Part I

Factor Proportions Theory

1

Trade Theory and Factor Intensities: An Interpretative Essay

Ronald W. Jones

Chapter Outline

Ever since Heckscher's 1919 pioneering contribution to international trade theory, and especially since Samuelson's early papers in the 1940s (Samuelson, 1948, 1949; Stolper and Samuelson, 1941), the concept of *factor intensity* has played a key role in explanations both of trade patterns and the consequences of international trade for local income distribution. This chapter's purpose is to discuss the uses that have been made of this concept and its applicability to problems that are couched in higher dimensions. As well I would like to suggest that it has an important role to play even in "new" trade theory in which the strong link between commodity prices and costs of production may be removed by the existence of imperfectly competitive markets. In what follows I review uses to which the concept of factor intensity has been put.

1 The Simple 2 × 2 Framework

Definitions of factor intensities are most simply provided in the case in which a pair of countries produces two commodities with the help of two distinct productive factors. Let labor and capital represent the two factors. Commodity 1 is deemed to be produced by relatively labor-intensive techniques if the ratio of labor to capital employed in its production exceeds that utilized by commodity 2. Assuming that technology exhibits constant returns to scale, this ratio is a non-increasing function of the ratio of the wage rate to capital rentals. For a country with given factor endowments, if the first commodity is labor intensive at one set of outputs, it must remain so for all feasible (and efficient) outputs in which factors are fully employed. However, even if the other country shares the same technology, the first commodity need not be labor intensive there; the factor-intensity ranking could be switched. We comment later on this phenomenon of *factor-intensity reversal.*

1.1 The Four Core Theorems

The various parts of Heckscher–Ohlin (HO) theory were brought together by Ethier (1974). In the 2×2 setting he conveniently referred to the four *core* propositions of this theory, stemming from the equilibrium conditions characterizing competitive markets. A pair of conditions links commodity outputs, x_1 and x_2, to the endowments of labor and capital, L and K *via* the technology matrix, A, and stipulates that the economy's demand for factors is equal to the available endowments. This presumes that there is enough flexibility in technology to allow this full employment of both factors:

$$a_{L1}x_1 + a_{L2}x_2 = L \tag{1.1}$$

$$a_{K1}x_1 + a_{K2}x_2 = K \tag{1.2}$$

A second pair of equilibrium conditions states that in a competitive equilibrium all profits are wiped out for commodities produced. That is, unit costs will equal prices:

$$a_{L1}w + a_{K1}r = p_1 \tag{1.3}$$

$$a_{L2}w + a_{K2}r = p_2 \tag{1.4}$$

The first core proposition is the Heckscher–Ohlin theorem, suggesting that relatively labor-abundant countries (with a higher labor to capital endowment ratio) will export labor-intensive commodities. The foundation for such a conclusion is the supply side of the model, since differences in tastes between countries, even those sharing the same technology, might offset systematic relative production differences reflective of factor endowment asymmetries. Is it the case that if both countries share the same technology, the country with the higher labor/capital endowment proportions will produce relatively more of the labor-intensive commodity when they both face the same free-trade commodity prices? Yes. If factor intensities are different between commodities, and both commodities are produced in each country, equations (1.3) and (1.4) state that factor prices are uniquely linked to commodity prices. (This relates to the second core proposition – the Factor Price Equalization theorem.) If commodity prices are fixed, the production pattern suggested by (1.1) and (1.2) is given by the *inverse* of the (technology) A-matrix; the relatively labor-abundant country will produce relatively more of the relatively labor-intensive commodity (x_1). The problem with identifying this result with the statement of the theorem (the *strong* form) is that tastes also affect the trade pattern. To get around this, a *weak* form of the theorem states that the country that has a relatively low autarky wage rate will export the labor-intensive commodity. This theorem makes use of the zero-profit conditions, equations (1.3) and (1.4), and does *not* require any matrix inversion, for it states that relatively low wage rates result in relatively low costs for the labor-intensive sector. The second core proposition, the Factor Price Equalization result, need not concern us here, other than to note that it requires (in the 2×2 case) that factor intensities between commodities indeed be different.

The third and fourth propositions (the Stolper–Samuelson theorem and the Rybczynski theorem) do not require that technologies be the same between countries. However, they do involve the properties of the inverse of the A-matrix. The Stolper–Samuelson theorem states that an increase in the relative price of the labor-intensive commodity serves unambiguously to increase the real wage, while the Rybczynski theorem (1955) states that an expansion of the labor endowment by itself (with no change in the capital supply) causes the capital-intensive activity to decline *if* commodity prices (and therefore factor rewards) remain the same. This latter proviso is necessary in order to keep the elements of the A-matrix unchanged.

Both of these latter two propositions involve more than a ranking of gainers and losers (among factor returns or outputs). As well they involve the *magnification* results that are more easily seen by considering small changes in prices and endowments and equilibrium adjustments in equations (1.1) to (1.4). Differentiating these two sets of equations, letting λ_{ij} indicate the fraction of the total supply of the ith factor required by the jth industry, and θ_{ij} the distributive share of the ith factor in the jth industry, with relative changes indicated by the hat notation ($\hat{x}$ is dx/x), yields equations (1.5) to (1.8);

$$\lambda_{L1}\hat{x}_1 + \lambda_{L2}\hat{x}_2 = \hat{L} + \delta_L(\hat{w} - \hat{r}) \tag{1.5}$$

$$\lambda_{K1}\hat{x}_1 + \lambda_{K2}\hat{x}_2 = \hat{K} + \delta_K(\hat{w} - \hat{r}) \tag{1.6}$$

$$\theta_{L1}\hat{w} + \theta_{K1}\hat{r} = \hat{p}_1 \tag{1.7}$$

$$\theta_{L2}\hat{w} + \theta_{K2}\hat{r} = \hat{p}_2 \tag{1.8}$$

where $\delta_L \equiv \lambda_{L1}\theta_{K1}\sigma_1 + \lambda_{L2}\theta_{K2}\sigma_2$; $\delta_K \equiv \lambda_{K1}\theta_{L1}\sigma_1 + \lambda_{K2}\theta_{L2}\sigma_2$. The σ's are the elasticities of substitution between labor and capital in the two sectors.

The first pair of full-employment equations states that the positive λ-weighted average of relative output changes is matched either by relative changes in factor endowments or by changes in factor prices that induce changes in input/output coefficients. The second pair does not need such a qualification, since the distributive share weighted average of the input/output coefficients in any industry vanishes as a second-order small when unit costs are being minimized.[1] Each equation states that the relative price change (equal to the relative unit cost change) is the appropriate weighted average of factor price changes.

The Stolper–Samuelson results can be obtained by subtracting equation (1.8) from equation (1.7) and solving for the change in the wage/rental ratio:

$$(\hat{w} - \hat{r}) = \{1/|\theta|\}(\hat{p}_1 - \hat{p}_2) \tag{1.9}$$

The term, $|\theta|$, is the determinant of coefficients in equations (1.7) and (1.8), and is also equal to the difference in labor's distributive shares between industries, $(\theta_{L1} - \theta_{L2})$. It is straightforward to show that the sign of this determinant is indicative of the factor intensity ranking of the two industries, positive if the first industry is labor intensive. If so, an increase in the relative price of the labor-intensive sector must increase the wage/rental ratio. The magnification result follows since $|\theta|$ is a fraction. More directly, since each commodity price change is flanked by factor-price changes, an increase in the relative price of the first commodity must result in:

$$\hat{w} > \hat{p}_1 > \hat{p}_2 > \hat{r} \tag{1.10}$$

A similar logic leads to the Rybczynski result. If commodity prices are held constant, so are factor prices (from (1.7) and (1.8)) and thus techniques, thereby simplifying equations (1.5) and (1.6). Subtracting equation (1.6) (thus simplified) from equation (1.5), letting $|\lambda|$ denote the determinant of factor allocation fractions or, what is the same thing, the difference between the fraction of the labor force used in the first industry and the fraction of the capital stock used there, $(\lambda_{L1} - \lambda_{K1})$,

$$(\hat{x}_1 - \hat{x}_2) = \{1/|\lambda|\}(\hat{L} - \hat{K}) \tag{1.11}$$

An increase in the relative endowment of labor compared with capital raises by a magnified amount the relative output of the first commodity. In more detail, if the endowment of labor increases relative to that of capital, with commodity prices constant,

$$\hat{x}_1 > \hat{L} > \hat{K} > \hat{x}_2 \tag{1.12}$$

The Rybczynski result refers to the fall in x_2's output if $\hat{K}$ is assumed to be zero.

