1 Theories of International Trade

This chapter offers a review of the standard Heckscher-Ohlin model of international trade that forms a basis for later empirical analysis of the sources of comparative advantage. The two fundamental hypotheses of this model are (1) there are factors of production that are immobile between countries, and (2) these factors are used in different combinations to produce different goods. A country will then possess a comparative advantage in good X if the country is relatively well endowed with factors that are used intensively in the production of X. Although a long list of restrictive assumptions is necessary to make this proposition a precisely defined mathematical truth, it nonetheless is hard to imagine a model in which the possession of immobile factors of production is not a source of comparative advantage. Moreover, with a broad definition of factors it becomes evident that the proposition that endowments are the source of comparative advantage is tautological. For example, the technological differences in the Ricardian model can be thought to arise from differing endowments of knowledge capital.

The way in which endowments confer comparative advantage is not tautological, however. In the simple traditional model with assumptions including constant returns to scale and equal numbers of factors and goods, trade is a linear function of the endowments. If the list of assumptions is altered, the relation between trade and endowments becomes nonlinear in ways that depend on the assumption that is altered. A linear relation between net exports and factor endowments serves as the working hypothesis for the empirical work subsequently presented. This choice is dictated by reasons of convenience and conceptual clarity, since, among the many convenient functional forms that could be used in the data analysis, only the linear form can be derived formally from a fully described general equilibrium model. An important purpose of this chapter is to alert the reader that there is a myriad of assumptions that could be made—and to discuss the kind of nonlinearities that might consequently be expected in the data set. Though overall the impression that is likely to be created is that the linear model is very fragile, it will be shown that linearity is preserved if there are nontraded goods, if there are more goods than factors, if consumption shares are income dependent, and even if there are certain kinds of transportation costs and tariff charges.

The traditional assumptions underlying the 2×2 textbook trade model are listed in section 1.1; the resulting theorems are derived in section 1.2; and the effects of departures from the assumptions are discussed

in section 1.3. This chapter is meant to be a fairly complete statement of international trade theory as it relates to the determinants of the composition of trade and provided it seems useful in studying empirical data. Hypotheticals, such as "autarky prices," that have no observable counterparts are excluded from discussion, as are models that do not produce adequately clear descriptions of the relation between the composition of trade and its observable determinants.[1] The discussion in this chapter is detailed when a specific relation between trade and factors endowments can be derived, but the discussion is brief when the theory can provide only an impression. The subsequent empirical work rests primarily on the simplest model and its extension to high dimensions. It is therefore sufficient to read sections 1.1 and 1.2 and the part of section 1.3 dealing with dimensionality.

1.1 Assumptions

There are six classes of assumptions that are used to produce trade theory's sharpest results.

1. *Dimensionality*. The number of goods n and the number of productive factors m are equal to 2: $n = m = 2$.

2. *Mobility*. (a) Factors of production move costlessly between industries within a country, but are completely immobile between countries. (b) Commodities move internationally at zero cost of transport and there are no other impediments to trade.

3. *Competition*. Both commodity and factor markets clear competitively, in the sense that all agents act as if they could buy or sell unlimited quantities at the prevailing market prices.

4. *Technology*. The same technological knowledge about the production of goods is costlessly available to all countries. The production functions exhibit constant returns to scale and diminishing marginal products.

5. *Factor Endowment Similarity*. The variability of factor endowment ratios among countries is less than the variability of factor input intensities across industries. (A precise definition of "less variability" is given below.)

6. *Demand Similarity*. Individuals consume as if each were maximizing an identical homothetic utility function.

1.2 The Basic Trade Theorems

The core of general equilibrium trade theory consists of four theorems that describe the responsiveness of outputs and factor prices to changes in output prices and factor supplies and a fifth that identifies which commodities are exported and which are imported. The factor price equalization theorem deals with the responsiveness of factor prices to factor supplies, holding fixed output prices. The Stolper-Samuelson theorem describes the relation between factor prices and output prices, holding fixed factor supplies. The Rybczynski theorem links outputs to factor supplies, given output prices. And the Samuelson reciprocity relations describe the correspondence between the Stolper-Samuelson effects and the Rybczynski effects. The fifth theorem, the Heckscher-Ohlin theorem, identifies the structure of trade as a function of either (a) the difference between autarky (pretrade) prices and posttrade prices or (b) factor supplies. Since autarky prices are generally unobservable, this book will make use of only the quantity version of the Heckscher-Ohlin theorem.[2]

THE FACTOR PRICE EQUALIZATION THEOREM All countries have identical factor prices.

Proof Let the goods be labeled X_1 and X_2 and let the factors be labor (L) and capital (K). A *unit-value isoquant* for commodity X_1 is depicted in figure 1.1. This is the set of combinations of capital and labor minimally

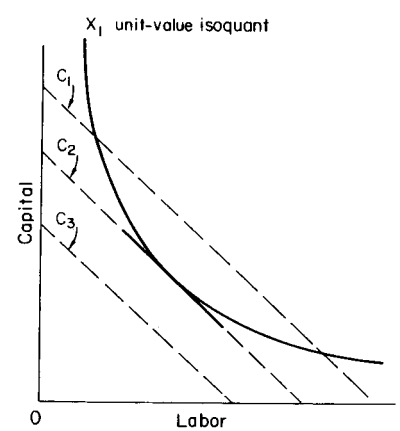

Figure 1.1
Unit-value isoquant and isocost lines.

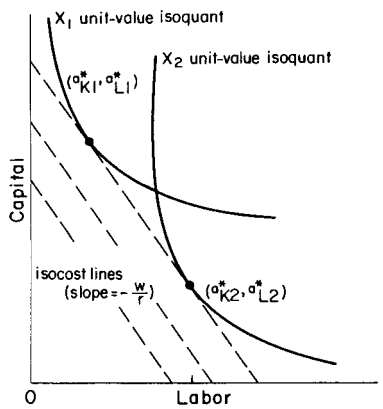

Figure 1.2
Equilibrium factor costs.

required to produce a unit value of output. Because commodity prices are assumed equalized by trade and because technologies are assumed identical, all countries have the same unit-value isoquant. The three straight lines labeled C_1, C_2, and C_3 in figure 1.1 are three hypothetical unit *isocost lines* defined as combinations of capital and labor that cost a unit value. A unit isocost line is defined algebraically as $1 = w_K K + w_L L$, where w_K and w_L are the rental rates for capital and labor services, respectively. Each isocost line has slope equal to $-w_L/w_K$, and from the fact that the three isocost lines in figure 1.1 are parallel we may infer that the ratio of w_L to w_K is the same in each case. Of these three unit isocost lines, only line C_2, which is tangent to the unit-value isoquant, is consistent with competitive equilibrium. If line C_1 were the unit-cost line, producers could hire a unit value of inputs and produce more than a unit value of output. In an attempt to exploit this profit opportunity by hiring inputs, producers would drive up the input costs, thereby shifting the unit-cost line downward, a process that continues until profit opportunities are exhausted, that is, until the unit-value isoquant and the unit-cost line are tangent. Likewise, if the isocost line were C_3, there would be no way for producers even to break even, and either factor costs would have to fall or the commodity would not be produced.

The unit-value isoquants for both commodities are depicted in the "Lerner diagram," figure 1.2 (Lerner, 1952). Only one unit-cost line is consistent with the production of both goods in equilibrium, since only

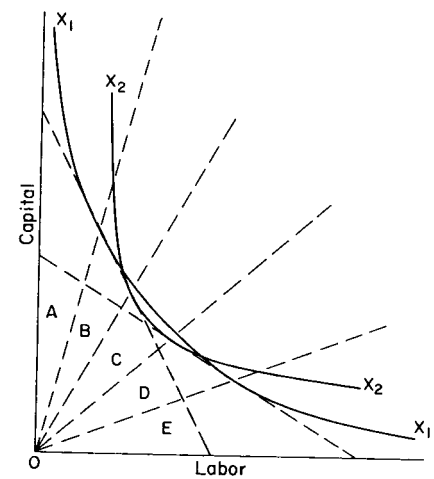

Figure 1.3
Factor intensity reversal.

one line is tangent to both unit-value isoquants. This line determines unique values for the factor rental rates w_K and w_L. Hence factor prices are equalized. Though this argument has referred to unit-value isoquants, the assumption of constant returns makes it apply to any level of output. ■

This argument is deficient in one respect. There is no assurance that the unit-value isoquants admit only a single tangent isocost line. An example to the contrary is illustrated in figure 1.3, in which there is a high wage equilibrium with X_1 produced with a capital intensive technique and a low wage equilibrium with X_1 produced with a labor intensive technique. The commodities X_1 and X_2 are said in this case to exhibit a *factor intensity reversal*, since one of the commodities can be produced efficiently with capital/labor ratios either more or less than the capital/labor ratio of the other, depending on the relative factor returns.

When there is more than one possible equilibrium set of factor returns, the choice among them depends on the factor endowment of the country. The allocation of a given endowment of capital and labor between the industries is illustrated in figure 1.4, where the vector V_1 indicates the factors allocated to industry 1 and the vector V_2 indicates the factors allocated to industry 2. These two vectors must lie along the expansion paths of the two industries and they must sum to the endowment vector (K, L). If the endowment vector (K, L) lies outside the cone between the

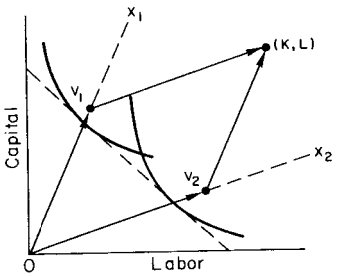

Figure 1.4
Allocation of factors between industries.

two expansion vectors, it is impossible to find two vectors along the expansion vectors that sum to the endowment vector, and consequently the factor prices associated with that cone are inconsistent with equilibrium. Return again to figure 1.3; this implies that the choice between the two factor price ratios depends on the endowment ratio. If the endowment is in a cone B with relative capital abundance, high wages are selected. If the endowment is in cone D with relative labor abundance, low wages are selected. If labor is even more abundant, and the endowment vector lies in region E, then the country specializes in X_1, and wages are still lower. Relative factor prices may then be found by placing an isocost line tangent to the X_1 isoquant at the endowment point.

The regions B and D in figure 1.3 are called *cones of diversification*. Countries with endowments in the same cone of diversification produce both goods using the same techniques and also have the same factor prices. Countries with endowments in different cones use different techniques and have different factor prices. Countries with endowments in none of the cones specialize in the production of one of the goods.

In order to ensure factor price equalization it is therefore necessary to invoke the following.

FACTOR ENDOWMENT SIMILARITY CONDITION Given the equilibrium commodity prices and the consequent family of cones of diversification, all countries either have factor endowments in the same cone or identical factor endowment ratios.

The cones of diversification will be wider, the more dissimilar are the productive techniques, and this condition can be stated as above that endowments must be more similar than (equilibrium) input intensities.

It may be noted in passing that this demonstration has made use of assumptions 1–5 with the exception of the part of 2a describing the immobility of factors between countries. Because factor prices are equalized, the economic incentive for migration is eliminated, and international mobility of factors is immaterial, provided such mobility does not affect the assumption about factor endowment similarity. Assumption 6 is used only in the limited sense that the production side of the economy maximizes the value of output.

