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NEIGHBORHOOD PRODUCTION STRUCTURES WITH  
APPLICATIONS TO THE THEORY OF INTERNATIONAL TRADE

Ronald W. Jones

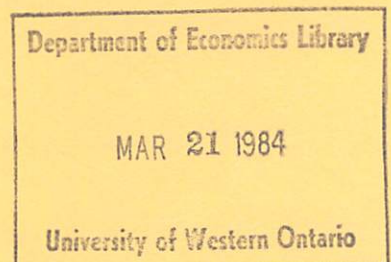
and

Henryk Kierzkowski

This paper contains preliminary findings from research still in progress and should not be quoted without prior approval of the author.

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**Neighborhood Production Structures with  
Applications to the Theory of International Trade**

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## Abstract

Imagine  $n$  industries located geographically on a circle with  $n$  factors of production interspersed evenly between pairs of industries. The neighborhood production structure allows each industry to employ only the two neighboring factors and each factor to have a choice of the two neighboring sectors. Multilateral concepts of factor intensity allow a general analysis of the effect on factor prices of changes in neighboring commodity prices. The model is applied to a two-country world in which two types of capital are internationally mobile but specific to world sector (X or Y) and labor is intersectorally mobile but trapped within each country. The key intensity relationships are intra-sectoral. If capital/labor comparisons across countries in the same industry are "consistent" with each other, factor price changes resemble those of the specific-factor model if prices rise in the world X-industry. But if one country boasts higher intra-industry capital intensity than the other in both sectors, real wages in both countries unambiguously rise if intensity differences are more disparate within the favored world X-industry. Other trade applications of the neighborhood production structure are described.

Neighborhood Production Structures with  
Applications to the Theory of International Trade\*

Ronald W. Jones

and

Henryk Kierzkowski

It is a common observation that general equilibrium models of production with many factors and commodities yield few unambiguous comparative statics results. The higher-dimensional version of the specific-factors model is an exception, with the stark contrast between  $n$  factors each tied to a separate production process and a single factor mobile among all activities supporting clear factor-price responses to changes in commodity prices. In the present paper we analyze a different kind of higher-dimensional structure, one in which no factor is specific to any single activity. The structure is inspired by a model in which geographic proximity is crucial: each productive process uses as inputs only those factors located in its immediate "neighborhood."

The paper first develops some general properties of the  $n$ -factor,  $n$ -commodity model with neighborhood productive structures. As in any model with matching numbers of factors and commodities, factor prices are uniquely related to commodity prices, independently of factor endowments (as long as  $n$  commodities are still produced). Furthermore, this relationship reflects the array of factor intensities, independently of the degree of substitutability between factors. We concentrate on the commodity price-factor price relationship (whose dual is the factor endowment-commodity output Rybczynski-

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type relationship), since the details of output responses to price changes depend in a more ambiguous manner on both factor intensities and factor substitutability.<sup>1</sup> Two branches of the general model are distinguished--the "cooperative" model, in which a single price rise in any sector jointly benefits the neighboring productive factors used as inputs to that sector, and the "non-cooperative" model, in which one factor gains and the other loses in the favored sector. A multilateral concept of factor intensity emerges as the crucial determinant of the winning factor in the favored sector. Further comparisons of factor intensity are developed viz., rankings within the two parts of the economy created when neighboring sectors share in a common price rise, the "favored" part comprising these neighboring sectors and the "fixed-price" part consisting of the rest of the economy.

In the succeeding section the results developed for the general model are shown to be applicable to smaller-scale models used in the theory of international trade. Of special interest is a two-country model of the world economy sufficiently open to allow not only free trade in commodities but also unimpeded international mobility of two types of capital, each type specific in its use to one of the two types of traded commodities produced by both countries. In such a world factor price changes depend upon the intra-industry factor intensity comparisons between countries rather than the traditional inter-industry intensity rankings between commodities within either country.

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<sup>1</sup> Detailed discussion of the interaction of factor intensities and factor substitutability in more general models of production is found in Jones and Easton (1983).

The final section of the paper offers some concluding remarks about the relationship between the model exhibiting the neighborhood production structure and the sector-specific model.