1.2 The Extent of Differences in Factor Intensities: A Measure

Differences in the intensity with which factors are utilized in the two sectors are important for the core propositions of the Heckscher–Ohlin theory. The role played by the *ranking* of the intensities is clear from previous remarks. What is also important is the *extent* of the difference in factor intensities. But here there is a subtle remark worth making: factor intensity differences are important, but the required extent of changes in factor prices is larger the *smaller* is the difference in factor intensities. When the relative price of the labor-intensive commodity rises, an increase in the wage rate relative to capital rentals is what is required in order to

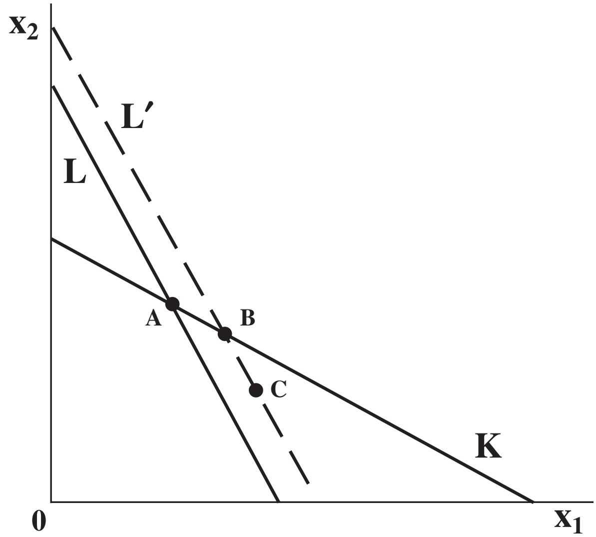

Figure 1.1 Endowments and outputs

raise the average cost of producing the labor-intensive commodity (relative to the capital-intensive commodity). Similarly, the necessary adjustment in outputs in response to a change in factor endowments is more severe the closer together are factor intensities. Figure 1.1 illustrates this point for an increase in the supply of labor with a given stock of capital and unchanged techniques (because commodity prices are being held constant as required to show the Rybczynski effect). For the given techniques the original labor and capital constraint lines intersect at A, where there is full employment of both factors. An increase in the supply of labor to the L′-line requires an output decline in capital-intensive x_2 and a magnified increase in labor-intensive x_1 (as in equation (1.12)) to point B. Now suppose the factor-intensity difference between commodities had been less pronounced – illustrated by a different capital-constraint line through point *A* but steeper, so that the increase in labor shifts outputs to point *C* instead of point *B*. The required output changes to accommodate a change in factor endowments would be more pronounced.

The $|\lambda|$ and $|\theta|$ determinants show the *ranking* of intensities by their sign and the *extent* of the difference in intensities by their size. There is a measure that serves to indicate the *size* of the difference in intensities, one that is always a positive fraction, and that is the product of the two determinants, $|\lambda|$, $|\theta|$. This is a measure that features prominently in the answer to the following question: if relative commodity prices change (by a small amount), by how much do relative outputs adjust? That is, what is the elasticity of relative outputs with respect to relative prices along the transformation schedule? Subtract equation (1.6) from equation (1.5) and solve for the relative change in outputs for given endowments:

$$(\hat{x}_1 - \hat{x}_2) = \{1/|\lambda|\}(\delta_L + \delta_K)(\hat{w} - \hat{r}) \tag{1.13}$$

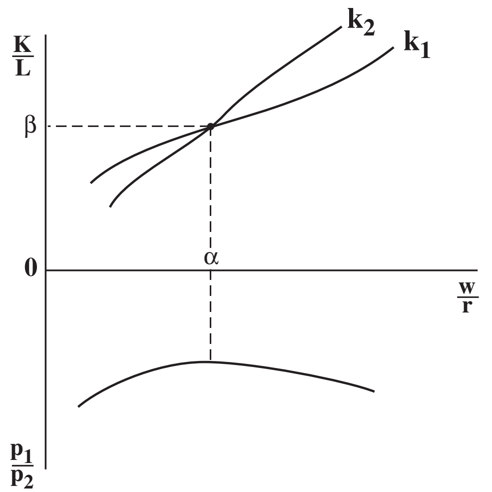

Figure 1.2 Factor-intensity reversal

From equation (1.9) the change in the factor price ratio is linked to the change in the commodity price ratio, so that substitution yields:

$$(\hat{x}_1 - \hat{x}_2) = \{1/|\lambda||\theta|\}(\delta_L + \delta_K)(\hat{p}_1 - \hat{p}_2) \tag{1.14}$$

Furthermore, each of the δ's is linked to the elasticity of substitution between capital and labor in a particular industry. Suppose these two elasticities are the same, denoted just by σ. Then the expression for relative output changes shown by (1.14) can be simplified. Let the coefficient of $(\hat{p}_1 - \hat{p}_2)$ be defined as the elasticity of supply, σ_S, along the transformation schedule. Then it is easy to show that:

$$\sigma_S = \{(1 - |\lambda||\theta|)/|\lambda||\theta|\}\sigma \tag{1.15}$$

The smaller is the product of the determinants (both positive if the first industry is labor intensive, and both negative otherwise) the greater must be the elasticity of supply. This product is thus a natural measure, lying between zero and unity, of the extent of the difference in factor intensities between sectors.

1.3 Factor-Intensity Reversals

Production functions can be characterized by constant returns to scale, identical between countries, and yet exhibit a different relative factor-intensity *ranking* between countries. The classic illustration is provided in figure 1.2, the so-called Harrod–Johnson diagram (Harrod, 1958; Johnson, 1957). The top quadrant relates the capital/labor intensity ratio to the wage/rental ratio for the common technology in the two countries. It illustrates a situation in which for low relative wages the first commodity is relatively capital-intensive, but for wage/rental ratios higher than α the ranking is reversed, with the first commodity becoming relatively labor intensive. If, in autarky, factor endowment proportions in the two countries lie on opposite sides of the critical β-ratio, the Heckscher–Ohlin theorem as a statement for trade patterns in both countries becomes logically invalid (Jones, 1956). Thus suppose that it is the home country that is capital abundant, with a wage/rent ratio higher than α, and suppose furthermore that it exports its capital-intensive commodity, x_2. That implies that the other country exports the first commodity, which, since its wage/rental ratio is lower than α, must be *its* capital-intensive commodity. That is, the labor-abundant country exports its capital-intensive good, violating the Heckscher–Ohlin theorem. In defense of the spirit of the Heckscher–Ohlin theorem, note that whatever the pattern of trade, the relatively capital-abundant home country must export a commodity that is produced by more capital-intensive techniques than is the commodity exported from abroad. This is little consolation, of course, to the Leontief procedure (1953) of comparing the manner in which the two commodities are produced within the same country in order to deduce the factor endowment ranking between countries.

The lower part of figure 1.2 illustrates the relationship between the commodity-price ratio and the wage/rental ratio. As shown, the relative cost of producing the first commodity would reach a minimum if the wage/rental ratio were given by α (in which case the transformation schedule would be linear). Thus the following theorem, in rough form, illustrates the connection between factor endowments and the trade pattern: the country whose endowment capital/labor ratio lies further away from critical β will have a comparative advantage in (and will be the exporter of) the commodity exhibiting the more flexible technology (the higher σ_j).