From the internationally determined prices of goods, we have been able to derive the factor prices and the factor input intensities (defined precisely below). These intensities are depicted in figure 1.2, where (a^*_{K1}, a^*_{L1}) and (a^*_{K2}, a^*_{L2}) are the amounts of capital and labor required to produce a unit value of X_1 and X_2, respectively. The input requirements a^*_{ij} per *unit value* of output can be transformed into input requirements a_{ij} per *unit* of output by multiplying by product prices: $a_{ij} = a^*_{ij}p_j$, where p_j is the product price. The input requirements a_{ij} are called *factor input intensities*, and can be collected into a *factor intensity matrix* symbolized by A.

The following definitions refer to relative factor intensities and relative factor abundance.

FACTOR INTENSITY DEFINITION Commodity X_1 is said to be the relatively capital intensive commodity if

$$a_{K1}/a_{L1} > a_{K2}/a_{L2}.$$

FACTOR ABUNDANCE DEFINITION A country endowed with capital K and labor L is said to be relatively abundant in capital if its share of the world's capital stock exceeds its share of the world's labor force:

$$K/K_w > L/L_w,$$

or equivalently if the country is more capital abundant than the world as a whole:

$$K/L > K_w/L_w,$$

where the w subscript refers to world totals. ■

Having established factor price equalization, we may now demonstrate the Heckscher-Ohlin theorem.

THE HECKSCHER-OHLIN THEOREM A country with balanced trade will export the commodity that uses intensively its relatively abundant factor and will import the commodity that uses intensively its relatively scarce factor.

Proof Denoting the output levels by X_1 and X_2, we may set factor supply equal to factor demand to obtain

$$K = a_{K1}X_1 + a_{K2}X_2,$$

$$L = a_{L1}X_1 + a_{L2}X_2,$$

which is a system that can be solved for outputs as a function of the endowments. If V represents the vector of endowments (K, L) and X the vector of outputs (X_1, X_2), then these equations may be written in matrix form as $V = AX$, or inverted as

$$X = A^{-1}V, \tag{1.1}$$

where the inverse exists provided the relative input intensities are unequal: $a_{K1}/a_{L1} \neq a_{K2}/a_{L2}$. Because of the linearity of these equations (and the consequent unresponsiveness of total world outputs to factor migration), we can also write total world outputs X_w as a function of total world endowments V_w:

$$X_w = A^{-1}V_w.$$

Since the relative prices of goods are given in world markets and hence are the same for all countries, assumption 6 implies that each country consumes commodities in the same proportions, that is,

$$C = sX_w,$$

where s is the country's consumption share of world output and C is its consumption vector.

Trade balance requires that the value of production equal the value of consumption, that is, $p'X = p'C = sp'X_w$, where p is the price vector (p_1, p_2). Thus if trade is balanced, the consumption share is the ratio of own GNP to world GNP:

$$s = p'X/p'X_w. \tag{1.2}$$

The vector of *net exports* is the difference between production and consumption:

$$\begin{aligned} T &= X - C \\ &= A^{-1}V - sA^{-1}V_w \\ &= A^{-1}(V - sV_w), \end{aligned} \tag{1.3}$$

which is A^{-1} times the vector of *excess factor supplies*:

$$V - sV_w = \begin{bmatrix} K - sK_w \\ L - sL_w \end{bmatrix} = \begin{bmatrix} K_w\left(\dfrac{K}{K_w} - s\right) \\ L_w\left(\dfrac{L}{L_w} - s\right) \end{bmatrix}.$$

It will now be demonstrated that if the country in question is relatively capital abundant, $K/K_w > L/L_w$, then this excess factor supply vector has signs $(+, -)$. This follows from the fact that the consumption share is a weighted average of the capital share and the labor share

$$s = \frac{p'X}{p'X_w} = \frac{p'A^{-1}V}{p'A^{-1}V_w} = \frac{w'V}{w'V_w} = \frac{[w_K K_w(K/K_w) + w_L L_w(L/L_w)]}{w_K K_w + w_L L_w},$$

where w is the factor reward vector: $w = (A')^{-1}p$. Thus s must fall between K/K_w and L/L_w, and consequently $K/K_w > s$ is equivalent to $K/K_w > L/L_w$.

To determine the sign of the net export vector of a capital abundant country, we need to determine the effect of premultiplying a vector with signs $(+, -)$ by the inverse of the matrix A:

$$A^{-1} = \begin{bmatrix} a_{K1} & a_{K2} \\ a_{L1} & a_{L2} \end{bmatrix}^{-1} = \begin{bmatrix} a_{L2} & -a_{K2} \\ -a_{L1} & a_{K1} \end{bmatrix} / |A|,$$

where the determinant is

$$|A| = (a_{K1}a_{L2} - a_{L1}a_{K2}) = a_{L1}a_{L2}\left(\frac{a_{K1}}{a_{L1}} - \frac{a_{K2}}{a_{L2}}\right).$$

If X_1 is the capital intensive industry, then $|A| > 0$, and A^{-1} has the sign pattern

$$A^{-1} = \begin{bmatrix} + & - \\ - & + \end{bmatrix}.$$

If the country is abundant in capital, the vector of excess factor supplies has sign pattern $(+, -)$, and trade therefore has sign pattern

$$T = \begin{bmatrix} + & - \\ - & + \end{bmatrix} \begin{bmatrix} + \\ - \end{bmatrix} = \begin{bmatrix} + \\ - \end{bmatrix},$$

meaning the capital abundant country exports the capital intensive commodity X_1 and imports the labor intensive commodity X_2. All other cases of the Heckscher-Ohlin theorem follow similarly.[3] ■

The primary intent of this book is to study the linkages between trade and factor endowments, but for completeness I will briefly state the other basic trade theorems.

THE RYBCZYNSKI THEOREM At constant commodity prices, an increase in the supply of a factor will lead to an increase in the output of the commodity that uses that factor intensively and a reduction in the output of the other commodity.

This follows directly from equation (1.1) and the sign patterns for A^{-1}. A somewhat more precise version of the theorem can be stated in terms of the percentage changes in outputs induced by percentage changes in inputs. From equation (1.1) we have

$$\hat{X}_1 = (dX_1)/X_1 = (a_{L2}dK - a_{K2}dL)/(a_{L2}K - a_{K2}L).$$

Thus

$$(a_{L2}K - a_{K2}L)\hat{X}_1 = a_{L2}K\hat{K} - a_{K2}L\hat{L},$$

$$a_{L2}K(\hat{X}_1 - \hat{K}) = a_{K2}L(\hat{X}_1 - \hat{L}),$$

or

$$(\hat{X}_1 - \hat{K}) = (\hat{X}_1 - \hat{L})(a_{K2}/a_{L2})/(K/L).$$

Thus if commodity one is the capital intensive commodity, $a_{K1}/a_{L1} > K/L > a_{K2}/a_{L2}$, we must have $|\hat{X}_1 - \hat{K}| < |\hat{X}_1 - \hat{L}|$, that is, X_1 must grow at a rate more similar to K than to L, and we must have $\text{sign}(\hat{X}_1 - \hat{K}) = \text{sign}(\hat{X}_1 - \hat{L})$. This implies that either $\hat{L} < \hat{K} < \hat{X}_1$ or $\hat{X}_1 < \hat{K} < \hat{L}$, which establishes.

JONES'S MAGNIFICATION RESULT At constant commodity prices, $a_{K1}/a_{L1} > a_{K2}/a_{L2}$ and $\hat{K} > \hat{L}$ imply $\hat{X}_1 > \hat{K} > \hat{L} > \hat{X}_2$.

The next result links factor prices to commodity prices. This linkage is implied by the zero-profit conditions

$$A'w = p, \tag{1.4}$$

where p is the vector of prices (p_1, p_2) and w the vector of factor rewards. This condition asserts that the price of a commodity is equal to the cost of producing it. Differentiating this expression produces $A'(dw) = dp$, since $(dA')w = 0$ by cost minimization.[4] Writing this as

$$dw = (A')^{-1}\, dp, \tag{1.5}$$

and again referring to the sign pattern of the inverse of a 2×2 positive matrix, we obtain.

THE STOLPER SAMUELSON THEOREM An increase in the price of the import good leads to an increase in the return to the scarce factor and a reduction in the return to the abundant factor.

Finally, by comparing (1.5) with (1.1) we obtain a result due to Samuelson (1953/1954):

THE RECIPROCITY RELATIONS

$$\partial X_j/\partial V_i = \partial w_i/\partial p_j, \qquad i = K, L, \quad j = 1, 2.$$

In words, the partial derivative of the supply of commodity j with respect to the total availability of factor i is equal to the partial derivative of the wage of factor i with respect to the price of commodity j. These reciprocity relations are used in chapter 7 to obtain indirect estimates of the effects of tariffs on factor returns from direct observation of the responsiveness of output to factor supplies.

1.3 The Effects of Departures from Assumptions

It takes neither great observational skills nor keen inquisitiveness to make one question the six assumptions and to make one wonder whether the results hold up if these assumptions are relaxed. A particularly troubling observation is the great international disparity in wage rates. For example, the agricultural wage rates reported in table 1.1 vary from a low of \$.046 per hour in India to a high of \$2.04 per hour in Denmark. Part of these differences might be explained by skill differences, but agricultural wages seem unlikely to include a reward for skills that is

Table 1.1
Agricultural wage rates ($/hour): 1972 or closest year data available

ARG	.31	JAP	.69
AUST	.97	KOR	.25
BLUX	1.30	MALA	.17
CAN	1.75	MAUR	.17
CHLE	.18	MEX	.22
CSTR	.22	NUZE	.86
CYP	.61	NOR	1.79
DEN	2.04	PHIL	.062
ELSAL	.63	PORT	.38
FIN	.96	SRIL	.078
FRA	.48	SPAIN	.38
GER	1.35	SWE	2.80
GANA	.18	TURK	.34
INDA	.046	UK	1.34
IRE	1.04	US	1.76
ISRL	.71	YUG	.49

Source: ILO, *Yearbook of Labor Statistics*, 1972.

sufficiently variable to account for the data in table 1.1. This observation encourages a search for assumptions that do not necessarily imply factor price equalization.

1.3.1 Dimensionality[5]

There surely are more than 2 commodities, and more than 2 factors as well. In an intertemporal model one might suppose that there are only 2 factors, labor and land, but these ought to be disaggregated along several quality dimensions. These primary factors can be combined to produce capital goods. But at a specific time, past savings decisions can be taken as given, and capital can be treated as a fixed input. At any instant there will be many types of capital that are relatively well suited to the production of particular commodities and that cannot be transformed into other kinds of capital. For example, human capital and machinery are not fungible except in the long run, and within a year, say, can be treated as separate factors of production. Identifying the particular categories of capital is a very delicate conceptual and empirical issue that interfaces with the mobility assumption. Automobile-stamping plants might be treated as a category of capital that is relatively suited to production of automobiles but not especially useful in the medium run to the production of textiles. For that matter, automobile workers have a certain amount of human capital invested in the auto industry because of special skills and mobility

costs. An explanation of trade in terms of exceedingly fine measures of capital would be too close to a tautology to be very satisfying, but simple distinctions between human and physical capital are appealing. In any case, it is clear that there are more than 2 factors of production, and it is essential that the model be enlarged.