#### I. Neighborhood Production Structures: General Properties

In the  $n$ -sector version of the model there exist  $n$  distinct productive activities, each only employing two different factors of production. Symmetry is further reflected in the requirement that every productive factor has two alternative employment outlets. The schematic illustration in Figure 1 shows each producing sector,  $x_j$ , geographically located on a circle, with each making use of the two neighboring factors shown by the arcs connecting the  $x_j$ 's. Thus  $x_2$  employs factors  $V_2$  and  $V_3$  while factor  $V_1$  has two sectors in which it finds work:  $x_n$  and  $x_1$ . No productive factor is completely specific, but mobility is restricted for each factor to the two neighboring productive sectors. Thus whereas in the general  $n \times n$  model of production each factor is potentially employable in all  $n$  sectors, in the neighborhood production structure this mobility is limited to the two nearby sectors for each and every factor.

Suppose the price of commodity  $j$  rises. In a competitive market the return to at least one of the factors employed in  $x_j$  must rise, and perhaps both do. The model featuring a neighborhood production structure allows each of these outcomes. The "cooperative" result, wherein a price rise redounds to the benefit of both factors employed in the favored industry, is a feature of models in which the number of producing sectors,  $n$ , is odd, whereas non-cooperative outcomes characterize models in which  $n$  is even. (The  $2 \times 2$  Heckscher-Ohlin model is the simplest case--the Stolper-Samuelson feature of a

price rise leading to a real gain for one factor and loss for the other is standard for that case.) These results follow immediately from a phenomenon characteristic of both models of this type: the ripple effect for the factor returns in that part of the economy in which commodity prices have not changed.

Let the industry favored by the price rise be the last one, sector  $\underline{n}$ . If the return to the first factor,  $w_1$ , rises, the return to other factor employed in the constant-price first sector,  $w_2$ , must fall, leading to a balancing rise in  $w_3$  since  $p_2$  is assumed constant, and a fall in  $w_4$ , etc. In any competitive model in which some commodity prices are constant, those factors employed in the constant-price sectors which experience an increase in returns must, by the competitive profit conditions, force other factor returns to fall. In the neighborhood production structure these balancing forces result in ripples of factor-price increases and decreases for alternatively sequenced factors.<sup>2</sup> Thus, in the case in which only  $p_n$  rises, if  $w_1$  rises and  $\underline{n}$  is odd, so does  $w_n$ . Factors  $V_1$  and  $V_n$ , the pair used in the favored  $n^{\text{th}}$  sector, share cooperatively in the rise in  $p_n$ . But, should  $\underline{n}$  be an even number, an increase in  $w_1$  sends ripples throughout the rest of the economy consistent only with a fall in  $w_n$ . The increase in  $p_n$  cannot be shared cooperatively by the two factors employed in producing  $x_n$ . Of course this argument only states that  $w_1$  and  $w_n$ , the returns to the two factors employed by favored-sector  $\underline{n}$ , must move in opposite directions. Which of the two factors gains depends upon factor intensities.

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<sup>2</sup> By contrast, in the higher dimensional specific-factors model an increase in the return to the single mobile factor would push down the returns to all specific factors used in constant-price sectors.



A principal result to be established now is that if the number of productive sectors,  $\underline{n}$ , is even, an increase in  $p_j$  (alone) will serve to increase the return to factor  $j$ , (and reduce the return to factor  $j+1$ , the other factor employed in the  $j^{\text{th}}$  sector) if and only if commodity  $j$  is relatively intensive in its use of factor  $\underline{j}$ . But a multilateral concept of factor intensity is required, one that contains information on all sectors of the economy. To proceed formally, let  $\hat{w}$  represent the vector of relative changes in factor prices,  $\hat{p}$  the vector of relative changes in commodity prices, and  $\theta_{ij}$  the distributive share of the earnings of factor  $\underline{i}$  in sector  $\underline{j}$ . By the competitive profit conditions,

$$(1) \quad \begin{bmatrix} \theta_{11} & \theta_{21} & 0 & \dots & 0 \\ 0 & \theta_{22} & \theta_{32} & \dots & 0 \\ 0 & 0 & \theta_{33} & \dots & 0 \\ \vdots & & & & \vdots \\ \vdots & & & \theta_{n-1,n-1} & \theta_{n,n-1} \\ \theta_{1n} & 0 & 0 & \dots & 0 & \theta_{nn} \end{bmatrix} \hat{w} = \hat{p}$$