1.4 The Factor Bias in Technical Progress

The 2×2 framework has often been used to analyze the effect of technical progress on relative factor prices, especially in a context in which the two inputs are unskilled and skilled labor. One of the propositions often put forth by international trade theorists is a corollary of the Stolper–Samuelson theorem: if technical progress takes place in one sector of an economy facing a given set of commodity prices, the real wage rate of unskilled labor rises if and only if that sector is unskilled-labor intensive. The crucial aspect of this statement is what it leaves out – no qualification is made as to the *bias* in technical progress. It is purported to hold whether or not progress is unskilled-labor saving or labor using. The formal support for such a proposition is provided by the competitive profit equations of change, (1.7) and (1.8). Suppose progress takes place in the first sector, so that at *given* factor prices one or both of the input-output coefficients in equation (1.3) fall sufficiently that the distributive share average of such changes, $(\theta_{L1}\hat{\alpha}_{L1} + \theta_{K1}\hat{\alpha}_{K1})$, is negative. This is the Hicksian measure of technical progress, and in equation (1.7) the absolute value of this expression would appear on the right-hand side. If L refers to unskilled labor and K to skilled labor (human capital), with the first sector L-intensive, the real

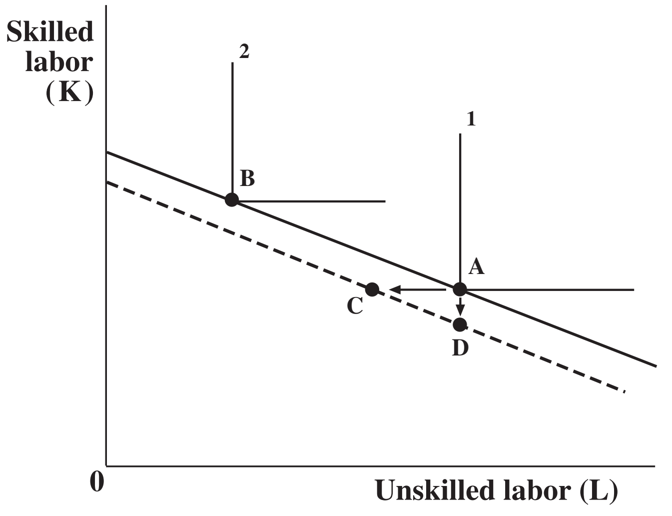

Figure 1.3 Biased technical progress

wage for the unskilled would unambiguously rise (and that for skilled workers would fall) regardless of the bias in such progress.

This result, which causes some dismay among labor economists (e.g., see the discussion in Collins, 1998), is very much a reflection both of the 2×2 dimensionality of the models and of an assumption that the extent of technical progress is small. By this is meant that the pattern of production is not affected. In section 2 we illustrate how, in a multi-commodity setting, progress in the capital-intensive sector might end up *improving* the position of unskilled labor. Here our objective is more modest: With finite technical progress, the *extent* of the factor-price change indeed depends upon whether progress is (Hicksian) unskilled-labor saving or labor using in its bias. The potential surprise lies in the nature of the connection. As I now illustrate, if technical progress takes place in the unskilled-labor intensive sector, the real wage for the unskilled will rise by *less* if such progress tends to require a higher ratio of unskilled labor (per unit of skilled labor) – i.e., if it is unskilled-labor using in its bias.

The argument follows that found in Findlay and Jones (2000). To simplify, suppose that there is no possibility of factor substitution in either sector. The initial situation is shown by points A and B for the two unit-value isoquants in figure 1.3. Points C and D indicate two alternative shifts in the corner-point A that represent the same Hicksian extent of technical progress (the dashed line is parallel to the initial line whose slope reveals the factor-price ratio). Point C represents pure Hicksian unskilled labor-saving progress and point D a pure skilled-labor-saving technical progress. The resulting effect on the relative wage rate for unskilled labor (L) would be revealed by the slope of the new factor-price line connecting point B either with point C or with point D. The unskilled real wage rate increases in either case, but even more so if progress *reduces* the demand for unskilled labor per unit

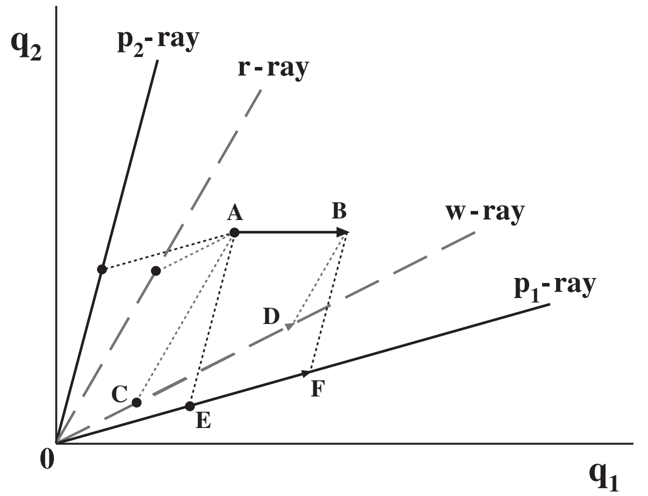

Figure 1.4 Joint production

of skilled labor (point C). The rationale for such a counter-intuitive result is that the move to C (instead of to D) narrows the extent of the factor-intensity difference between sectors (as measured earlier by $|\lambda|$ or $|\theta|$ or their product, $|\lambda|\ |\theta|$) and thus allows a greater magnification effect.

1.5 Joint Production

Two of the four core propositions depend heavily on an assumption about production that is standard in much of economic theory, *viz*. that production processes involve one or more inputs and yield a single output. Thus the strong asymmetries between output and endowment changes shown by the ranking in (1.12) and between commodity and factor price changes shown by (1.10) are supported by the assumption that there is no joint production. But these are not razor's edge types of results; a bit of jointness will not overturn the magnification effects.

Figure 1.4 illustrates a case in which the Stolper–Samuelson theorem holds despite the existence of joint production. (A similar use of this diagram was made by Chang, Ethier, and Kemp, 1980.) Shown along the axes are the prices of two different *activities*, each of which requires labor and capital as inputs, and yields outputs of commodities 1 and 2. On the one hand each price, q_i, represents the sum of labor costs and capital costs, much as in equations (1.3) and (1.4) with activity prices replacing the commodity prices, p_i. As well, the price of each activity is the sum of the value of commodity outputs from the unit level of the activity. In figure 1.4 the cone spanned by the wage ray and the rental ray is contained by the cone spanned by the two commodity price rays. If so, an increase in the price of the first activity with the price of the second activity held constant (the move from point A to point B), increases the price of the first commodity from 0E to 0F, and of the wage rate from 0C to 0D. The latter change is relatively larger, so that the real wage must rise as in Stolper–Samuelson, despite the presence of joint production. The key assumption is that the disparity in the composition of outputs in a comparison of the two activities is greater than the factor-intensity difference in inputs (further details are found in Jones, 2001).

As to the other pair of propositions in the core, the factor price equalization result is robust as long as the two activities are linearly independent,[2] and the Heckscher–Ohlin theorem can be restated in terms of the country location of *activities*. From such a pattern the actual trade routing of commodities could then be deduced from the output intensity of activities (as well as patterns of demand).