The Even Model, $n = m > 2$ The factor price equalization theorem holds in the even case regardless of the number of factors. Imagine the 3-dimensional picture analogous to figure 1.2. The three unit-value isoquants instead of being lines are surfaces—think of three bowls—and the isocost lines are planes instead of straight lines. Only one of these planes rests squarely on all three bowls; hence there is only one set of factor prices consistent with the production of all three goods. As in the 2-dimensional case, factor intensity reversals[6] can occur, but, regardless, for any set of commodity prices there will be a set of cones of diversification, and all countries in the same cone will have the same factor rewards.

The Heckscher-Ohlin theorem in one sense is dramatically altered, but in another sense is not altered at all by high dimensionality with $m = n$. The basic equations of the model, (1.1)–(1.3), which determine the output vector, the consumption share, and the trade vector, need not be altered. If factor prices are equalized, the factor intensity matrix A will be the same in each country, and equations (1.1)–(1.3) are an immediate consequence. However, the interpretation of these equations in the 2×2 case depends on properties of the inverse of a 2×2 positive matrix. Namely, the inverse of the factor intensity matrix A has one of two distinct sign patterns, depending on the ordering of the capital intensities of the 2 goods. Things become much more complex in higher dimensions.[7] Suppose the country is abundant in the first factor and scarce in the other two in the sense that the excess factor supply vector $V - sV_w$ has sign pattern $(+, -, -)$. You can then determine the sign of the first element of the trade vector $T = A^{-1}(V - sV_w)$ from knowledge of only the sign of A^{-1} in two cases:

$$\begin{bmatrix} + & - & - \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix} \begin{bmatrix} + \\ - \\ - \end{bmatrix} = \begin{bmatrix} + \\ \cdot \\ \cdot \end{bmatrix},$$

$$\begin{bmatrix} - & + & + \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix} \begin{bmatrix} + \\ - \\ - \end{bmatrix} = \begin{bmatrix} - \\ \cdot \\ \cdot \end{bmatrix}.$$

What are the circumstances in which the first row of A^{-1} has one of these two sign patterns? Consider the inverse of A with factors capital (K), labor (L), and land (M):

$$A = \begin{bmatrix} a_{K1} & a_{K2} & a_{K3} \\ a_{L1} & a_{L2} & a_{L3} \\ a_{M1} & a_{M2} & a_{M3} \end{bmatrix}.$$

To find the first row of A^{-1} we need to compute the cofactors

$$C_{11} = \det \begin{bmatrix} a_{L2} & a_{L3} \\ a_{M2} & a_{M3} \end{bmatrix} = a_{L2}a_{L3}\left(\frac{a_{M3}}{a_{L3}} - \frac{a_{M2}}{a_{L2}}\right),$$

$$C_{12} = -\det \begin{bmatrix} a_{K2} & a_{K3} \\ a_{M2} & a_{M3} \end{bmatrix} = a_{M2}a_{M3}\left(\frac{a_{K3}}{a_{M3}} - \frac{a_{K2}}{a_{M2}}\right),$$

$$C_{13} = \det \begin{bmatrix} a_{K2} & a_{K3} \\ a_{L2} & a_{L3} \end{bmatrix} = a_{L2}a_{L3}\left(\frac{a_{K2}}{a_{L2}} - \frac{a_{K3}}{a_{L3}}\right),$$

and the determinant of A:

$$|A| = a_{K1}C_{11} + a_{L1}C_{12} + a_{M1}C_{13}.$$

Then the relevant elements of $B = A^{-1}$ are

$$B_{11} = C_{11}/|A|,$$

$$B_{12} = C_{12}/|A|,$$

$$B_{13} = C_{13}/|A|.$$

The condition that we are seeking is that B_{11} has sign opposite of B_{12} and B_{13}. By inspection of the cofactors this places rather bizarre and complicated restrictions on the factor intensities in industries 2 and 3. If industry 2 is less land intensive than 3 (relative to labor), $C_{11} > 0$, then industry 2 must be more capital intensive (relative to land) than 3, but 2 must also be less capital intensive (relative to labor) than 3.

In higher dimensions it thus becomes impossible to state the Heckscher-Ohlin theorem in a useful way analogous to its statement in the 2-dimensional case. But who really cares? All this is saying is that there exists a simple algorithm for determining the sign of the trade vector T in the 2-dimensional case, but the algorithm becomes more complex in higher dimensions. The degree of complexity remains trivial for a computer given

dimensions well above 3, even though 3 strains the human mind. What we might do to assist limited human beings is to rephrase the Heckscher-Ohlin theorem in a correct and informative way. To do this, note that the vector of factors required to produce the vector of outputs X is the vector AX. Thus

DEFINITION The *factors embodied in net exports* form the vector AT, where A is the matrix of factor intensities and T is the vector of net exports.

The vector AT can have positive or negative elements, meaning that factor services (embodied in goods) can be either exported or imported. Then we can rewrite equation (1.3) as Vanek (1968) does,

$$AT = V - sV_w, \tag{1.6}$$

meaning that the factors embodied in net exports equal the excess factor supplies. This set of equations serves as the foundation for the subsequent data analysis and are referred to as the *Heckscher-Ohlin-Vanek* (*HOV*) *equations*. In order to express these equations in the words of the Heckscher-Ohlin theorem, we need a definition of factor abundance applicable to the multidimensional case:

FACTOR ABUNDANCE DEFINITION A country is said to be abundant in factor i if its share of the world's supply of the factor exceeds its consumption share ($V_i/V_{wi} > s$).

Note that if trade is balanced, $B = 0$, then equation (1.6) implies that

$$s = p'X/p'X_w = p'A^{-1}V/p'A^{-1}V_w = w'V/w'V_w = \sum w_i V_{wi}(V_i/V_{wi})/\sum w_i V_{wi}.$$

In words, s is a weighted average of the abundance ratios V_i/V_{wi} with weights equal to world earnings $w_i V_{wi}$. Thus the factor abundance definition compares the abundance ratio of a selected factor with an average of all abundance ratios. With this definition, we can interpret equation (1.6) as the

HECKSCHER-OHLIN-VANEK THEOREM A country will export the services of abundant factors and import the services of scarce factors.

This way of reexpressing the Heckscher-Ohlin theorem properly emphasizes the point that it is factor services that are being exchanged through trade. Commodities serve only as a bundle within which factor services are wrapped.

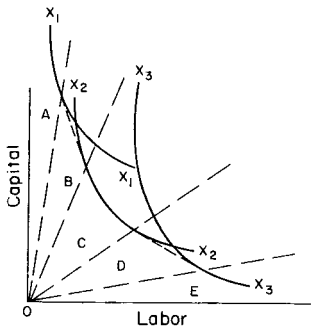

Figure 1.5
Unit-value isoquants, factor prices not equalized.

There is no simple algorithm in the $m = n > 2$ case for linking the signs of the trade vector to the signs of the excess factor supply vector. For the same reasons, the linkages of commodities to factors implied by the Stolper-Samuelson and the Rybczynski theorems become incomprehensibly complex. All three theorems depend on the sign pattern of the inverse of the factor intensity matrix, which in 2 dimensions is a function of rather straightforward qualitative information, namely, the sign of the determinant. In higher dimensions, the required qualitative information becomes so complex that it is just as convenient to condition these theorems on complete quantitative knowledge of the factor intensity matrix A. Namely, the derivatives of outputs with respect to endowments are collected in the matrix A^{-1}, and the derivatives of factor prices with respect to commodity prices are collected in the matrix A'^{-1}. Measuring A^{-1} is an important empirical task that can be done, as in Chipman (1977/1978), by regressing internal goods and factor prices on traded goods prices or, as in this work, by regressing outputs on factor supplies or trade on excess factor supplies.

More Goods Than Factors, $m < n$ If there are more goods than factors, there are new ways for the factor endowment similarity condition to be violated. Barring that possibility, the model remains basically the same as the $m = n > 2$ model. Consider, for example, the 3-good 2-factor case depicted in figure 1.5 with unit-value isoquants for goods X_1, X_2, X_3. This figure is similar to figure 1.3. As in that case, if the endowments of all countries are in the same cone of diversification, then all countries will have the same factor prices. Here, however, at least 1 of the 3 goods will

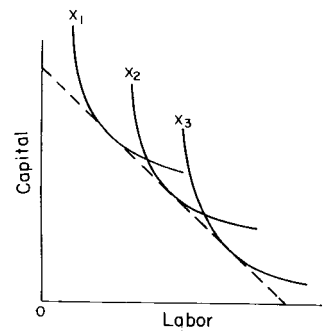

Figure 1.6
Unit-value isoquants, factor prices equalized.

then not be produced; for example, if the endowments are all in cone B, X_3 is not produced. The lack of supply of X_3 would then put upward pressure on the price of X_3. A rise in the price of X_3 shifts the unit-value isoquant in toward the origin until figure 1.6 occurs, at which point all three goods can be produced at nonnegative profit. What this means is that similarity in factor endowments will imply that commodity prices will adjust so that an equilibrium such as depicted in figure 1.6 occurs, with all countries having the same factor rewards and all using the same factor intensities A.

The matrix A is not square, however, and cannot be inverted. The set of equations $AX = V$ leaves X indeterminate. (X has n elements but there are only m equations, $m < n$.) Outputs, and consequently trade, have a degree of indeterminateness equal to $n - m$. As an illustration consider the 1-factor 2-good (Ricardian) model. All countries have straight line production possibilities curves with the same slopes. A country could attain its optimal consumption point with no trade by matching production and consumption. Alternatively, the production point can be anywhere on the production possibilities line, and the optimal consumption point can still be achieved by a suitable choice of trade. Although trade is indeterminate, the net flow of factor services is not. That is, equation (1.6) still holds. What is happening is that any given net export of factor services $V - sV_w$ can be achieved in many different bundles of net exports T.

A way to resolve the indeterminacy of trade and production is to hypothesize small international transportation costs that deter trade but are otherwise negligible. In the 1-factor Ricardian model, no trade would then

occur. For the more general model suppose that it costs c_j to exchange commodity j internationally. If these costs are small enough that factor price equalization is imperceptibly altered, we can suppose that the economy minimizes transportation costs $\sum_j c_j|T_j|$ subject to the constraint $AT = V - sV_w$. Whatever the solution to this linear programming problem may be, it will have the property that it is a linear function of the excess factor supply vector $V - sV_w$.

