob) reports the discounted present value of optimal reallocation of factors once the costs of mobility are subtracted. The third variant (NoMove) is the discounted present value of national income if factors remain in their initial uses but production is valued at world prices. After reallocation costs are considered, countries with capital endowments 18 through 55 choose not to reallocate factors of production.[ix]

The differing behaviors of the four groups of countries can be deduced from the illustration of long-run net exports of good Y provided in Figure A4. Two lines are superimposed in the diagram. The nearly straight line for countries 9 through 99 represents the net export of good Y predicted by the model with zero mobility cost (q_j =0) for both factors. Superimposed on that is the pattern of trading outcomes for economies with the positive costs to mobility posited here. The first group is the group that reallocates factors to produce good Y – countries with capital endowments between 55 and 99. For this group, the quantity exported is almost identical, while the capital/labor ratio in Y production is a bit larger, than in a zero mobility cost world. For the second group, with capital endowments between18 and 55, there is no factor reallocation. The net exports of Y are taken from an unchanged quantity produced of Y because of the changed relative price on the world market for consumers. These net exports (or, for countries with capital endowments less than 32, net imports) are less than would be predicted by the zero-mobility-cost model. For the third group, factor reallocations toward Z-good production lead to net exports nearly identical to those in the no-factor-mobility case. Finally, for the fourth group, complete specialization in Z production yields nearly the same net import of Y for both scenarios.

Figure A5 illustrates this difference across groups of countries in terms of the capital/labor ratios used to produce good Y. The existence of mobility costs drives a wedge between the capital-labor ratios observed in countries reallocating factors to the two sectors. For those countries reallocating factors, the capital-labor ratio depends only upon the direction of specialization and the technology, and not on other features of the economies. In the countries for which reallocation is unprofitable, by contrast, there is a wide range of capital-labor ratios consistent with the initial conditions of the economies. These are illustrated by the upward-sloping sequence of ratios for the countries with capital endowments between 18 and 55.

[viii] Balanced trade across the 99 countries is not imposed.

[ix] This is an overstatement of the factor immobility implied by the model, because I do not allow mobility of just one factor. For a number of the countries at the two ends of this spectrum it will be welfare improving to reallocate capital but to maintain labor in its initial position. These countries would have the features of "specific-factor" economies.

Table A3
Simulation Results, 2x2x99 model

	Autarky		Optimal Reallocation		National Income			τ_k	τ_l
K	K_y	L_y	ΔK_z	ΔL_z	HO	CostMob	NoMove		
10	7.79	9.9	6.4	9.31	290.1	279.4	261.2	0.92	0.78
15	9.53	9.9	5.11	7.2	320.3	312.4	311.1	0.91	0.79
20	15.66	9.9	3.84	5.19	354.5	348.6	349.6	0.91	0.81
25	19.57	9.9	2.31	3.27	388	384.2	385.5	0.90	0.82
30	23.36	9.9	0.75	1.37	420.6	419.2	420.3	0.89	0.83
35	27.26	9.9	-0.85	-0.45	451.3	450.5	452.5	0.89	0.89
40	31.15	9.9	-2.4	-2.15	485.9	482.8	484.4	0.89	0.87
45	35.04	9.9	-3.92	-4	517.8	513.1	514.4	0.89	0.85
50	40.98	9.9	-3.61	-5.5	550.9	544.6	546	0.88	0.75
55	45.08	9.9	-4.89	-7.25	583.5	574.9	575	0.88	0.74
60	49.18	9.9	-6.18	-9.2	616.1	605.2	603.2	0.88	0.73
65	53.28	9.9	-7.43	-11.1	648.6	635.4	630.8	0.88	0.72
70	57.38	9.9	-8.71	-13.1	681.2	665.7	657.7	0.88	0.71
75	61.48	9.9	-10	-15.05	713.8	695.8	684.1	0.88	0.79
80	65.57	9.9	-11.2	-17	746.4	726.2	710.1	0.88	0.69
85	69.67	9.9	-12.41	-19.05	779.1	756.5	735.6	0.88	0.68
90	73.77	9.9	-13.63	-21.05	811.7	786.8	760.5	0.88	0.68
95	78.37	9.9	-15.41	-23.05	844.2	816.6	784.3	0.88	0.65

Labor endowment is fixed at 50 in all simulations.