1.6 Factor-Market Distortions

A factor of production may be used in both sectors of the economy and yet receive a different remuneration in each. Harberger (1962) in his work on corporate income tax provided an early example. Johnson and Mieszkowski (1970) suggested that trade union activity also illustrated a case of factor-market distortion. In Jones (1971a) a general treatment was provided, one that came under heavy criticism from Neary (1978). Factor-market distortions open up the possibility that a ranking by distributive shares (the θ-matrix) could differ from the physical factor-intensity ranking provided by the ratios of factors used (or the λ-allocation ranking). For example, an industry that had a higher labor/capital ratio might pay its workers less than a unionized sector with a higher wage rate. Equations (1.5) and (1.6) suggest how the λ-ranking connects the output pattern to factor endowments, while equations (1.7) and (1.8) illustrate how the value distributive shares (the θs) connect factor returns to commodity prices. With factor-market distortions, the sign of the $|\lambda|$ determinant could become different from that of the $|\theta|$ determinant. This seems to open up the possibility that the increase in a commodity price might cause output in that sector to decline. If, say, the *first* commodity is labor intensive in a physical sense but capital intensive in a value sense, a rise in its price would lower the wage rate, encouraging more labor-intensive techniques to be adopted in each sector, and thus causing an increase in the output of the *second* commodity, which is capital intensive in a physical sense. Neary objected that such an inverse price–output supply relationship could be ruled out on stability grounds. Thus seeming paradoxical responses of outputs to changes in commodity prices would not be observed.

Later we discuss the specific-factors model. For example, two types of labor, unionized and non-unionized, might be considered as specific to each sector of a two-sector economy because the union can limit entry. But in this case the differences in wage rates are endogenous to the system, whereas the kinds of distortion to which the Neary objection holds are exogenous. Since labor has natural units, it would be possible to compare factor allocation coefficients as in the regular 2×2 model, but with different wage rates the $|\lambda|$ determinant and the share $|\theta|$ determinant could have different signs. Nonetheless, if the union-inspired wage discrepancy was to disappear, and over time wages adjust as the formerly unionized sector attracts labor, Jones and Neary (1979) argue that the adjustment process would be stable.

2 The Multi-Commodity, Two-Factor Case

In the case in which there are potentially many commodities that a country could produce, but only two factors, there is little difficulty in ordering commodities by their factor intensities, assuming away, again, the problem of factor-intensity reversals. There are clear advantages that the multi-commodity case (still only two factors) has over the previous section's two-commodity framework. Perhaps the most important of these concerns the question of the degree of concentration allowed by, or forced by, the existence of free trade in world markets. In the limit a country may pull resources completely out of producing (n – 1) traded commodities. The two-commodity case severely limits the extent to which trade exhibits such concentration. A basic question then concerns *which* commodities are produced, and how are the differences in factor intensities and factor endowments connected to such a choice.

2.1 The Hicksian Composite Unit-Value Isoquant

The geometric construction known as the Hicksian composite unit-value isoquant is the device most often used to illustrate the multi-commodity case. Given a country's knowledge of technology and its factor endowments, exposure to world markets with known commodity prices suffices to determine the answer to questions about production patterns. If the country's technology does not match up with that available in other countries, there may be some commodities that this country could not efficiently produce in world markets regardless of its factor endowments; it may possess a Ricardian comparative disadvantage in such goods. For each of the other commodities consider the unit-value isoquant, combinations of labor and capital that produce a single dollar's worth of output at world prices. The *convex hull* of this set of isoquants represents the Hicksian composite, and the bold locus in figure 1.5 illustrates a three-commodity case. The intersection of the endowment ray with this composite yields the output bundle, which may consist of a single commodity or a pair. If world prices are unconnected with this country's technology, there will generally only be as many commodities that can be produced as there are factors, in this case two. For example if endowments are shown by the β-ray, only commodity 2 is produced. By contrast, with endowments given by the α-ray, the bundle of inputs at point G is the efficient way of earning \$1 on world markets, and this involves producing around 30 cents worth of commodity 1 and 70 cents worth of the second commodity. The α-ray cuts the chord connecting technique A for producing the first good and technique B for producing the second at point G. Note that at these prices and endowments it is not only production of commodity 3 that is ruled out, also not viable are many *factor intensities* of producing the other two

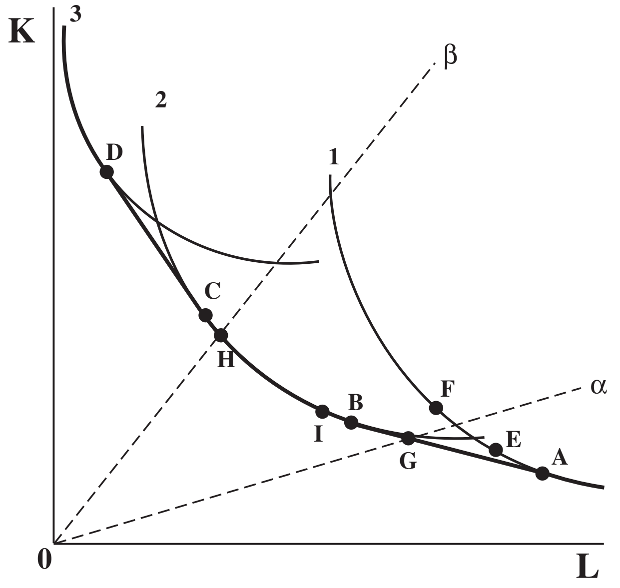

Figure 1.5 Hicksian composite unit value isoquant

commodities. Point F indicates a technique for producing the first commodity that would be ruled out by competition – indeed this technique is dominated by some of the techniques of producing commodity 2. But even point E is inefficient, not because there is another, better *single* way of earning $1, but because a combination of points A and B is superior.

In the case in which many commodities are represented in the Hicksian composite unit-value isoquant, what is the relationship between the *trade* pattern, factor endowments and factor intensities? An easier preliminary question concerns the *production* pattern. Each commodity represented in the composite has only a range of intensities that are viable. The endowment ray either selects a unique commodity with those exact factor proportions (e.g., point H for the β-ray), or, if two commodities are efficient, the two flanking techniques for the pair of commodities, e.g., techniques A (for the first commodity) and B (for the second) if the endowments lie along the α-ray. All commodities not produced will be imported if there is any local demand at world prices. Thus typically a country's imports will contain commodities that would, if produced at home, require more capital per unit of labor than contained in the endowment bundle as well as less capital per unit of labor than in endowments. As to exports, it will be the single good produced if there is only one such commodity, and either one or both of the commodities produced if the endowment ray cuts a flat. But relatively small variations in the endowment ray along a given flat could well alter the trading pattern as one of the commodities ceases to be exported and becomes imported instead. Perhaps the moral of the story is that in the multi-commodity case factor endowments are not clear

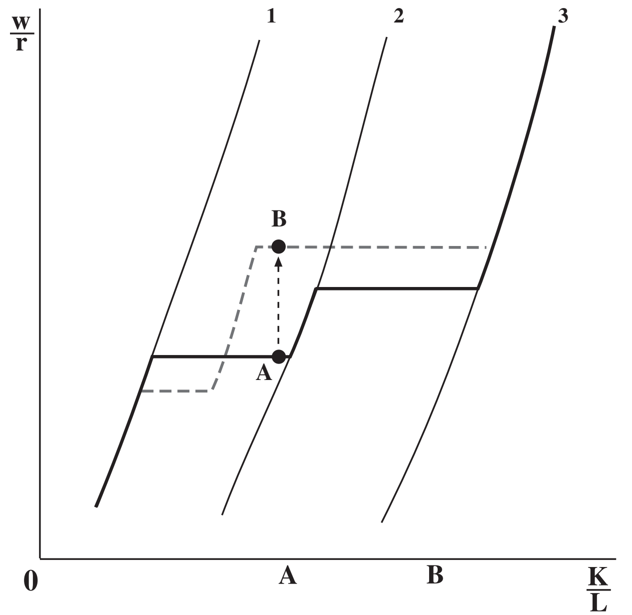

Figure 1.6 Technical change and factor prices

indicators of trade patterns, but they do serve to single out a production pattern involving one or two commodities produced using factor intensities *close* to the endowment ratio (Jones, Beladi and Marjit, 1999).