More Factors Than Goods Results necessarily change more substantially if there are more factors than goods. Then it is impossible to derive the (internal) factor prices from the (external) commodity prices. This can be understood easily with reference to a model with 3 factors and 2 goods. A figure analogous to figure 1.2 is 3 dimensional, with each factor measured on a different axis. The unit-value isoquants are surfaces (bowls), and the isocost surface is a plane. In the 3×3 case, we have three bowls upon which to rest the plane. If there are only 2 goods, then there are only two bowls and the plane cannot be supported by these bowls alone. Thus there are many sets of factor prices that could support the production of both goods. Corresponding to each of these factor price planes there is a minimum cost combination of inputs. The factor exhaustion equation can be written as

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix},$$

where the elements a_{ij} depend on the particular factor price plane. For most values of a_{ij} this system cannot be solved for (X_1, X_2). It is necessary to select factor prices such that the given endowment vector goes through the line connecting the two tangency points (a_{11}, a_{21}, a_{31}) and (a_{12}, a_{22}, a_{32}). Thus the factor matrix A will change in a complicated way as the endowment vector changes. The resulting relation between trade and endowments is highly complex.

1.3.2 Factor Endowment Similarity

If countries are sufficiently similar in their factor endowments, the factor price equalization theorem and a version of the Heckscher-Ohlin theorem hold provided the number of factors is less than or equal to the number of commodities. But if countries are sufficiently dissimilar, they may specialize production in different subsets of commodities, or they may use

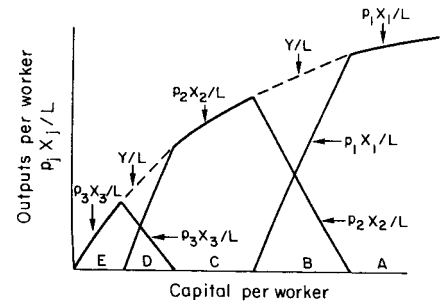

Figure 1.7
Outputs and GNP: 3 goods and 2 factors.

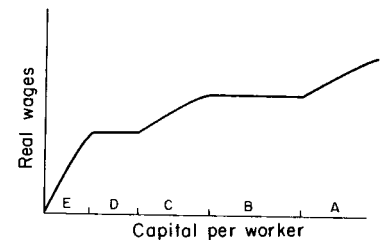

Figure 1.8
Wage rates: 3 goods and 2 factors.

different input combinations to produce the same commodity. If the first occurs, countries will be said to be *completely specialized.* If the second occurs, and if the country is not completely specialized, the technology is said to admit economically relevant *factor intensity reversals.* In either case, factor prices will not be equalized. If countries are completely specialized, the content of the Heckscher-Ohlin theorem is preserved, though the precise linear form is not. If factor intensity reversals occur, even the content of this theorem can be reversed.

Consider, for example, the model with 3 goods and 2 factors depicted in figure 1.5. Countries with endowment vectors located in cone B will specialize in the production of the relatively capital intensive commodities. Countries with less capital compared to labor, such that their endowment vectors are located in cone D, will have lower wage rates and will specialize in production of the two relatively labor intensive commodities. The outputs per man and the corresponding wage rates as a function of capital per man implied by figure 1.5 are depicted in figures 1.7 and 1.8.

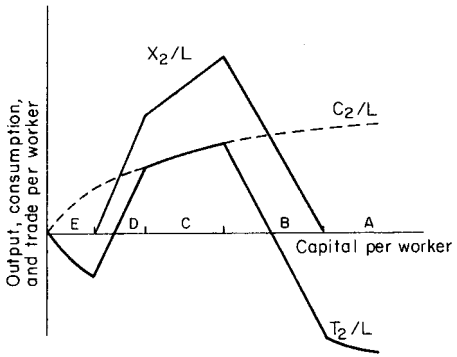

Figure 1.9
Output, consumption, and trade: 3 goods and 2 factors.

At very low capital/man endowment ratios, countries have low wage rates and specialize in X_3, the labor intensive commodity. As the capital per man increases, countries shift production progressively into more capital intensive industries, and wage rates correspondingly increase. In the cones of diversification B and D, the output per worker functions are linear in capital per worker, and the wage rates are insensitive to small changes in the endowments. In the regions of complete specialization, A, C, and E, countries produce only 1 good and have wage rates that increase with the capital abundance.[8]

It is apparent from figure 1.7 that the intellectual content of the Heckscher-Ohlin model is unaffected by this kind of dissimilarity in factor endowments. Countries with abundant capital will specialize in the capital intensive goods and will necessarily exchange these for the labor intensive goods. From an empirical standpoint, however, the relation between trade and endowments is not universally linear and rather unpleasant estimation problems arise. Take, for example, commodity X_2 and assume that half of GNP is spent on consuming X_2. Figure 1.9 depicts the output per man and consumption per man, assumed to be equal to half of GNP per man. Trade per man, the difference between output and consumption, is also shown. This is indeed a rather peculiarly shaped function, with X_2 exported by countries with intermediate capital abundance. We shall be alert to such nonlinearities when the data are examined.

Figure 1.7 can also be used to depict outputs if there are factor intensity reversals, except that X_3 is treated as the same product as X_1. As the

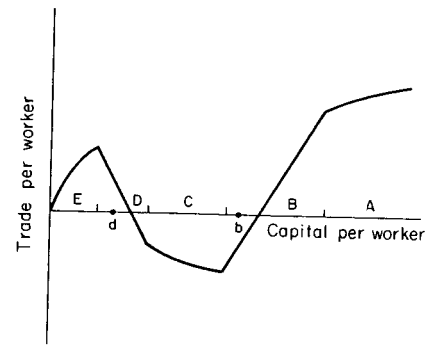

Figure 1.10
Trade per worker: factor intensity reversals.

capital per man endowment sweeps through the cones A–E in figure 1.3, the output levels vary in the same way as they do as capital per man sweeps through the cones in figure 1.5. If, as before, we take consumption of $X_1 = X_3$ to be a fixed fraction of GNP, net exports per man become the function depicted in figure 1.10. If there are no factor intensity reversals, there will be one interval of capital abundance ratios K/L that imply exports of the commodity. The item is exported when the capital intensity of the commodity is similar to the capital abundance ratio of the country. If there are factor intensity reversals, the trade curve may wander back and forth across the horizontal axis many times, and there will be many intervals of K/L values for which the commodity is exported. Factor intensity reversals can, as a consequence, negate the Heckscher-Ohlin theorem. Consider a two-country world composed of country b in cone B and country d in cone D, depicted in figure 1.10, with b importing and d exporting X_1. As far as b is concerned, X_1 is the capital intensive good; an increase in k would increase net exports of X_1. But b, the capital abundant country, is importing the capital intensive good.

1.3.3 Mobility

The simple general equilibrium model uses an unlikely pair of extreme assumptions about the mobility of goods and factors. Goods can be moved anywhere without cost. Factors can move costlessly inside the boundaries of a country, but cannot climb over the high fences that are assumed to surround all countries. Both these mobility assumptions are studied in this section.

Table 1.2
Fraction of gross fixed capital formation financed from abroad[a]

Country	1960	1965	1970	1975	1977
United States	−.0261	−.0273	.0044	−.0486	.0999
Japan	−.0128	−.0375	−.0301	.0020	−.0528
Germany	−.1075	−.0025	−.0823	−.1389	−.1143
Korea	.8602	.4944	.4014	.3705	.0029
United Kingdom	.0955	.0446	−.0392	.1004	−.0045
France	−.0885	−.0355	−.0115	−.0319	.0230
Italy	.0882	−.0487	.0361	.0639	.0332
Canada	.0554	.0106	−.1299	.0617	.0014

Source: *International Financial Statistics*, selected monthly reports.
a. Trade deficit as a fraction of domestic investment.

International Factor Mobility The international movement of capital and labor has for some countries in some time periods been quite substantial. For example, recent guest worker programs brought 30 million temporary workers to Europe. The Swiss labor force in 1970 was 33% foreign, a figure that fell to 18% by 1977 (Ruffin, 1982). Capital mobility also can be substantial, as is suggested by table 1.2, which indicates the share of domestic investment financed from foreign sources for several countries. Korea in the 1950s and 1960s was particularly dependent on foreign capital.

The international mobility of some factors may be so great that the assumption of free mobility is more accurate than the traditional one of mobility at infinite cost. A mobile factor should not properly be thought to be a source of comparative advantage. It will now be shown also that a mobile factor will not alter the basic structure of the model. Consider, for example, a 2-good model with 2 internationally immobile factors, labor (L) and land (M), and 1 internationally mobile factor, capital (K). The production functions can be written as

$$X_1 = F_1(L_1, M_1, K_1),$$

$$X_2 = F_2(L_2, M_2, K_2),$$

with each function exhibiting constant returns to scale. For any levels of L_1 and M_1, producers will hire capital services from the international market at the given rate w_K so as to maximize revenue minus capital costs $p_1X_1 - w_KK_1$, where p_1 is the international price of X_1. This maximization will therefore imply that K_1 is chosen so that $w_K = p_1\,\partial F_1(L_1, M_1, K_1)/\partial K_1$. This equation can be solved for K_1 as a function of L_1 and M_1:

$K_1 = h(L_1, M_1; w_K/p_1)$, where the real return on capital is a parameter determined in the international markets. This function h exhibits constant returns to scale, since if L_1 and M_1 are doubled, in order to maintain the marginal product of K at the level w_K/p_1, it is necessary also to double K_1.[9] As a consequence the composite function $X_1 = F_1(L_1, M_1, h(L_1, M_1; w_K/p_1))$ also exhibits constant returns to scale. The model with mobile capital can therefore be written as

$$X_1 = F_1^*(L_1, M_1; w_K/p_1) \equiv F_1(L_1, M_1, h_1(L_1, M_1; w_K/p_1)),$$

$$X_2 = F_2^*(L_2, M_2; w_K/p_2) \equiv F_2(L_2, M_2, h_2(L_2, M_2; w_K/p_2)),$$

with labor and land conferring comparative advantage in accordance with the simple theory described in section 1.2. Factor price equalization is a consequence, which in turn implies that input intensities are the same in all countries. We may therefore write the relations between outputs and inputs as $AX = V$, where A is a fixed 3×2 matrix of factor intensities, X is the 2×1 vector of outputs, and V is the 3×1 vector of inputs including the mobile factor K. These three equations determine the three unknowns X_1, X_2, and K as linear functions of the 2 fixed factors L and M. The model with mobile factors therefore expresses outputs and trade as a function of immobile factors only and includes auxiliary relations between the mobile and the immobile factors. It is equivalent in content to the even model if the number of immobile factors is equal to the number of traded goods.[10]

Nontraded Goods Transportation costs greatly impede the international exchange of some goods and most services. Nontraded goods make up a large fraction of GNP. For the United States in 1958, for example, construction, transportation, communications, wholesale/retail trade, finance, insurance and real estate, services, and government contribute 62% of GNP (source: U.S. Department of Commerce, *The National Income and Product Accounts of the United States*, 1929–1974). At the outset, it seems unlikely that nontraded goods will greatly affect the qualitative conclusion that net exports depend on resource availability. But it is a great surprise that if we assume countries are sufficiently similar that factor prices are equalized, the existence of non-traded goods requires no adjustment at all to the Vanek equations.[11] Suppose there are m factors V, m traded goods X, and q nontraded goods Z. If factor prices are equalized, the factor intensities are equal as well, and we may write the equations of equilibrium in the factor markets as $AX + A_zZ = V$, where

A_z is the $m \times q$ matrix of factor intensities of the nontraded goods. Also, if factor prices are equalized, the zero-profit conditions imply equalization of the prices of nontraded goods, $p_z = A_z' w$, and from identical homothetic tastes we may conclude that all countries consume in the same proportions, $C = sX_w$, $C_z = sZ_w$, where X_w and Z_w are vectors of total world levels of outputs and s is the consumption share. From these, we can derive the Heckscher-Ohlin-Vanek equations:

$$\begin{aligned} AT &= AX - AC = AX - sAX_w \\ &= (V - A_z Z) - s(V_w - A_z Z_w) \\ &= V - A_z Z_w s - s(V_w - A_z Z_w) = V - sV_w. \end{aligned}$$

Furthermore, the consumption share can be found by imposing the trade balance condition $p'X = p'C$; then using $C = sX_w$, $X = A^{-1}(V - A_z Z) = A^{-1}(V - sA_z Z_w)$, and $X_w = A^{-1}(V_w - A_z Z_w)$, we can solve for $s = p'A^{-1}V / p'A^{-1}V_w$, which is the GNP ratio computed as if no resources were devoted to the production of nontraded goods. The reader may verify that GNP computed as if no resources were devoted to the production of nontraded goods is equal to actual GNP. This can occur because of the indeterminacy of production in this model with more goods than factors.