The determinant of coefficients,  $|\theta|$ , is shown in (2):

$$(2) \quad |\theta| = \prod_j \theta_{jj} - \prod_j \theta_{j+1,j} \text{ where } j+1 = 1 \text{ for } j=n.$$

Suppose only  $p_n$  rises. Then the solution for  $\hat{w}_n$  is shown in (3):

$$(3) \quad \hat{w}_n = \frac{1}{|\theta|} \prod_{j \neq n} \theta_{jj} \cdot \hat{p}_n$$

Therefore the sign of the determinant,  $|\theta|$ , dictates the fate of factor  $\underline{n}$  when the price of commodity  $\underline{n}$  rises when  $\underline{n}$  is even.<sup>3</sup>

<sup>3</sup> If  $\underline{n}$  is odd, the expression for  $|\theta|$  becomes  $(\prod_j \theta_{jj} + \prod_j \theta_{j+1,j})$  which must be positive.

The multilateral concept of factor intensity appropriate for models with neighborhood productive structures is that sector  $j$  uses factor  $j$  intensively in a multilateral sense if and only if  $|\theta|$  is positive. (Note what this entails: If sector  $j$  employs factor  $j$  intensively in this multilateral sense, then sector  $i$  employs factor  $i$  intensively, for all  $i$ . No two sectors can have a multilateral intensity in the same factor.) Consider the  $n^{\text{th}}$  sector, which uses factors  $V_n$  and  $V_1$ .  $V_n$  is also used to produce  $x_{n-1}$  and  $V_1$  to produce  $x_1$ . The economy can be considered to be aggregated into two parts: favored-sector  $n$  and the rest of the economy, and the latter also employs  $V_n$  and  $V_1$  (and all other  $V_j$  as well).  $|\theta|$  is positive if and only if

$$(4) \quad \frac{\theta_{nn}}{\theta_{ln}} > \frac{\theta_{n,n-1}}{\theta_{n-1,n-1}} \cdot \frac{\theta_{n-1,n-2}}{\theta_{n-2,n-2}} \cdots \frac{\theta_{21}}{\theta_{11}}$$

Each  $\theta_{ij}$  equals  $w_1 a_{ij} / p_j$ , so that the inequality in (4) can be rewritten as in (4'):

$$(4') \quad \frac{a_{nn}}{a_{ln}} > \frac{a_{n,n-1}}{a_{n-1,n-1}} \cdot \frac{a_{n-1,n-2}}{a_{n-2,n-2}} \cdots \frac{a_{21}}{a_{11}}$$

Both sides of this inequality have dimensionality factor  $n$  per unit of factor  $1$  and thus involve a comparison of sector  $n$ 's use of  $V_n$  and  $V_1$  relative to the rest of the economy's use of these two factors. The logic and interpretation of this argument are analogous to the problem of assigning commodities to countries according to a multilateral criterion for comparative advantage in a Ricardo-Graham model of trade.<sup>4</sup>

To pursue the idea of separating the economy into two parts (favored sector  $n$  where price has risen and sectors  $1$  through  $n-1$  where prices are constant), consider the competitive profit conditions of change in the constant-price sectors. These are shown by the first  $n-1$  equations in (1).

<sup>4</sup> See the discussion in Jones (1961).