This setting is also useful in revealing likely alterations in production patterns for an open economy capable of growing in the sense of accumulating capital (relative to the size of its labor force). Such growth will certainly not be balanced. Instead, there would be a steady increase in the production of commodities with greater and greater capital/labor requirements coupled with declining production of the more labor-intensive items. Even smooth *aggregate* rates of growth would be accompanied by a strong asymmetry in *sectoral* performance at the micro level (Findlay and Jones, 2001).

2.2 Technical Progress of Finite Size

Previously we alluded to the possibility that the factor-saving bias in technical progress that is confined to the capital-intensive sector of an economy would have no effect on the result that the relative (and real) wage rate would fall if the change is small, but might reverse this outcome if the progress is of finite size (Findlay and Jones, 2000). Here we can illustrate this result in the three-commodity case, figure 1.6. The technology of producing the three commodities is reflected in the upward sloping schedules. For given initial world prices, the bold sections on each curve show ranges of factor endowment proportions in which complete specialization takes place. The two bold horizontal stretches illustrate ranges of factor endowments for which incomplete specialization to two different commodities is required to achieve full employment. Suppose the initial equilibrium reflects the endowment proportions and factor prices shown by point A. The dashed sections reflect technological progress of a finite extent in the second commodity (thus extending at both ends the range of factor endowments for which complete specialization in the second commodity would be achieved at the given world commodity prices). As illustrated, this change is biased in favor of requiring a heavier use of labor (or unskilled labor in the earlier interpretation) compared to capital (or skilled labor) at any given factor price ratio. Initially the country produces both commodities 1 and 2. Technical progress has taken place in the relatively more capital intensive of these two, but as a consequence the wage/rental rate has *increased* to the level shown by B. The pattern of production has been altered so that in the new equilibrium the country produces commodities 2 and 3 and in this pair commodity 2 is relatively labor intensive. With such a change in the production pattern the bias in technical progress comes into its own in affecting factor prices. Here it is the labor-using bias that results in an increase in the wage rate, a result in line with the partial-equilibrium reasoning often used by labor economists.

Jones and Kierzkowski (2001) argue that international *fragmentation* of a previously vertically-integrated production process is analogous to technical progress in that overall productivity can be increased by losing a fragment in which a country does not possess a comparative advantage. The point to emphasize here is that such fragmentation is not a marginal, infinitessimal event. By its very nature, fragmentation involves finite changes in the pattern of production.

3 The Multi-Factor Case

Must the use of factor-intensity rankings be abandoned if more than two factors are used in production processes? No. A later part of this section addresses the general setting in which the economy produces many commodities, each requiring a unique composition of many inputs. But first I begin with the more simple three-factor case, and especially the most popular version, the specific-factors model.

3.1 The Specific-Factors Model in the 3 $\times$ 2 Setting

In this setting the factor proportions used in the two sectors are not directly comparable since each industry uses a (specific) factor not used in the other industry. This is a setting in which the use of distributive factor shares comes into its own. In the 2×2 case, if the first industry utilized a higher labor/capital ratio in production, it also exhibited a higher labor distributive share. If labor is the mobile factor in the specific-factors framework, a comparison once again can be made of its distributive share in the two sectors even though the other factor is different between sectors. The factor-intensity ranking would thus be freed up of the necessity of a focus on the *same pair* of factors.

Earlier, a comparison of the factor allocation fractions in an industry was also used to indicate a factor-intensity ranking. Applied directly here it would only state that each industry was intensive in the use of its specific factor. However, the λ-allocation fractions can be used to yield the same information about labor intensity as does the θ-distributive share ranking. Consider the ratio of labor's distributive share in the jth sector with the fraction of the labor force used there, θ_{Lj}/λ_{Lj}. Simple substitution reveals that this is equivalent to the ratio θ^L/θ_j, where θ^L refers to labor's share in the national income and θ_j refers to industry j's share of the national income. Alternatively phrased:

$$\theta_{Lj}/\theta^L = \lambda_{Lj}/\theta_j \tag{1.16}$$

As discussed more explicitly later, labor's share in the national income must be a weighted average of its share in every sector, and the share of the output of each industry in the national income must be a weighted average of the factor allocation fractions used in that industry. Therefore either expression in equation (1.16) could be taken as an index of the intensity with which labor is used in that sector.

Unlike the 2×2 case, factor intensities alone no longer determine factor prices from commodity prices. This is true in any setting in which factors outnumber commodities produced. Furthermore, even if commodity prices are held constant, any change in factor endowments requires output changes in order to equilibrate factor markets (as before), but such changes no longer depend only upon factor intensities. So what do factor intensities tell us even in this stripped-down specific factors context?

As developed in Jones (1971b or 2000), the most direct way to ascertain the role of factor intensities in the specific-factors model is to solve for changes in the return to the mobile factor. Let this be labor, with specific factor V_i in industry i. The full employment condition for labor is then as shown in equation (1.1). In addition, each output is constrained by the amount of the specific factor employed there: $a_{ii}x_i = V_i$. Differentiate each of these and substitute into the differentiated form of (1.1) to obtain (1.17):

$$\sum \lambda_{Li}(\hat{a}_{ii} - \hat{a}_{Li}) = -\{\hat{L} - \sum \lambda_{Li}\hat{V}_i\} \tag{1.17}$$

Changes in the factor intensities adopted in each industry can be related either to the change in the ratio of factor prices in that industry via the elasticity of factor substitution (as used previously in note 1) or to the change in the ratio of the wage rate (w_L) to the price of that industry's output via the elasticity of demand for labor in that industry (the elasticity of the marginal physical product of labor schedule). Taking the latter route,

$$(\hat{a}_{ii} - \hat{a}_{Li}) \equiv \gamma_{Li}(\hat{w}_L - \hat{p}_i) \tag{1.18}$$

This leads to the solution for the change in mobile labor's return with respect to changes in commodity prices and to changes in factor endowments:

$$\hat{w}_L = \sum \beta_j \hat{p}_j - [1/\gamma_L]\{\hat{L} - \sum \lambda_{Lj}\hat{V}_j\} \tag{1.19}$$

where $\beta_j \equiv \lambda_{Lj}\gamma_{Lj}/\gamma_L$ and $\gamma_L \equiv \Sigma\lambda_{Lj}\gamma_{Lj}$.

This solution confirms that the increase in either commodity price raises the return to mobile labor, but by a dampened relative amount. Clearly, both factor-demand elasticities and factor intensities enter into the determination of factor returns when commodity prices are altered. Rewriting each of the β-coefficients as the product of three terms helps to reveal the role of factor-intensity rankings. Thus:

$$\beta_j = \theta_j i_j s_j \tag{1.20}$$

where $i_j \equiv \lambda_{Lj}/\theta_j$ and $s_j \equiv \gamma_{Lj}/\gamma_L$.

The expressions s_j and i_j represent, respectively, the elasticity of demand for labor in sector j expressed relative to the economy-wide labor demand elasticity, and the labor intensity of sector j. As already argued, a sector is deemed to be labor intensive if and only if the fraction of the labor force it employs is greater than the fraction that sector's output represents of the national income. Therefore the extent of the wage rise when the price of a single sector increases depends on the importance of that industry, on the relative degree of substitutability between factors in that industry, and the labor intensity index of the industry (and is the product of these three characteristics).

Once the wage rate is determined, the competitive profit conditions can be utilized to solve for the change in rental rates for the two specific factors. In this 3×2 case,

$$\theta_{11}\hat{w}_1 + \theta_{L1}\hat{w}_L = \hat{p}_1 \tag{1.21}$$

$$\theta_{22}\hat{w}_2 + \theta_{L2}\hat{w}_L = \hat{p}_2 \tag{1.22}$$

In the 2×2 case competitive profit conditions are typically used to examine the effect of a change in relative commodity prices. In the specific-factors case a different use is often made of these two conditions. Suppose the relative price of goods remains unchanged. In particular, suppose commodity prices do not change but the return to the commonly used factor, labor, goes down. (For example, the labor supply might have increased.) What can be said about the returns (rentals) to the specific factors? Both returns rise, and the factor-intensity comparison now tells us which specific factor return rises relatively more. This will be the return to the first specific factor if and only if θ_{L1} exceeds θ_{L2}, that is, if and only if the first industry is labor intensive. If the wage rate had risen instead, the factor-intensity ranking would indicate which specific-factor return would change more, in this case in a downward direction.