Transportation Costs, Tariffs, and Other Trade Impediments Transportation costs, tariffs, subsidies, and quotas impede the international flow of commodities and can alter the composition of trade. Indeed, Travis (1964) argues that tariffs on labor intensive imports can explain the Leontief finding that the United States in 1947 was a net exporter of labor services. Pre-Kennedy round tariff rates of selected countries are reported in table 1.3. Freight factors—the ratio of transport cost to value of shipments—for U.S. imports are recorded in table 1.4. Generally speaking the tariff rates are higher than the transport costs even after the Kennedy round reductions. The combined charge for importing into the United States in some cases was as high as 25%, which is a number that seems high enough to have an impact on the composition of trade.

To decide how to deal with trade impediments at an empirical level, we shall have to study their effects on our general equilibrium model. As will be shown, the effects are quite complex; this complexity, together with the difficulty of measuring trade impediments for the large number of countries in the subsequent empirical work, forces us (reluctantly) to restrict a consideration of the effect of trade impediments to the informal study of anomalous observations.

Table 1.3
Average tariffs on dutiable, nonagricultural imports as percentage of c.i.f. value (before Kennedy round cuts)[a]

Category	U.S.	EEC	U.K.	Japan
Mineral products	9.9	9.4	9.3	12.0
Chemical products	17.8	14.3	18.8	19.7
Rubber products	11.3	15.0	13.6	15.1
Hides, furs, leather products	16.2	9.2	17.7	19.9
Wood and cork products	6.8	10.9	5.2	15.6
Pulp and paper	10.9	10.7	16.6	6.7
Textiles	21.4	16.0	20.6	23.5
Footwear and headwear	16.1	17.8	22.8	26.3
Stone, ceramic, and glass products	21.0	14.1	16.4	16.9
Base metals and metal products	8.5	9.9	12.8	11.0
Nonelectrical machinery	11.9	11.1	14.2	15.6
Electrical machinery	13.6	14.2	20.1	17.8
Transportation equipment	7.1	15.4	20.0	18.4
Precision instruments	21.1	13.3	26.4	19.1
Miscellaneous	19.5	16.5	20.1	14.7
Total	13.5	12.8	16.6	15.5

Source: Preeg (1970).
a. Final agreement on the Kennedy Round tariff reduction was signed in June 1967. Overall tariff reduction for nonagricultural dutiable imports was in 36–39% range. Tariff reduction for agricultural dutiable imports was 20%.

To demonstrate the effects of price differences induced by trade impediments on the general equilibrium model, it is mathematically convenient to assume log-linear technologies and tastes. A unit-value isoquant for commodity j is assumed to be $1 = p_j \alpha_j \prod_i V_{ij}^{\theta_{ij}}$, where p_j is the product price and V_{ij} is the input of factor i. By taking the logarithm, this unit-value isoquant can be written as

$$0 = \ln p_j + \ln \alpha_j + \sum_i \theta_{ij} \ln V_{ij}. \tag{1.7}$$

Then minimizing cost, $\sum w_i V_{ij}$, subject to the unit value constraint (1.7), we obtain the first-order condition $w_i = \lambda \theta_{ij} / V_{ij}$, where λ is the Lagrange multiplier. Then using constant returns to scale $\sum_i \theta_{ij} = 1$ and zero-profit $1 = \sum_i w_i V_{ij}$, we can solve for $\lambda = 1$. Thus $w_i V_{ij} = \theta_{ij}$; in words, the value share of factor i in production of commodity j is set equal to θ_{ij}. Inserting this condition back into (1.7), we have

Table 1.4
Freight factors: averages by commodity groups[a]

SITC[b]		Average of reported freight factors
011	Meats, fresh, frozen, etc.	11
013	Meats in containers, meat preparations, etc.	4
031	Fish, fresh, frozen, etc.	7
051	Fruit, fresh, and nuts, fresh or dried	13
061	Sugar and honey	7
071	Coffee	5
081	Feeding-stuff for animals	18
112	Alcoholic beverages	9
231	Crude rubber	13
262	Wool and other animal hair	5
281	Iron ore and concentrates	26
283	Ores and concentrates, nonferrous	14
331	Petroleum, crude and partly refined	15
332	Petroleum products	14
442	Fixed vegetable oils, excluding soft	6
512	Organic chemicals	4
631	Veneers, plywood board, etc.	16
653	Textile fabrics, woven, excluding cotton	6
664	Glass	14
665	Glassware	11
666	Pottery	12
674	Iron and steel plates and sheets	11
732	Road motor vehicles	9
841	Clothing	5
851	Footwear	7
861	Scientific, medical, etc., instruments and apparatus	2
894	Toys, games, sporting goods, etc.	9
899	Manufactured articles n.e.s.	9

Source: Lipsey and Weiss (1974).
a. Freight charges as a percentage of value.
b. All groups with 30 observations or more. Some of the SITC titles are abbreviated here.

$$\sum_i \theta_{ij} \ln w_i = \ln p_j + \ln \alpha_j + \sum_i \theta_{ij} \ln(\theta_{ij}).$$

In matrix form this can be written

$$\Theta' \ln(w) = \ln(p) + \ln(X_0), \tag{1.8}$$

where Θ' is the matrix of factor shares (with rows summing to one), $\ln(w)$ and $\ln(p)$ refer to vectors with logarithms of factor prices and logarithms of commodity prices as elements, and $\ln X_0$ is a vector with the logarithms of outputs as elements: $\ln X_j(\theta_j) = \ln(\alpha_j) + \sum_i \theta_{ij} \ln \theta_{ij}$.

Since the value share of factor i in commodity j is $\theta_{ij} = w_i V_{ij}/p_j X_j$, it follows that it takes $\theta_{ij} p_j / w_i = A_{ij}$ of factor i to produce one unit of commodity j. Thus the matrix of factor intensities is

$$A = \{A_{ij}\} = \{\theta_{ij} p_j / w_i\} = W^{-1} \Theta P,$$

where W is a diagonal matrix with w on the diagonal and P is a diagonal matrix with p on the diagonal. Therefore the relation between outputs and inputs becomes

$$X = A^{-1} V = P^{-1} \Theta^{-1} W V, \tag{1.9}$$

with W a function of P according to (1.8).

We assume also that countries choose the commodity vector to maximize the Cobb-Douglas utility function $\sum_j \gamma_j \ln(X_j)$, with $\sum_j \gamma_j = 1$. Maximizing utility subject to an income constraint, $Y^* = \sum p_j C_j$, implies that the budget share $p_j C_j / Y^*$ is set equal to the elasticity γ_j. Thus the consumption vector can be written as

$$C = \begin{bmatrix} \gamma_1/p_1 \\ \gamma_2/p_2 \\ \vdots \\ \gamma_n/p_n \end{bmatrix} Y^* = P^{-1} \gamma Y^*, \tag{1.10}$$

where p_j are the internal prices. The income level Y^* is determined by the trade balance condition $1'(X - C) = 0$, where it is assumed that quantity units are selected so that the world prices are all equal to one. From the trade balance condition, we solve for the "money" income level:

$$Y^* = \sum_j X_j \Big/ \sum_j (\gamma_j / p_j).$$

Net exports may be obtained by subtracting (1.10) from (1.9). Using the result that $A_p^{-1} = P^{-1}\Theta^{-1}W_p$, where the p subscript indicates price dependent variables, we may write the trade vector in value terms as

$$PT_p = \Theta^{-1}(V_p^* - s_p^* V_w^*), \tag{1.11}$$

where $V_p^* = W_p V$ is the vector of resources evaluated at the internal factor prices; $V_w^* = W_1 V_w$ is the vector of world resources evaluated at factor prices applicable if there were no trade impediments, $p = 1$; and $s_p^* = (\sum X_i / \sum X_{iw})/(\sum \gamma_j / p_j)$ is the GNP ratio evaluated at external prices with world outputs computed as if there were no trade impediments, all divided by a factor less than one, adjusting consumption levels upward to account for the higher internal price levels.

Equation (1.11) is surprisingly similar to the HOV equations derived when there were no trade impediments, that is, when $P = I$. The only changes that are required to allow for trade impediments are (1) trade and resources must be expressed in value terms with internal prices used for valuation, and (2) the consumption share must be adjusted to account for the distortions in production and consumption. It should be noted that trade impediments can reverse the sign of the elements of the factor abundance vector $V_p^* - s_p^* V_w^*$. For example, as Travis (1964) has argued, trade impediments could raise the return to labor, thereby increasing the internal value of labor; at the same time, the impediments would lower the consumption share, so that labor could be switched from a scarce factor to an abundant factor. [Can this happen if there are only 2 goods?]