The first of these can be solved for  $\hat{w}_1$  in terms of  $\hat{w}_2$ :

$$\hat{w}_1 = - \frac{\theta_{21}}{\theta_{11}} \hat{w}_2$$

The second can, in similar fashion, be solved for  $\hat{w}_2$  in terms of  $\hat{w}_3$  and, continuing this way, the  $(n-1)^{\text{st}}$  equation shows that:

$$\hat{w}_{n-1} = - \frac{\theta_{n,n-1}}{\theta_{n-1,n-1}} \hat{w}_n$$

Successive substitutions allow us to solve for  $\hat{w}_1$  in terms of  $\hat{w}_n$ :

$$\hat{w}_1 = (-1)^{n-1} \frac{\prod_{j \neq n} \theta_{j+1,j}}{\prod_{j \neq n} \theta_{jj}} \hat{w}_n$$

Now rewrite this expression together with that for sector  $\underline{n}$  (which has risen in price) as equation set (5):

$$(5) \quad \left( \prod_{j \neq n} \theta_{jj} \right) \hat{w}_1 + (-1)^n \left( \prod_{j \neq n} \theta_{j+1,j} \right) \hat{w}_n = 0$$

$$\theta_{1n} \hat{w}_1 + \theta_{nn} \hat{w}_n = \hat{p}_n$$

This aggregation of sectors 1 through  $(n-1)$  allows us to represent it as a part of the economy using factors  $V_1$  and  $V_n$  just as does sector  $\underline{n}$ . If  $\underline{n}$  is an odd number, the first equation in (5) would suggest a production process where factor  $\underline{n}$  is an output (since the coefficient of  $\hat{w}_n$  would be negative), but clearly an increase in  $p_n$  would, in cooperative fashion, raise both  $w_1$  and  $w_n$ . If  $\underline{n}$  is even, the typical two-by-two result is obtained wherein an increase in  $p_n$  raises, by a magnified amount, the return to the factor used intensively in that sector and lowers the return to the other factor. The concept of factor intensity relevant here, of course, is the sign of  $|\theta|$  in (2), which is the determinant of coefficients in (5).

### A. Neighboring Price Rises in Co-operative Models

For some purposes it is useful to investigate the impact on the factoral distribution of income when two neighboring sectors both share in a rise in price (of the same relative magnitude) while prices remain constant in the rest of the economy. We consider, first, the solution in the case of "cooperative" models, where  $\underline{n}$  is an odd number.

Let sectors  $\underline{n}$  and  $\underline{1}$  share a common price rise:  $\hat{p}_{\underline{n}} = \hat{p}_{\underline{1}} = \hat{p}$ . Factors in the economy can then be grouped into three categories: (a) A single factor,  $V_1$ , is "specific" to the two sectors which have experienced a price rise; (b) Two "edge" factors,  $V_{\underline{n}}$  and  $V_2$ , are used both in that part of the economy favored by the price rise ( $x_{\underline{n}}$  and  $x_1$ ) and in the rest of the economy; and (c) The remaining factors,  $V_3, \dots, V_{\underline{n}-1}$ , are used exclusively in sectors which have not experienced a price rise. For these factors, the ripple effect described earlier can be expected to hold: if  $w_3$  rises,  $w_4$  will fall, and so on, with  $w_{\underline{n}-1}$  falling (since  $\underline{n}$  is an odd number).

In the cooperative model the return to "specific" factor  $V_1$ , used in the two favored sectors, must rise.  $w_1$  would rise if either of the sectors employing the first factor were to experience a price rise, and perforce must rise if they both do. But not both "edge" factors,  $V_{\underline{n}}$  and  $V_2$ , can rise in price. Suppose  $w_2$  falls. Then, as just described, a ripple effect runs from  $w_3$  (which rises) through  $w_{\underline{n}-1}$  (which falls). Therefore  $w_{\underline{n}}$  must rise since  $p_{\underline{n}-1}$  is constant. The question remaining to be resolved when neighbors  $x_{\underline{n}}$  and  $x_1$  experience a price rise is whether "edge" factor 2 or the other edge factor,  $\underline{n}$ , will to some extent share in these gains. Once again factor intensities tell the story.