How about endowment changes when commodity prices are kept constant? If the endowment of a specific factor increases, the output in which it is used goes up and the other output falls. (Note, however, that the output of the favored industry does not rise by proportionally as much as the endowment – no magnification effect here.) Suppose, instead, that the endowment of the mobile factor (labor) rises. Not surprisingly, both outputs expand. But which output rises relatively more? The answer does not depend only upon factor intensities, since the difference in the substitutability between labor and the specific factor from industry to industry is also important. However, suppose the elasticity of factor substitution is the same between sectors. Then the output of the first sector will rise by relatively more than that of the second if and only if the first sector is relatively labor intensive (Jones, 1971b). Factor-intensity rankings must share influence with characteristics of factor substitutability in the specific-factors model, but if the elasticity of substitution is similar between sectors, factor-intensity rankings once again dictate the behavior of output changes in response to alterations in factor endowments.

Suppose, now, that each sector uses a type of labor that has a unique level of skills. In particular, let the first industry use unskilled labor and capital as inputs, and the second industry use skilled labor and (the same kind of) capital. Off stage suppose there is an educational process whereby the unskilled can be converted to skilled. This is like a change in factor endowments. Assuming commodity prices are constant, what is the effect of such training on the wage rates of the two types of labor? The reduction in the supply of the unskilled serves to raise both wage rates (as the return to capital falls), but the increase in the pool of skilled labor would have the opposite effect – to raise the return to capital and lower both wage rates. What is the net effect? There are two aspects to this question. First, does the return to capital rise or fall? And second, if it rises, so that both wage rates fall, does the *wage premium* received by skilled workers increase or fall? The answer to the second query depends on the distributive-share version of the factor-intensity ranking. The answer to the first query, however, depends upon the physical capital/labor ratios in the two sectors. With both types of labor sharing a common physical unit of measurement, the λ-comparisons can be made, and the θ-comparison need not be the same. Thus if the sector employing skilled workers is physically the capital-intensive sector, the education process brings more labor to this sector, accompanied by a smaller supply of capital than is used in the second sector. The result is that the return to capital increases and both wage rates fall. However, if the skilled-wage premium is high enough, the second sector could be the labor-intensive sector measured by distributive shares. In such a case, the rise in the return to capital would lower the skilled wage rate by less than that for the unskilled. That is, the departure of some unskilled workers to join the ranks of the skilled could serve not only to lower the unskilled wage rate, but also to heighten the skill premium.[3] The discrepancy between the λ and θ rankings does not lead to the difficulties cited earlier since this is not a factor-market distortion.

3.2 The General 3 × 2 Model

The properties of the three-factor, two-commodity model in which all three factors are actively employed in each sector have been spelled out in Jones and Easton (1983). A new complication, absent in the specific-factors model, is the possibility of factor complementarity or of a strong asymmetry in the degree of factor substitutability. With all three factors mobile, factor i, previously the specific factor used in industry i, is now only the most intensively used factor there (i.e., an *extreme* factor). Once again we focus on the role of the factor-intensity ranking in connecting commodity price changes to factor returns, on the one hand, and endowment changes to outputs, on the other.

Suppose an economy with fixed endowments experiences an increase in the relative price of the first commodity. Could the same effect on factor prices as in the specific-factors model occur in this more general case? Yes, if there is sufficient symmetry among the various factor-substitution elasticities. But suppose the two "extreme" factors, V_1 and V_2, are especially good substitutes for each other, compared with the degree of substitutability of either extreme factor with labor. This implies that the factor returns, w_1 and w_2, cannot move very far apart. In such a case the burden of altering the relative cost of producing the two commodities (to match the given increase in the relative price of the first commodity) falls on a change in the wage rate. It is precisely at this point that the factor-intensity ranking becomes important. Although labor's distributive share lies somewhere in the middle of the share ranking (i.e., $\theta_{11} > \theta_{L1} > \theta_{21}$), more can be gleaned by a comparison of labor's distributive shares in the two industries. Thus if θ_{L1} exceeds θ_{L2}, the first sector is relatively labor intensive compared with the second and an increase in the wage rate will raise costs more in the first than in the second industry. The required factor-price changes, given that w_1 cannot alter much relative to w_2 because of the assumed relatively high degree of factor substitutability between the two extreme factors (in both sectors), are that the wage rate for labor rises relative to either commodity price change, and relative to changes in the other two returns. Although $\hat{w}_1$ will exceed $\hat{w}_2$, it might fall short of $\hat{p}_2$ (as must $\hat{w}_2$).

Without going into any detail, we might note that if both extreme factors are particularly good substitutes for each other, they come close to being a "composite" factor. In this case, let the first industry be labor intensive (as above) in the sense of having a larger labor share. Then an increase in the endowment of the first factor at constant commodity prices could serve to *reduce* the output of the first commodity because it is intensive in the factor (labor) that has *not* been increased. (Details are found in Jones and Easton, 1983. See also Thompson, 1987.)

3.3 Higher-Dimensional Cases

Before turning to a general statement of factor intensities, we consider briefly several other models where factors exceed commodities by one. First, consider the scenario in Jones and Dei (1983) and Jones (2000) concerning foreign investment. Assume that the home country, specialized completely in producing the first commodity at home, is able also to produce it in an enclave located abroad by utilizing the foreign labor force. Foreign labor is also used abroad to produce the second commodity, with the aid of a fixed amount of a specific factor. The specific factor used in the first industry (capital) is either used at home or shipped to the enclave. (The foreign country owns no capital of this type.) This is a 4×3 model: home labor and foreign labor, home type of capital and a foreign specific factor. Foreign labor can be used either to produce its own national commodity or sent to the enclave, while home capital also has two choices in producing a single commodity at home or in the enclave. (The three commodities are home output, output in the enclave, perhaps with different technology than used at home, and foreign national output.)

From an initial equilibrium in this setting, in which the rate of return to capital is equated between the home country and the enclave, suppose the price of the first commodity increases. Before any further international capital flows, the rate of return to capital goes up by the same relative amount at home as the price rise, but by a *magnified* amount abroad, because the enclave can attract foreign labor from the foreign hinterland. Hence more capital flows from home to the enclave. But what happens to the wage rate in each country? As capital leaves the home country the initial wage increase is dampened. Indeed, the wage rate might even fall. However, in the enclave the rise in price draws labor from the foreign national industry and thus causes the foreign wage to rise. It might rise even more than the home wage. What would be the necessary condition for this? With reference to equations (1.21) and (1.22) (with capital now the "mobile" factor), the paradoxical-sounding outcome in which foreign workers, producing their own national commodity (which has not risen in price), find their wages increasing by more than home workers (employed only in producing the good that has increased in price) must follow if home production is capital-intensive relative to that in the enclave.

Another example raises the number of factors and commodities by one. It presupposes that there are two countries, each producing both commodities, and the price of the first commodity increases throughout the world. (The number of commodities, four, treats each country's activities as separate from the other's.) The factor specific to the first commodity is assumed to be internationally mobile (such as oil rigs if oil is produced in the first industry). Thus this model is a juxtaposition of specific-factors models for each country, linked by the internationally mobile capital. Will the first specific factor move between countries? Yes, if the return prior to movement is different in the two countries, although in each the return will rise by a greater proportion than the commodity price. Suppose, now, that in the home country output of the first commodity represents a significantly larger fraction of the national income than it does abroad. In this event the wage increase at home can be expected to be larger than that abroad – note the role of θ_j in equation (1.20) – and, if technologies in the first industry are roughly comparable between countries, the return to the specific factor (prior to relocation) cannot rise by as much as in the foreign country. The consequence is a flow of the internationally-mobile factor specific to the industry that has gone up in price into the country that is the relatively *unimportant* producer.