Figure A4

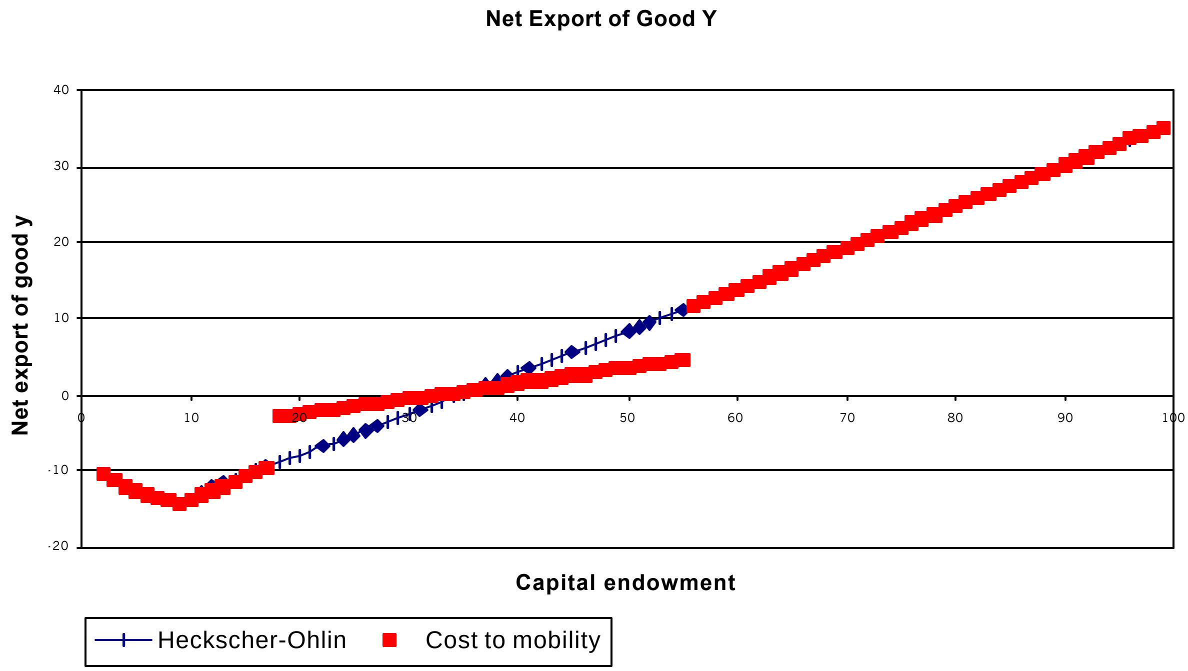
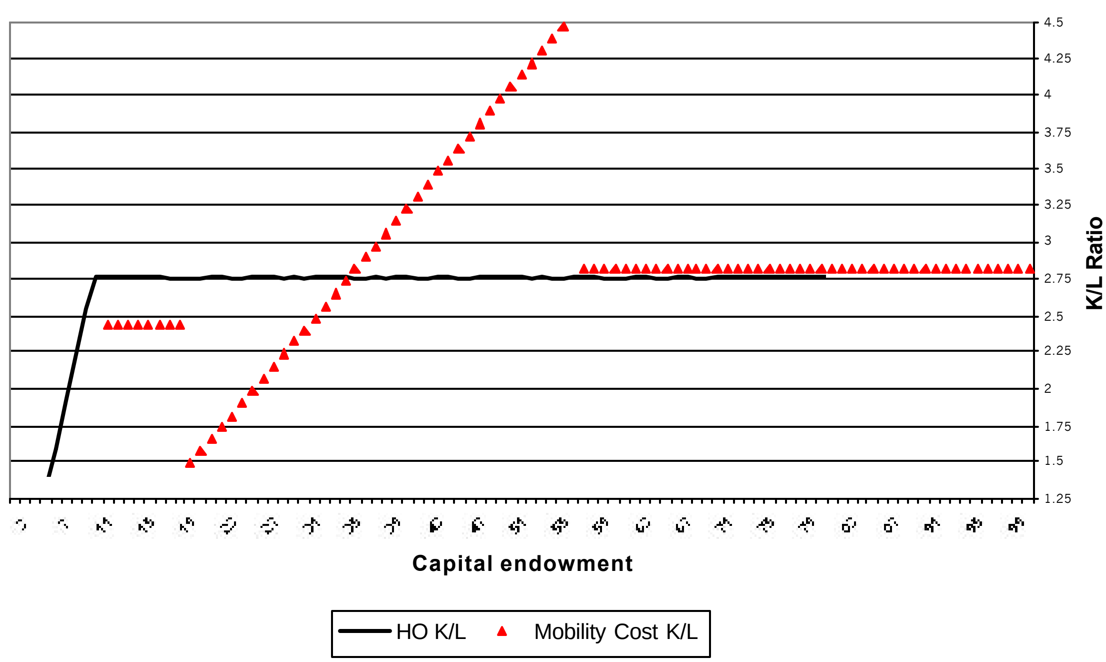


Figure A5: **Capital-labor ratios used in producing good Y**



Appendix: Estimation using alternative definition of S_c

for derivation, see Conway (2001)

With R_{2ic} as regressor:

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Regression	31	444644	14343.3	97.78	<.0001
Residual	266	40148.9	150.9		
Uncorrected Total	297	484792			
Corrected Total	296	482902			