Formally, solve equation set (1) for  $\hat{w}_n$  when  $\hat{p}_n = \hat{p}_1 = \hat{p} > 0$ , to obtain

$$(6) \quad \frac{\hat{w}_n}{\hat{p}} = \frac{(\theta_{11} - \theta_{1n})}{|\theta|} \prod_{j \neq 1, n} \theta_{jj}.$$

The determinant,  $|\theta|$ , must be positive if  $n$  is an odd number, so that a strictly bilateral comparison of factor 1's distributive share in the two sectors in which it is employed determines the fate of "edge" factor  $V_n$  (as well as the other "edge" factor,  $V_2$ ).

The rationale underlying this result is straightforward. "Specific" factor 1 must experience an increase in its return. Therefore if  $\theta_{11}$  exceeds  $\theta_{1n}$ , less is available to pay factor 2 (the other factor used in the first industry) than to pay factor  $n$  (the other factor used in the  $n^{\text{th}}$  sector). Therefore  $\hat{w}_n$  would exceed  $\hat{w}_2$ .<sup>5</sup> But we have already established that one edge factor must rise in price and other other fall, so that  $w_n$  rises and  $w_2$  falls. Furthermore, since  $w_2$  falls,  $w_1$  must rise by a magnified amount (i.e.,  $\hat{w}_1 > \hat{p}$ ), which limits the rise in  $w_n$  (so that  $\hat{w}_n < \hat{p}$ ).

The pattern is thus clear. Should any two neighboring sectors be the only ones to share a common rise in price, the return to the factor shared by both must rise by a magnified amount. One of the edge factors experiences a less-than-proportionate rise in its return--the edge factor with a greater distributive share in the favored sectors of the economy--while the return to the other edge factor falls. Remaining factor returns exhibit the ripple phenomenon, alternatively rising and falling.

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<sup>5</sup> That is, if both  $\hat{p}_1$  and  $\hat{p}_n$  equal a common  $\hat{p}$ , and "edge" factor  $n$  is more intensively used (in  $x_n$ ) than is "edge" factor 2 (in  $x_1$ ),  $\hat{w}_n$  must lie "closer" to  $\hat{p}$  than does  $\hat{w}_2$ . This argument, central to subsequent results in non-cooperative models, is developed in more detail below.

There is a sense in which factor-price behavior in the cooperative model ( $\underline{n}$  odd) when two adjoining neighbors experience a common price rise resembles that of the non-cooperative model ( $\underline{n}$  even) when only one sector has a rise in price. Perhaps this result is to be expected in that joining the two neighbors into a Hicksian composite sector reduces the number of sectors from  $\underline{n}$  to  $\underline{n}-1$ . In each case one "edge" factor experiences a gain and the other a loss. But in the cooperative model only a bilateral concept of factor intensity is required to identify the winner, whereas in the non-cooperative model a multilateral concept of factor intensity is needed. We turn, now, to the non-cooperative model when two adjoining sectors experience a common price rise.

#### B. Neighboring Price Rises in Non-cooperative Models

We follow the same procedure in letting  $p_{\underline{n}}$  and  $p_{\underline{1}}$  rise by an identical proportional amount ( $\hat{p}$ ), with all other commodity prices constant. The ripple effect is once again present, but with  $\underline{n}$  an even number we can immediately conclude that both "edge" factors,  $\underline{n}$  and  $\underline{2}$  must rise or fall together. That is, if  $w_{\underline{2}}$  rises,  $w_{\underline{3}}$  must fall, and succeeding even-numbered factor prices rise, including  $w_{\underline{n}}$ .

With the qualitative similarity in the experience of the two "edge" factors established, it becomes tempting to ask the circumstances under which factor price responses to neighboring price rises in non-cooperative models resemble those of the specific-factor,  $(n+1) \times n$  model. In particular, with  $p_{\underline{n}}$  and  $p_{\underline{1}}$  rising, can the return to factor 1, that factor used exclusively (or "specifically") in the favored sectors of the economy, rise relatively more than  $p_{\underline{n}}$  and  $p_{\underline{1}}$ , the return to "edge" factors  $\underline{n}$  and  $\underline{2}$  behave like "mobile"

factors (these are used partly in the favored sectors and partly in the rest of the economy) and rise, but by less than  $p_n$  and  $p_1$ , with some aggregate measure of the returns to all other factors falling? (These other factors are "specific" to that part of the economy not experiencing a price rise; of course the ripple effect precludes all these factor prices from falling).