Factor Market Distortions According to the popular press, one of the major reasons why the U.S. markets for iron and steel and automobiles are being so effectively penetrated by foreign competitors is that unions have managed to raise wages in those industries to the point where they are no longer competitive. The effect of unions may be partially revealed by a study of the distribution of wages across industries. The first column of table 1.5 contains 1975 U.S. hourly wage rates by manufacturing sector. The highest wages are paid by refineries and the lowest are paid by the clothing industry. Much of the differences in wages across industries is probably due to skill differences, but unions or other barriers to mobility may also have an effect. If wage differences were entirely due to skill differences, then the distribution of wages across industries in other countries would be expected to be similar to the U.S. wages. Wages in four other countries may also be found in table 1.5, both in absolute

Table 1.5
Wages by manufacturing sector (average hourly earnings): 1975[a]

ISIC	Description	U.S.	Japan	France	Germany	U.K.
311–313	Food, beverage	4.57	2.85(.63)	2.69(.59)	3.60(.79)	2.54(.56)
314	Tobacco	4.51				
321	Textiles	3.40	2.25(.66)	2.45(.72)	3.34(.98)	2.32(.68)
322	Clothing	3.19	1.89(.59)	2.15(.67)	3.00(.94)	2.07(.65)
323–324	Leather, footwear	3.23	2.51(.78)	2.32(.72)	2.97(.92)	2.36(.73)
331	Wood	4.28	2.52(.59)	2.39(.59)	3.60(.84)	2.53(.63)
332	Furniture	3.75	2.50(.67)		3.95(1.05)	
341	Paper	4.99	3.39(.68)	3.01(.60)	4.03(.81)	2.82(.54)
342	Printing, publishing	5.36	3.91(.73)	3.38(.63)	4.47(.83)	
351	Industrial chemicals	5.93	4.24(.77)	3.18(.58)	4.51(.76)	2.75(.50)
352	Other chemicals	5.05			3.83(.76)	
353–354	Refineries	6.42	4.46(.69)	—	5.20[b](.81)	3.04(.47)
355–356	Rubber and plastic products	4.35	3.39[c](.78)	2.74(.63)	3.78(.87)	2.61(.60)
36	Nonmetallic	4.89	3.16(.65)	2.94(.60)	3.82(.78)	2.62(.54)
37	Basic metal industries	6.17	4.18(.68)	3.17(.51)	4.17(.68)	2.69(.44)
381	Metal products	5.04	3.34(.66)	2.79(.55)	3.74(.74)	2.51(.50)
382	Nonelectrical machinery	5.36	3.64(.68)	2.97(.55)	4.22(.79)	2.68(.50)
383	Electrical machinery	4.58	3.16(.69)	2.73(.60)	3.68(.80)	2.57(.56)
384	Transport equipment	6.02	3.65(.61)	3.11(.52)	4.40(.73)	2.92(.49)
385	Scientific, measuring, etc.	4.56	3.21(.70)	2.68(.59)	3.62(.79)	2.45(.54)
390	Other	3.79	2.98(.79)	2.69(.71)	3.40(.90)	2.22(.59)

Source: ILO, *Yearbook of Labor Statistics*, 1977.
a. Wages relative to U.S. averages in parentheses.
b. 353.
c. 355.

level and relative to the corresponding U.S. wage. It is true that clothing wages are the lowest in each of these countries and refinery wages are the highest. There is generally a high degree of similarity in the wage distributions of each of these countries, and this is evidence that skill differences account for much of the cross-industry variability in wages.

But there are some subtle differences in these distributions that are revealed by the wage rates divided by the corresponding U.S. wage rates. The Japanese wage rates are relatively low (about 60% of U.S. wages) in clothing, wood, and transport equipment. The French, German, and U.K. wage rates are relatively low in the basic metal industries and in transport equipment. This seems to be pretty clear evidence of the impact of the United Auto Workers, and the United Steel Workers of America, and maybe even the Brotherhood of Textile Workers ("Look for the union label").

If unions are effective in raising wage rates and/or restricting employment, it can be expected that the composition of trade will shift to take advantage of the relatively low costs in the nonunion sectors. Factor market distortions such as unions both alter the output vector and also lower the consumption share. On the assumption that the primary effect is to distort the output vector, we concentrate here on the output changes induced by unions and other forms of distortions in the two-sector model.

This section describes the effects of unions or other labor market distortions in the two-sector general equilibrium model with prices of commodities determined exogenously in the international markets. Three kinds of distortions are considered: (1) a minimum wage with a covered sector (X_1) and an uncovered sector (X_2); (2) a license requirement for work in the X_1 sector, with the number of licenses limited; (3) a tax on labor earnings with a covered sector (X_2) and an uncovered sector (X_1). Depending on its bargaining posture, a union could be thought of as imposing any one of these three distortions. It could bargain for a high real wage, for a restricted union membership, or for a union wage higher than the nonunion wage.

Partial equilibrium analysis suggests that each of these three distortions would have the same effects: a higher wage, fewer workers, and less output in sector X_1; a lower wage, more workers, and more output in X_2. This partial equilibrium analysis fails to take into account reallocation of capital between the sectors and the consequent shifting of the labor demand schedules. When these are properly taken into account, the effects are sharply different depending on whether the union sector is capital intensive or labor intensive. What follows is a summary of the results. Derivations may be found in appendix A.

The licensing restriction and the tax on labor earnings produce the same qualitative results, but these can differ from the minimum wage. In all cases, the wage in X_1 and the wage in X_2 move in the same direction. If the unionized sector is the relatively capital intensive sector, the expected results occur, namely: wages rise, more in the union sector than in the nonunion sector; capital intensities rise; the return on capital falls; the number of workers and the level of output in the union sector fall; and the level of output in the nonunion sector rises.

But unionization of the labor intensive sector produces surprising results. If the union bargains for a minimum wage, it will, of course, receive a wage rate higher than initially but at the same time lower than the nonunion wage. Employment and output in the union sector will actually increase, while employment and output in the nonunion sector will decrease. But this equilibrium is dynamically unstable, since workers will quit the unionized industry to seek employment elsewhere at higher wage rates. If the union restricts the number of employees, or bargains for a wage higher than the nonunion wage, the union wage rate will actually fall, though by an amount less than the reduction in the nonunion wage.

The conclusion that seems warranted by this discussion is that unionization of the capital intensive sector will reduce output and decrease net exports of the unionized commodity, but that unionization of the labor intensive sector will drive it completely out of existence.

Factor Market Adjustment Costs: Short Run Models The basic model combines two extreme assumptions about the mobility of factors. Internationally factors cannot migrate at all, but internally between industries factors are perfectly mobile. These extreme assumptions are the ones most conveniently handled at a theoretical level. We have already seen that perfect international mobility of some factors does not dramatically alter the model. Similarly, complete immobility of some factors between industries can be interpreted in terms of factors so specialized that they can be used in only a single industry. However, if we assume partial mobility, the model changes dramatically. Comparative advantage in one period becomes a source of comparative advantage in another period. The effect can go either forward or backward in time, since anticipated swings in future comparative advantage necessitate anticipatory investments.

If the dynamics of comparative advantage were a concern, it is quite clear that short run adjustment costs would have to be considered, but the cross-section data analysis in this book involves no dynamics at all. Though it is not impossible that adjustment costs might substantially influence the cross-section trade pattern, this does seem unlikely. For empirical work relating to this issue see Chenery and Taylor (1968); for models of adjustment see Mayer (1974), Mussa (1974), and Leamer (1980).

1.3.4 Technology

It has been assumed that technological knowledge is free, that production functions exhibit constant returns to scale and diminishing marginal

products. Without explicitly saying so, we have ruled out also externalities, intermediate inputs, and joint products. Each of these assumptions can have important implications for international trade.

Specialized Factors Though the model summarized by equation (1.1) appears to require that all factors be used in all industries, this is not the case. The existence of industry-specialized factors implies that particular elements of the factor requirements matrix A may be set to zero. If it is known that there exists a block of elements in the A matrix that are all zero, then there may be a corresponding block of zeros in the A^{-1} matrix. The existence and knowledge of such specialized factors implies interesting relations between outputs and inputs. For example, suppose that there are two inputs, labor (L) and land (M), and 2 commodities, agricultural (X_1) and industrial (X_2). If land is not used to produce the industrial commodity we may write the A matrix as

$$A = \begin{bmatrix} a_{L1} & a_{L2} \\ a_{M1} & 0 \end{bmatrix}.$$

The inverse of this matrix can be used to solve for the outputs as follows:

$$X = A^{-1}V = (-a_{M1}a_{L2})^{-1}\begin{bmatrix} 0 & -a_{L2} \\ -a_{M1} & a_{L1} \end{bmatrix}\begin{bmatrix} L \\ M \end{bmatrix}$$

$$= \begin{bmatrix} M/a_{M1} \\ (a_{M1}L - a_{L1}M)/a_{M1}a_{L2} \end{bmatrix}.$$

Thus even though both labor and land are used to produce agricultural goods, the output of agricultural goods depends only upon the endowment of land. And although land is not used to produce industrial goods, the level of output of industrial goods depends on both the endowment of labor and the endowment of land. This apparently paradoxical result stems trivially from the fact that full employment requires that land must be fully utilized in the agricultural sector. This, together with the fixed input requirement a_{M1}, determines the level of agricultural output M/a_{M1}. Since the labor residual left over for industrial production is then dependent upon the endowment of land (that is, $L - X_1a_{L1} = L - Ma_{L1}/a_{M1}$), it becomes obvious that the level of industrial output is also dependent upon the endowment of land.

This relation suggests that resources such as agricultural land will have a negative impact on the comparative advantage of, say, chemicals

and will be primary determinants of agricultural output. This type of relation would explain, in part, results such as those obtained by Keesing and Sherk (1971), who found that "large" less-developed countries (LDCs) have a comparative disadvantage in manufactures, where large is defined as low population density.

Public Resources Climate is an important determinant of the location of agricultural production. Specialized knowledge is likewise critical to various manufactured products. Both climate and knowledge have the feature that the use of the factor to produce one good does not apparently reduce the stock of the factor for the production of other goods. This contrasts with the model reported previously in which the use of a certain amount of a resource for the production of one commodity implies that the quantity available for other commodities is reduced by an equal amount.

It is, not difficult, however, to treat climate conceptually and empirically as a private resource. In order to make use of a favorable climate to produce agricultural goods, it is necessary to have arable land. To give a more personal example, the purchase of a California home has made me painfully aware of the price of sunshine. The resource to which the theory refers is thus neither climate, nor arable land, but rather the physical amount of land in a particular climate zone. Then the assumption of constant returns to scale in agriculture does seem acceptable if the inputs are capital, labor, and land disaggregated by climate type.

Similarly, knowledge, which might be thought to render special technological advantages to particular countries, can be used only if it is embodied in either physical or human capital. But one may question whether constant returns to scale is a credible assumption in this case. Once a single scientist reveals the knowledge of how to produce more efficiently, a second scientist may have no marginal product.

Intermediate Inputs There is a substantial amount of trade in raw materials and semifinished goods. As will be shown, the trade of inputs does not alter fundamentally the simplest trade theory outlined previously, and in particular, the conclusion of linearity is not affected. The production functions of a 2-good model may be written as

$$Q_1 = F(K_1, L_1, X_{21}),$$

$$Q_2 = G(K_2, L_2, X_{12}),$$

where X_{21}, X_{12} are the intermediate goods used, respectively, in the production of commodities 1 and 2, and Q_1 and Q_2 are the levels of production.