Parameter	Estimate	Approximate Std Error	Approximate 95% Confidence Limits	
b_K	-0.2016	0.1317	-0.4609	0.0578
b_{LPT}	-0.1489	0.0855	-0.3173	0.0195
b_{LCL}	-0.2331	0.0892	-0.4087	-0.0575
b_{LSA}	-0.7590	0.0625	-0.8821	-0.6359
b_{LSE}	-0.2450	0.0734	-0.3896	-0.1005
b_{LAG}	-1.9334	0.2335	-2.3930	-1.4737
b_{LPR}	-0.3467	0.1753	-0.6919	-0.00155
b_{NCR}	-0.1084	0.7666	-1.6179	1.4010
b_{NPA}	0.1788	0.3148	-0.4410	0.7985
h_K	0.1114	0.2387	-0.3585	0.5813
h_{LPT}	0.0665	0.1081	-0.1463	0.2794
h_{LCL}	0.0411	0.1472	-0.2487	0.3310
h_{LSA}	0.7020	0.0474	0.6087	0.7953
h_{LSE}	0.0737	0.0842	-0.0922	0.2395
h_{LAG}	2.1458	0.2311	1.6906	2.6009
h_{LPR}	0.2688	0.2159	-0.1563	0.6938
h_{NCR}	0.6934	3.0488	-5.3096	6.6963
h_{NPA}	1.3572	2.2079	-2.9900	5.7044
g_1	-0.8106	0.0792	-0.9665	-0.6548
g_2	-0.7653	0.0823	-0.9273	-0.6034
g_3	-0.6729	0.1144	-0.8981	-0.4477
g_4	-0.5737	0.0780	-0.7272	-0.4202
g_5	-0.4401	0.0714	-0.5807	-0.2995
g_6	-0.3839	0.1610	-0.7009	-0.0669
g_7	-0.3137	0.1516	-0.6123	-0.0151
g_8	-0.2541	0.1353	-0.5204	0.0123
g_9	-0.1484	0.0739	-0.2939	-0.00297
g_{10}	0.0152	0.2275	-0.4327	0.4631
g_{11}	0.1176	0.0774	-0.0347	0.2699
g_{12}	0.3109	0.0876	0.1384	0.4835
g_{13}	0.5942	0.1858	0.2284	0.9600

The g coefficients represent groups of countries, not necessarily single countries.

With R_{1ic} as regressor:

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Regression	33	448748	13598.4	102.28	<.0001
Residual	264	36044.4	136.5		
Uncorrected Total	297	484792			
Corrected Total	296	482902			

Parameter	Estimate	Approximate Std Error	Approximate 95% Confidence Limits	
b_K	-0.3765	0.2208	-0.8112	0.0582
b_{LP}	-0.2252	0.0952	-0.4127	-0.0378
b_{LC}	-0.2754	0.1428	-0.5567	0.00580
b_{LS}	-0.7129	0.0621	-0.8351	-0.5907
b_{LS}	-0.1951	0.0817	-0.3560	-0.0342
b_{LA}	-0.3635	0.1265	-0.6127	-0.1144
b_{LP}	-0.3482	0.2130	-0.7676	0.0711
b_{NC}	-0.0450	0.7448	-1.5114	1.4215
b_{NP}	0.1834	0.5608	-0.9208	1.2877
h_K	-30.3881	15.5857	-61.0767	0.3004
h_{LPT}	-13.4163	3.2108	-19.7384	-7.0943
h_{LCL}	-13.8263	7.2575	-28.1165	0.4639
h_{LSA}	-3.5578	0.1800	-3.9123	-3.2034
h_{LSE}	-6.2729	1.7744	-9.7668	-2.7791
h_{LAG}	-4.0174	0.5008	-5.0035	-3.0313
h_{LPR}	-17.0829	7.2191	-31.2974	-2.8683
h_{NCR}	-171.0	487.5	-1130.9	788.9
h_{NPA}	-6.8553	32.4788	-70.8065	57.0960
g_1	-0.6276	0.1360	-0.8953	-0.3599
g_2	-0.5721	0.0987	-0.7665	-0.3777
g_3	-0.4277	0.0805	-0.5862	-0.2691
g_4	-0.3556	0.3065	-0.9591	0.2479
g_5	-0.3417	0.1405	-0.6183	-0.0650
g_6	-0.3027	0.0834	-0.4670	-0.1385
g_7	-0.1925	0.0705	-0.3314	-0.0537
g_8	-0.1215	0.0855	-0.2899	0.0468
g_9	-0.0261	0.1455	-0.3126	0.2604
g_{10}	0.0312	0.1123	-0.1899	0.2522
g_{11}	0.1367	0.0764	-0.0137	0.2872
g_{12}	0.2374	0.0767	0.0864	0.3884
g_{13}	0.3141	0.1345	0.0493	0.5790
g_{14}	0.5462	0.0886	0.3718	0.7206
g_{15}	0.8260	0.1777	0.4760	1.1759

The g coefficients represent groups of countries, not necessarily single countries.