In this 5×4 setting only one type of capital is internationally mobile. But suppose both types of capital can flow between countries although remaining specific to a certain kind of activity. This is the scenario investigated in the *neighborhood production structure* of Jones and Kierzkowski (1996). Thus let X-type and Y-type capital be sector specific, but internationally mobile, with labor trapped within the borders of each country. Suppose taste changes in the world cause an increase in the price of the X-type good produced in each country, with no change in the price of Y-type goods. The kind of reasoning associated with the specific-factors model might suggest a consequent magnified increase in the return to X-type capital, a dampened rise in the wage rate in each country, and a fall in the return to Y-type capital. This could be the outcome, but is not necessary. Even if in each country the

X-type good was capital-intensive compared with the Y-sector, the wage rate in both countries might increase by more than the price of X-type goods, and the return to X-type capital rise not by as much, or even fall. Certainly in this 4×4 setting factor intensities matter – indeed they are the *only* things that matter. However, it is the *intra-industry* comparison of capital's distributive share between countries that is crucial. For this bizarre-sounding result what is required is that one country have a higher intra-industry capital share *in both sectors,* and the share spread between countries in the favored X-industry exceed that in the other industry. Details are omitted here, but found in Jones and Kierzkowski (1996).

The specific-factors model in the 3×2 case generalizes very easily to the case in which there are n sectors, each employing a factor specific to that sector, and each sector as well making use of a mobile factor (e.g., labor) available to all sectors. This is a big advantage in empirical work, where the number of sectors the economy is deemed to have is arbitrary. Thus a single price rise will serve unambiguously to reward the factor used specifically in that sector, to reduce the return to all other specific factors, and to bring about a nominal increase in the return to the mobile factor, which is smaller, relatively, than the commodity price rise. Furthermore, the change in the reward to the mobile factor is given by an expression similar to that developed in equations (1.19) and (1.20). Suppose the mobile factor is labor (L). Now consider a price increase for a single commodity, j, in a country closed to trade. In general the price level change is $\Sigma\theta_i\hat{p}_i$. With only one price change this becomes $\theta_j\hat{p}_j$. If this commodity is "typical" in its degree of factor substitutability, so that s_j in equation (1.20) is unity, and assuming factor endowments do not change, $\hat{w}_L$ will exceed the change in the price level if and only if i_j exceeds unity. That is, for a closed economy the labor intensity of mobile labor indicates the direction of change in the return to the mobile factor in *real* terms in the sense of the price index (although not in terms of the single price rise).

Turning back to the more general 3×2 case, Ruffin (1981) noted the following property: suppose there is an endowment change at given commodity prices. Then the *sign*, although not the *size*, of the response of factor rewards depends *only* upon the factor-intensity ranking and not at all on the pattern of factor substitutabilities. This proves to be a result that generalizes to the case in which the number of factors exceeds the number of commodities by only one (Jones, 1985a). Formal solutions for factor price changes include characteristics of the degree to which factors are substitutable for each other since there are more factors than commodities. But their purpose is only to determine the size, not the direction, of factor movements. The key lies in the subset of competitive profit conditions, of the kind illustrated for the 2×2 case in equations (1.7) and (1.8). There are n of these in the general $(n + 1) \times n$ case, and they are completely free of substitutability characteristics because cost minimization sends the weighted average of changes in input-output coefficients in any industry to zero. In the more general case in which the number of factors exceeds the number of commodities by more than one, the sign of factor price changes subsequent to an endowment change depends both upon factor intensities and substitutabilities, but the competitive profit equations of change, involving only the intensity terms (through the distributive shares), still have an independent role to play. For example, suppose the price of a single commodity, j, increases. Take any two other industries, say *i* and *m*, and number the factors in descending order of the ratios of their factor intensities. Then it cannot be the case that every factor reward on one side of the ordering rises while all others fall (Jones, 1985a).

The importance of factor intensities in the multi-factor, multi-commodity case is especially revealing in the event that the number of factors exactly equals the number of produced commodities, and all activities are linearly independent. In such an event an alteration in commodity prices (not large enough to change the production pattern) results in a unique response of factor prices, independent of any (small) changes in factor endowments. And this response depends *only* upon factor-intensity rankings. Although the existence of open trading markets does not guarantee such a balance in numbers, it is generally true that a country need not produce more commodities than it has factors of production. In any event, this "even" case has attracted much attention in the literature. Are there restrictions on the array of factor intensities strong enough to ensure that the Stolper–Samuelson theorem survives? Strong skepticism was frequently expressed in earlier years, and of course much depends upon the particular way in which the theorem is expressed for higher-dimensional cases. The *strong* form of the theorem states that an increase in any commodity price is associated with a greater relative increase in the return to some factor "intensively" used in that sector and a fall in every other factor return. Kemp and Wegge (1969) provided what sounded like a quite restrictive condition on factor intensities to investigate this strong form of the theorem. They assumed that for any pair of distinct factors, s and r, and distinct industries, s and t, the distributive share matrix satisfies the condition:

$$\theta_{ss}/\theta_{rs} > \theta_{st}/\theta_{rt} \tag{1.23}$$

That is, each factor is paired with a particular industry such that its factor share there relative to any other factor's share in that industry exceeds the ratio of those two factor shares in any other industry. Kemp and Wegge proved that this condition was sufficient to establish the strong form of the Stolper–Samuelson theorem when there are three factors and three commodities, but supplied a counter-example for the 4×4 case. Although generally condition (1.23) is not sufficient, they did prove that it was necessary. Chipman (1969) examined the *weak* form of the Stolper–Samuelson theorem, stating that an increase in any commodity price would increase the real return to the associated intensive factor, although some other factor returns might rise as well. His restriction on intensities was weaker than in (1.23), requiring only that every θ_{ss} exceed the share of factor s in all other industries. This proves to be sufficient for the weak form in the 3×3 case, but not in higher dimensions.

Since that time stronger criteria for factor-intensity rankings were supplied for each version of the theorem – Jones, Marjit and Mitra (1993) for the strong version and Jones and Mitra (1999) for the weak version. In the strong version, for example, the extra conditions require that factor intensities (or ratios) for the unintensive factors used in an industry do not vary much from sector to sector. After all, the strong form requires all factors save one to lose when a price rises; this will follow if the ratio of the factor shares for the losers does not vary a great deal from industry to industry.

Even though sufficient conditions can thus be stated to prove strong or weak forms of the Stolper–Samuelson theorem (and, by reciprocity, the Rybczynski theorem) in the higher dimensional $n \times n$ case, the severity of these conditions might suggest that these propositions are best reserved for smaller-dimensional models. This would, in my view, represent a mistake because the essence of the Stolper–Samuelson theorem is that *any* factor of production can have its *real* return enhanced by the indirect means of altering some commodity prices (it may take more than one). All it takes to prove this is that there is no joint production (or not too much) and that there are at least as many commodities as factors of production (Jones, 1985b).