First we need to demonstrate that factor prices are equalized by trade. Profits in industry 1 are

$$p_1F(K_1, L_1, X_{21}) - w_K K_1 - w_L L_1 - p_2 X_{21}$$
$$= p_1 L_1 f(k_1, x_{21}) - w_K L_1 k_1 - w_L L_1 - p_2 L_1 x_{21},$$

where $k_1 = K_1/L_1$ and $x_{21} = X_{21}/L_1$. Differentiating this with respect to L_1, k_1, and x_{21} yields three conditions for profit maximization: $p_1 f_1 = w_K$, $p_1 f_2 = p_2$, and $p_1 f = w_K k_1 + w_L + p_2 x_{21}$, the last condition implying zero profits. There are three equivalent equations for industry 2, and these six equations can be solved for the six unknowns, w_L, w_K, k_1, x_{21}, k_2, x_{12}, as function of the product prices.[12]

Since the prices of the inputs can be taken as given, the factor intensities can also be taken as given, and the factor exhaustion equations become

$$V = \begin{bmatrix} K \\ L \end{bmatrix} = \begin{bmatrix} a_{K1} & a_{K2} \\ a_{L1} & a_{L2} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = AQ,$$

with intermediate inputs

$$\begin{bmatrix} X_{12} \\ X_{21} \end{bmatrix} = \begin{bmatrix} 0 & b_{12} \\ b_{21} & 0 \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = BQ.$$

The outputs available to meet final demand are therefore

$$X = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} - \begin{bmatrix} X_{12} \\ X_{21} \end{bmatrix} = Q - BQ$$
$$= (I - B)A^{-1}V.$$

This establishes the result that intermediate inputs do not make essential changes in the model. Where before we had the matrix A of direct input intensities, we need only substitute the matrix $A(I - B)^{-1}$ of direct plus indirect intensities. There is one important difference, however. The cones of diversification are defined with respect to the direct requirements; that is, it is assumed that endowments V are such that $Q = A^{-1}V$ is a positive vector. It is not necessary for final output $X = (I - B)A^{-1}V$ also to be positive, since intermediate inputs can be purchased from abroad. This means that trade can have very substantial welfare benefits, since the posttrade consumption line need not be tangent to the pretrade consumption possibilities curve in the positive quadrant. (The reader is encouraged to draw a figure to illustrate this.)

Economies of Scale The model described in section 1.2 postulates that countries, like holograms, can be divided into arbitrarily small pieces, with each piece retaining the complete image of the whole. But when countries are as small as Iceland, for example, with a work force of 100,000, it is hard to imagine automobile assembly plants or large steel mills located there. Because economies of scale at some small levels of output are obviously important, we can expect to see very small countries with trade patterns quite unlike their larger counterparts.

Another observation that forces one to think of economies of scale is the substantial amount of trade in similar products among the advanced industrialized countries. This seems hard to square with the Heckscher-Ohlin model, which seems to suggest that countries with similar resources ought to export the same products, and which consequently implies that the intensity of trade among similarly endowed countries should be less than the intensity of trade among dissimilarly endowed countries.

The level of intraindustry trade and its increase over time, documented by Balassa (1967), Kravis (1971), and Grubel and Lloyd (1975), has sparked a considerable amount of both theoretical and empirical work on scale economies. An excellent review of this literature is provided by Helpman (1982). Among the conclusions of this literature are that (1) trade can occur between identical countries, (2) commodities with identical input coefficients may be exchanged, (3) trade may make factor prices more unequal, (4) there may be multiple equilibria, (5) an increase in the supply of an endowment may increase the output of both commodities, and (6) protection may raise the return of the abundant factor and lower the return of the scarce factor.

This rapidly accumulating literature on economies of scale contains many interesting models and many interesting results. But it remains quite unsuitable as a foundation for a data analysis since it offers nothing nearly as concrete as the Heckscher-Ohlin-Vanek equations. It has been demonstrated by Markusen and Melvin (1981) that in a 2-goods model there exists an equilibrium, with the larger country exporting the good subject to increasing returns to scale and the small country exporting

the good subject to constant returns to scale. But the precise relation between exports and size remains unstated; moreover, no effort is made to generalize to the case of more commodities. If there are more commodities, it is to be expected that the problem of multiple equilibria is greatly exacerbated.

The attitude that I adopt in this book concerning economies of scale combines a wish and an apology. The wish is for a fully articulated, multigood, multifactor empirically implementable model with scale economies. I really do think much of international trade is associated with scale economies, and it is a great disappointment that the empirical work presented does not deal seriously with economies of scale. The apology is that the level of aggregation and the use of net export rather than exports and imports separately reduce the possibility that scale effects are important. This statement is given theoretical support by Helpman's (1981) model of trade in differentiated products. Helpman assumes that there is one standardized product with constant returns to scale and a continuum of differentiated products, each with an identical production function subject to increasing returns. Each country then produces different varieties of the nonstandardized product, and consequently there is intraindustry trade. But *net* trade is predicted by Heckscher-Ohlin theory: If the standardized product is labor intensive, then the labor abundant country exports the standardized product and has net imports of the nonstandardized product.

Technological Differences In common parlance, India, which uses labor intensive methods in agriculture, is said to employ a different technology than the United States, which uses capital intensive methods. This statement fails to distinguish between differences in knowledge and differences in factor prices as the cause of the differences in factor intensities in the two countries. In order to be precise, we refer to knowledge as *technology* and to the adaptation of knowledge to local factor prices as the choice of *technique*. It seems more likely that Indians choose a labor intensive technique because of low wages than that they are unaware of the capital intensive technique used in the United States.

An economist ought to be uncomfortable assuming technological differences, and Ricardo is treated unfairly when his name is associated with this idea. According to the classic Ricardian example, Portugal exchanges wine for cloth from Britain because Portugal is relatively

efficient in the production of wine. The source of this comparative advantage was not Ricardo's concern, but it has been interpreted by many modern writers as "technological differences." This very superficial account of the causes of international trade seems to suppose that there are either biological differences between the Portugese and the British that preclude each from emulating the productive techniques of the other or rather effective counterintelligence agents.

The Heckscher-Ohlin model is much more satisfying, since it accounts for comparative advantage without having to appeal to the "demon" of technological differences. Namely, Portugal is relatively well endowed in land with a Mediterranean climate. The British indeed have the knowledge; but they lack the resources for efficient production of wine.

Ricardo's concern was to demonstrate the welfare gains from exchange even when one country has an absolute advantage in all commodities. For this purpose the source of the comparative advantage need not be identified, and we must suppose that he never intended to suggest that technological knowledge in Britain was different from that in Portugal. But by assuming that all countries have exactly the same technology, the Heckscher-Ohlin model goes too far, since it assumes that knowledge is free. A more satisfying viewpoint is that knowledge and the dissemination of knowledge are uncertain consequences of economic investments.

Models of knowledge formation and dissemination are currently popular. The special role in world trade played by the United States during the decades of the 1960s and 1970s gave many economists the impression that an important source of U.S. comparative advantage is technological knowledge, or knowledge capital. A "technological gap" was thought to exist, and a "product cycle" was hypothesized by which knowledge of product and production technique was disseminated to the more backward countries. Among the basic references are Kravis (1956), Hufbauer (1966), Posner (1966), Vernon (1966), Gruber, Mehta, and Vernon (1967), and Keesing (1967).

These theories tend to be descriptive rather than analytic. They also focus on dynamic questions concerning the evolution of trade patterns over time, often at a very disaggregated level. In contrast, the cross-section data analysis in this book uses highly aggregated commodity classes and ignores altogether any reasons why the intertemporal evolution of trade might not conform to the static cross-country pattern. "Tech-

nological differences" are here allowed to have an impact on trade, but only through the employment of scientists and engineers who enhance the productivity of other factors.

Exhaustible Resources The sharp rise in the price of oil in the decade of the 1970s and the attendant cries of doom concerning the depletion of a resource essential to the well-being of mankind gave rise to a large literature on the theory of exhaustible resources. It turns out not to be very difficult to alter the HOV model to allow for exhaustible resources if there is perfect foresight. All that is required is an expansion of the list of commodities and renewable resources to distinguish the period of supply. If τ is the number of periods in the model, n is the number of goods produced in each period, m is the number of renewable resources, and q is the number of nonrenewable resources, then the number of commodities and resources are equal in the sense of the HOV model if $\tau n = \tau m + q$. If this somewhat unusual condition holds, and if the other usual assumptions hold, factor prices will be equalized, since the model is mathematically the same as the static model already discussed. Similarly, the vector of outputs and trade will be a linear function of the vector of resources. This means that the output of a commodity in any period will be a function of the original stock of the nonrenewable resource and the whole sequence of time-dated supplies of the renewable resources. This conclusion is distinctly uncomfortable from an empirical point of view, since it requires a vast increase in the list of variables that determine trade. There is fortunately one escape from this dilemma. At each instant there are $m + q$ factor market equilibrium relations that express the $m + q$ resources actually used in the period as functions of the level of production of the n goods produced in the period. If n of these equations are selected, they can be inverted to express outputs of the n commodities as linear functions of a set of renewable resources supplied in the period and a set of nonrenewable resources used in the period, n resources in total. Although this is exactly what is done in the empirical work, it should be kept in mind that the use of a nonrenewable resource in any period is properly thought to be an endogenous variable depending on the flows of the renewable resources. Moreover, this discussion has ignored what may be the most essential aspect of exhaustible resources: uncertainty about the total stock available and uncertainty about the sequence of future prices.

1.3.5 Preference Dissimilarity

Most of the structure of the general equilibrium trade model comes from the production side. The assumption of identical homothetic tastes is made to assure that results concerning production translate into results concerning the difference between production and consumption, that is, trade. The economist's euphemism "identical homothetic tastes" means that individuals facing identical commodity prices will consume commodities in the same proportions. Of course, neither individuals nor countries actually have identical budget shares, as can be seen from the data in table 1.6, which indicates the composition of private consumption expenditure for many countries. The proportion spent on food, for example, varies from the low of 14.4% for the United States to a high of 59.7% for India. What this and some of the other categories suggest is that the budget shares depend on the income level, though differences in tastes are probably required to explain the tobacco shares and the recreation shares. (For example, why does Singapore have such a high share devoted to recreation, education, and entertainment?)