It is possible to give a factor-intensity ranking for an economy with any number of factors and any number of industries, making use of the factor-allocation λ-fractions and the distributive share θ-fractions so useful in the core 2×2 setting. First, we note that the share of any industry (j) in the national income, θ_j, is a weighted average of the allocation fractions used in that industry, with the weights provided by the share of each factor (i) in the national income, θ^i. Thus:

$$\sum_i \theta^i \lambda_{ij} = \theta_j \tag{1.24}$$

This implies that the weighted average of the (λ_{ij}/θ_j) is unity across factors. If one of these terms exceeds unity, we define industry j as being intensive in its use of factor i. This is an intensity comparison not between industry j's use of factor i with that of some other industry, but instead a comparison with the economy as a whole. Also, industry j can be considered to be intensive in its use of the ith factor compared with its use of the kth factor if (as in the 2×2 case) λ_{ij} exceeds $\lambda_{kj.}$ A similar set of remarks applies to the θ-matrix of distributive factor shares. Thus a weighted average over industries of the share of the ith factor (with weights provided by industry shares of the national income) yields the share of the ith factor in the national income:

$$\sum_j \theta_j \theta_{ij} = \theta^I \tag{1.25}$$

Once again, this can be re-interpreted, in this case to state that the weighted average of the (θ_{ij}/θ^i) terms is unity across industries. Now recall equation (1.16). There are two equivalent ways to compare the intensity of industry j's use of factor i with the national average – the fraction of factor i allocated to the jth sector with the importance of the jth sector in the national income, on the one hand, and the distributive share of factor i in industry j compared with factor i's share of the national income on the other. For many purposes it is the bilateral comparison of the factor intensity in an industry with the national average that is required, and equation (1.16) indicates the two alternative routes that can be taken.[4]

This section concludes by pointing out two potential pit-falls in the use of factor intensities. The first refers to the example of distributive shares in the 3×2 case presented in Jones (1977): The three factors are labor (L), capital (K), and land (T), and the shares in each industry are: (θ_{L1}, θ_{K1}, θ_{T1}) = (0.2, 0.1, 0.7) for the first industry and (θ_{L2}, θ_{K2}, θ_{T2}) = (0.5, 0.3, 0.2) for the second industry. Since θ_{L1}/θ_{K1} does indeed exceed θ_{L2}/θ_{K2}, industry 1 employs a higher labor/capital ratio than industry 2. But suppose the wage rate rises by 10 percent and the rental on capital falls by 10 percent (with land rentals held constant). What happens to the ratio of costs in the two industries? In the first industry costs have risen by 1 percent while in the second industry costs have risen by double this amount, 2 percent. The direct difference between factor shares yields better information than does the ratio.

The second example is found in Minabe (1967), who cites the following distributive share θ-matrix and its inverse:

$$\begin{bmatrix} 10/26 & 8/26 & 8/26 \\ 8/20 & 10/20 & 2/20 \\ 8/20 & 2/20 & 10/20 \end{bmatrix}^{-1} = \begin{bmatrix} -39 & 20 & 20 \\ 26 & -90/8 & -110/8 \\ 26 & -110/8 & -90/8 \end{bmatrix}$$

Each diagonal entry is the largest in its row. However, the inverse of this share matrix has a strictly negative diagonal. That is, the increase of any commodity price causes the factor most intensively used there to suffer a fall in its reward. As discussed earlier, even stricter conditions are required to satisfy the Stolper–Samuelson theorem.

4 Further Remarks

Differences in the input composition with which commodities are produced have played a key role in the development of international trade theory. In more formal treatments, even of the core 2×2 version, a distinction is often made only of "commodity 1 vs. commodity 2". However, this framework has also been used to distinguish between two *classes* of commodities. Indeed, in the earlier contributions to growth theory (with some applications to trade theory), much attention was paid to the capital/labor-intensity ranking between consumption goods and capital goods. The specter of instability or lack of convergence to a long-run growth path was raised in the case in which capital goods were produced by capital-intensive techniques. If commodity prices did not adjust, the Rybczynski result from trade theory suggested that if capital were to grow more rapidly than labor, there would be magnified expansions of the capital goods produced, so that the gap between the capital stock and labor force would grow ever wider.

In trade theory a distinction is often made between those commodities that are traded *vs*. commodities that are not traded. A somewhat similar distinction can be made on the input side, between the class of inputs or productive factors that have international markets and those (such as labor) that have purely national markets. In the *middle products* approach of Sanyal and Jones (1982) this was a sharp distinction; all goods that were traded required a further input of local labor before appearing as final consumption goods. In this framework there is a natural tendency for non-tradeables (consumer goods) to be labor intensive compared to tradeables, since they add labor to tradeables. This invites the comparison with Wicksell's example wherein the final consumer good (wine) was naturally capital intensive because it added time to the capital stock (bottles in storage to be aged).

The entire literature that we have alluded to so far has typically been characterized by the assumption that markets are purely competitive. How does the concept of factor intensity fare when subjected to the kind of criticism emanating from "new trade theory" that markets are not perfectly competitive? After all, this has as a consequence that often commodity prices are no longer tied closely to costs – firms make profits. Therefore a detailed analysis of the composition of unit costs ceases to be that important.

Two comments on such a charge come to mind. First is the role of "shock absorber" played by profits over the course of the business cycle. In good times profits expand, thus moderating the increase in costs. In bad times profits contract or become losses, thus again serving to moderate downward pressure on unit costs. Thus compared with perfect competition, the induced effect on factor returns brought about by changes in commodity prices may be dampened if markets are imperfectly competitive. Second, consider the problem facing a multinational firm engaged in worldwide competition, albeit of an imperfectly competitive nature, when it has to decide on the country location of its productive activities. Even if such a firm makes profits, it is the cost comparisons between countries for various activities that become crucial, and with it a concern about differences in factor intensities between commodities and factor prices between countries.

Worth emphasizing as well is the treatment of factor intensities accorded by the early literature on monopolistic competition with increasing returns. Products were differentiated in the minds of consumers, but not in terms of production structures. Thus the factor intensity used in any (horizontally differentiated) variety was the same as in any other. Given this kind of assumption, it was difficult (of course) to link trade patterns for differentiated products to differences in factor endowments. Assuming that products were differentiated by quality instead opens up the possibility that higher quality varieties are produced by more capital-intensive techniques (Falvey and Kierzkowski, 1987), so that trade patterns can once again be linked to factor endowments.

Traditional trade theory has often focused on the impact of changes in commodity prices on the distribution of income. In technical terms this implies all the difficulties involved in finding regular patterns in the inverse of the matrix of input-output coefficients (assuming enough commodities are produced so that such a matrix is invertible). But such a process is not required in order to proceed from differences in wages and other factor prices to the consequences for unit costs. No matter how many commodities or factors are involved, a knowledge of distributive factor shares and factor allocation fractions yields information about the contribution of differences in factor prices to the array of costs of production. This highlights the importance of the concept of factor intensities to both "old" and "new" theories of international trade.

Notes

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1 The separate a_{ij} coefficients are solved from a pair of equations of change for each industry: Minimum costs entail $\Sigma_i \theta_{ij} \hat{a}_{ij} = 0$ and the definition of the elasticity of substitution

states that $\sigma_j \equiv (\hat{a}_{Kj} - \hat{a}_{Lj})/(\hat{w} - \hat{r})$. This yields the solutions: $\hat{a}_{Lj} = -\theta_{Kj}\sigma_j(\hat{w} - \hat{r})$ and $\hat{a}_{Kj} = \theta_{Lj}\sigma_j(\hat{w} - \hat{r})$ (see Jones, 1965).

2 For a disagreement on this statement see Samuelson (1992) and Jones (1992).

3 A more complete description of this kind of result, in which endowment changes lead to movements of skilled and unskilled wage rates in the same direction, is found in Jones and Marjit (2001).

4 Several results for general cases are available in the literature. Thus Ethier (1982) established a correlation result between the product of changes in factor prices and the technology matrix, on the one hand, and changes in commodity prices on the other. Dixit and Norman (1980) took a duality approach and suggested the second derivative of the revenue function (with respect to the price of commodity *j* and the endowment of factor *i*) as a more general definition of factor intensity. In cases of more factors than goods this mixes up intensity features with factor substitution elasticities. Neary (1985) introduced "as-if" input-output coefficients, but they may take on negative values in large-scale models that are aggregated.

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