Income dependent consumption can be easily introduced into the model. Suppose that within each country all citizens share equally in the ownership of all resources, and consequently each has the same level of income. Then we might write the consumption vector of a typical country as

$$C = (C_0 + C_1 y)L = C_0 L + C_1 Y,$$

where y is expenditure per worker, $C_0 + C_1 y$ is the consumption vector of a typical worker, L is the total number of workers, and Y is total expenditure. Total expenditure can also be written as $p'C$, where p is the vector of prices. From the condition $Y = p'C = p'C_0 L + p'C_1 Y$ we conclude that $p'C_1 = 1$ and $p'C_0 = 0$. To equilibrate supply and demand, we set world consumption equal to world output: $C_0 L_w + C_1 Y_w = A^{-1} V_w$. This expression allows us to write $C_1 = (A^{-1} V_w - C_0 L_w)/Y_w$. The trade vector then becomes

$$\begin{aligned} T &= A^{-1}V - C \\ &= A^{-1}V - C_0 L - C_1 Y \\ &= A^{-1}V - C_0 L - (A^{-1}V_w - C_0 L_w) Y/Y_w \\ &= A^{-1}(V - sV_w) - C_0(L - sL_w), \end{aligned} \tag{1.12}$$

Table 1.6
Composition of private consumption expenditure (%): 1975[a]

Country	1	2	3	4	5	6	7	8	9	10
AUSL	23.5		2.6	8.4	16.7	9.1	6.1	15.3	6.6	11.7
AUST	20.4	5.5	2.5	12.4	13.8	10.0	4.5	15.1	6.7	9.1
BLUX	25.5		1.8	7.2	15.2	15.0	7.2	11.4	4.3	12.4
CAN	20.1		2.2	8.4	18.1	9.1	3.0	14.6	9.5	14.9
CYPR	32.8	5.7	3.8	9.8	11.4	8.1	1.8	19.6	5.9	1.1
DEN	20.7	9.1		5.4	12.5	12.3	—	12.4	27.6	
LSAL	34.4	4.6	1.6	10.6	8.1	12.2	4.4	10.4	7.1	6.6
FIN	26.9	7.4	2.3	8.1	13.2	9.4	3.2	17.8	8.7	3.1
FRA	20.0	3.1	0.9	8.0	15.0	10.6	11.2	12.0	6.6	12.5
GER	24.8		2.3	10.7	16.3	13.0	3.1	12.6	7.2	10.0
GANA	53.7	3.8	1.2	14.2	11.5	3.7	1.4	3.3	3.8	3.4
GRCE	38.2	3.4	2.8	11.4	12.5	9.3	3.4	10.5	4.4	4.1
HOND	44.1	6.9	2.5	11.3	13.4	6.6	5.9	3.1	5.1	1.1
HOKO	32.8		1.8	8.6	14.8	8.0	7.8	7.3	7.4	11.5
ICE	20.4	5.1	2.7	9.2	15.5	11.7	7.7	14.4	6.9	6.5
INDA	59.7	2.2	2.5	7.7	7.7	3.6	2.1	7.6	3.2	3.7
IRE	26.5	14.6	5.6	8.1	12.4	7.7	2.3	9.8	8.0	5.0
ISRL	24.4	2.2	1.6	8.5	20.7	11.2	7.3	9.0	11.2	4.0
ITLY	31.3	3.1	2.3	8.6	13.4	6.0	8.5	11.0	5.6	10.2
JAMC	35.4	5.0	4.5	4.3	11.6	6.8	2.3	13.8	4.3	12.0
JAP		33.0		10.0	14.2	8.0		32.0		2.8
KORA	49.3	5.0	3.7	10.8	7.5	3.2	3.2	5.3	4.8	7.2
LIBY	34.5	1.1	2.8	10.0	18.1	4.5	3.0	12.9	3.7	9.4
MALY	37.2	2.6	5.0	5.8	13.1	6.7	2.0	13.4	5.9	8.4
MLTA	31.7	7.3	5.7	11.7	8.4	13.8	5.7	15.7	8.1	−8.3
MAUR	26.1	8.5	3.3	4.5	—	7.3	2.2	7.8	5.8	30.5
NETH	19.7	3.3	2.4	9.2	13.5	10.8	11.2	9.7	8.5	11.6
NOR	21.6	5.0	2.4	8.6	13.1	8.9	8.6	11.9	8.1	11.8
PANM	59.2	5.6	2.1	6.6	14.7	10.4	6.1	9.4	7.8	−21.9
PLIP	56.9	4.1	3.0	7.1	8.8	4.8	2.4	2.2	4.1	6.6
SRIL	57.7	3.2	6.6	8.0	6.8	3.4	1.7	10.0	2.6	0.0
SING	25.5	3.7	2.9	9.1	11.1	9.9	3.0	12.2	12.3	10.2
SPAN		37.7		11.1	14.9	9.2	4.4	12.0	8.4	2.5
SWE	20.1	5.4	2.6	7.2	19.9	6.6	4.1	14.2	8.7	11.3
SWIT	20.9	8.6		5.4	18.8	6.5	7.6	10.6	9.1	12.5
THAI	46.5	5.9	3.3	8.6	6.9	5.6	6.2	8.2	8.4	0.4
UK	18.4	8.6	4.4	8.6	19.3	7.3	1.0	13.5	10.0	9.0
US	14.4	1.9	1.5	7.3	19.5	7.5	10.8	15.1	8.6	13.4
YUG	38.0	8.2	3.4	11.7	—	9.9	4.2	10.8	3.9	3.3

Source: U.N., *Yearbook of National Accounts Statistics*.
a. Consumption categories: 1 = food; 2 = beverages (alcoholic and nonalcoholic); 3 = tobacco; 4 = clothing and footwear; 5 = gross rent, fuel, and power; 6 = furniture, equipment, and household operation; 7 = medical care and health expenses; 8 = transportation and communication; 9 = recreation, education, and entertainment; 10 = other (miscellaneous goods and services, statistical discrepancy, direct purchases abroad by resident HH, (—) direct purchases domestically by nonresidents, (—) net value of gifts in kind sent abroad).

where s is the GNP share Y/Y_w implied by the trade balance condition

$$0 = p'T = p'A^{-1}V - sp'A^{-1}V_w - p'C_0(L - sL_w),$$

where $p'C_0 = 0$, as noted previously.

Thus income dependent consumption shares of the linear form considered here call for a rather modest change in the model. We merely have to interpret the responsiveness of trade to the excess supply of labor $(L - sL_w)$ as arising from two sources—a production effect and a consumption effect. All other excess factor supplies have only the production effect $A^{-1}(V - sV_w)$. Countries with labor shares equal to GNP shares, or equivalently with per capita incomes equal to world per capita income, will have trade in conformance with the Heckscher-Ohlin-Vanek equations $T = A^{-1}(V - sV_w)$. Countries that have an abundance of labor will tend to import the commodities consumed by the poor, and conversely, countries that have a scarcity of labor will tend to import the commodities consumed by the rich. Regardless, trade remains a linear function of the endowments.

1.3.6 What Is Capital?

The traditional production theory that lists capital as one of the inputs often leaves capital undefined, and students who are given the task of measuring the capital used to produce a good are usually dumbfounded. One doctoral student proposed to study the textile industry at the firm level and prepared a questionnaire in which plant managers were requested to list how many workers were employed and how much capital was used. To this student, measurement of labor and measurement of capital are tasks requiring the same modest arithmetic skills—you simply add them up. A closer consideration of production processes suggests there are five classes of inputs: land, labor, other commodities, buildings, and machinery. Each one of these five categories can contain some "capital," and the problem of identifying the various components of capital and forming them into single composite is a difficult conceptual and empirical task.

Capital is listed as one of the inputs into a production process in an elliptical reference to the fact that production takes time. It might seem more realistic to write output as a function of the number of workers and the number of machines. But if machines are instantaneously produceable by labor and are completely consumed in the production process,

then in fact output is an instantaneous function of labor alone. The tradition of writing capital as the input instead of machines is thus a reminder that it takes time to produce machinery and that machinery is only partially consumed by the production process. A second reason for writing capital instead of machines as the input is that there may be many alternative kinds of "machines" (also buildings, human capital, improvements to land, inventories) that under a special assumption can be aggregated into a single input, called capital. The special assumption is that the relative prices of all these inputs are constant. Any analysis by means of the static model that involves relative price changes—say, studies of technological change or analysis of tax effects—has to be viewed with great suspicion, since the capital aggregation is rendered inappropriate.

Whether the basic theorems of trade hold up when capital is treated seriously seems very doubtful, but Kemp (1973) and Ethier (1979b) have demonstrated that they do. The model considered by Ethier has two commodities and one primary input. It is assumed that it takes one period to produce commodities, with a production function depending on labor as the sole primary input and both of the commodities as intermediate inputs. The zero-profit condition if prices are constant can be written as

$$p = Bp(1+\rho) + A_L w, \tag{1.13}$$

where $p = 2 \times 1$ vector of commodity prices, $B = 2 \times 2$ matrix of intermediate input requirements, ρ = rate of interest, $A_L = 2 \times 1$ vector of labor inputs, and w = wage rate paid at the end of the period. (To the student: How does this compare with the static model with intermediate inputs?)

The labor input to produce the vector of outputs X is $A_L'X$, and the full employment condition is

$$A_L'X = L.$$

The capital stock K is defined as the value of intermediate goods in process

$$p'B'X = K.$$

The row vector $p'B'$ defines the capital input requirements, and these two equations can be used to solve in the usual way for X as a function of K and L:

$$X = \begin{bmatrix} p'B' \\ A_L' \end{bmatrix}^{-1} \begin{bmatrix} K \\ L \end{bmatrix}, \tag{1.14}$$

which is exactly the same as equation (1.1), from which we derived the Heckscher-Ohlin result. What has not been demonstrated, however, is the factor price equalization theorem, which is necessary to assure that B and A_L are the same for all countries. Because product prices are taken as given, the production functions can be written in terms of two inputs—labor and the Hicksian composite of the two intermediate goods, which we call capital. Factor price equalization then follows in exactly the same way as before—namely, there is only one wage/rental rate, $w/(1+\rho)$, that could support the production of both commodities.

An explicit derivation of the Hicksian composite input is useful, since it emphasizes the fact that the capital composite depends on relative prices, which implies that relative prices are parameters of the production function relating output to capital and other inputs. Let the production function of X_1 be $X_1 = f(X_{11}, X_{12}, L)$, where X_{11} and X_{12} are intermediate inputs of goods 1 and 2 in the time-phased model. Efficient production requires that for every value of X_1 and L, the cost of X_{11} and X_{12} is minimized. Let this minimum cost be

$$C = \left\{ \min_{X_{11}, X_{12}} (1+\rho)(p_1 X_{11} + p_2 X_{12}) \middle| X_1 = f(X_{11}, X_{12}, L) \right\},$$

which is a nondecreasing function of X_1. (Minimal cost is an increasing function of output.) We may therefore invert this function to express X_1 as a function of L and C. This minimization is unaffected if instead we had minimized $C/(1+\rho)p_2$. Thus we can write X_1 as a function of the labor input L, and the capital composite $K \equiv C/(1+\rho)p_2 = (p_1/p_2)X_{11} + X_{12}$.

The production functions for X_1 and X_2 may therefore be written as $X_1 = F(K_1, L_1; p_1/p_2)$, $X_2 = G(K_2, L_2; p_1/p_2)$, where I have properly included the relative price p_1/p_2 as a parameter. A figure such as figure 1.1, which depicts isoquants, must implicitly be taking relative prices p_1/p_2 as given, since any change in p_1/p_2 will necessitate a change in the isoquants. This is unimportant for the factor price equalization theorem, the Heckscher-Ohlin theorem, and the Rybczynski theorem, since these results take prices as given. But the Stolper-Samuelson theorem and the Samuelson reciprocity relations deal with cases in which prices are ex-

plicitly variable. These results also apply to time-phased models, as can be seen by differentiating (1.13) and using the cost minimization conditions.[13]

As discussed by Kemp (1973) and Ethier (1979b), this model can be generalized to have any timing of inputs and any finite durabilities of capital. The basic trade theory, somewhat surprisingly, still remains unscathed by the charge that it treats capital naively.[14] But time is not an essential element in the static trade theorems, and the very difficult problems of defining and modeling capital in a dynamic world can therefore be avoided. Any study of dynamical changes would surely require a deeper treatment of capital than is evidenced by the traditional model that lists capital as an input along with other factors.