Since equation set (1) allows ready formal solutions for factor price changes we exhibit, first, the solution for the change in the "specific" factor return,  $\hat{w}_1$ ;

$$(7) \quad \frac{\hat{w}_1}{\hat{p}} = \frac{\prod_{i \neq 1} \theta_{ii} - \prod_{i \neq 1} \theta_{i,i-1}}{|\theta|}$$

Even if this is positive, of additional interest is the possible magnified effect of increases in  $p_1$  and  $p_n$  on  $w_1$  as can be read from solution (7') for  $(\hat{w}_1 - \hat{p})$ :

$$(7') \quad \frac{\hat{w}_1 - \hat{p}}{\hat{p}} = \frac{\prod_{j \neq 1, n} \theta_{jj} - \prod_{j \neq 1, n} \theta_{j+1, j}}{|\theta|}$$

Secondly, consider the fate of "edge" factors 2 and n:

$$(8) \quad \frac{\hat{w}_2}{\hat{p}} = \frac{(\theta_{11} - \theta_{1n})}{|\theta|} \prod_{j \neq 1, n} \theta_{j+1, j}$$

$$(9) \quad \frac{\hat{w}_n}{\hat{p}} = \frac{(\theta_{11} - \theta_{1n})}{|\theta|} \prod_{j \neq 1, n} \theta_{jj}$$

Equations (7'), (8), and (9) reveal that not only is the sign of  $|\theta|$  important in determining the ranking of factor prices, so also is the comparison between  $\prod_{j \neq 1, n} \theta_{jj}$  and  $\prod_{j \neq 1, n} \theta_{j+1, j}$ , on the one hand, and  $\theta_{11}$  and  $\theta_{1n}$ , on the other. The sign of  $|\theta|$  has already been associated with a multilateral factor-intensity ranking. The other two comparisons are also

directly associated with factor-intensity rankings, those for "edge" factors  $\underline{2}$  and  $\underline{n}$  in the two partitions of the economy: the "favored" part (sectors  $\underline{1}$  and  $\underline{n}$ ), and the "fixed-price" part (consisting of sectors  $\underline{2}$  through  $\underline{n-1}$ ).

Consider, first, the significance of the factor intensity ranking within the favored part of the economy. In each of sectors  $\underline{1}$  and  $\underline{n}$  the commodity price rise (common to both sectors) is a positive convex weighting of the change in "specific" factor return,  $\hat{w}_1$  (common to both sectors) and the other factor return associated with that sector ( $\hat{w}_2$  in sector 1 and  $\hat{w}_n$  in sector  $\underline{n}$ ):

$$\theta_{11} \hat{w}_1 + \theta_{21} \hat{w}_2 = \hat{p}$$

(10)

$$\theta_{1n} \hat{w}_1 + \theta_{nn} \hat{w}_n = \hat{p}$$

Without further knowledge of the rest of the economy it is impossible to tell from the conditions in the favored part of the economy alone whether  $\hat{w}_1$  exceeds  $\hat{p}$  (with "edge"  $\hat{w}_2$  and  $\hat{w}_n$  falling short of  $\hat{p}$ ) or whether positions are reversed so that both  $\hat{w}_2$  and  $\hat{w}_n$  exceed  $\hat{p}$  (with  $\hat{w}_1$  less than  $\hat{p}$ ). Nonetheless, the factor-intensity ranking within the favored part of the economy does indicate which of  $\hat{w}_2$  and  $\hat{w}_n$  lies closer to  $\hat{p}$ . Thus if sector  $\underline{1}$  uses factor 1 intensively in a bilateral comparison with sector  $\underline{n}$  ( $\theta_{11} > \theta_{1n}$ ), the weight attached to  $\hat{w}_n$  in (10),  $\theta_{nn}$ , must be greater than the weight attached to the other "edge" factor,  $\hat{w}_2$  ( $\theta_{21}$ ), and  $\hat{w}_n$  must, as a consequence, lie closer to  $\hat{p}$  than does  $\hat{w}_2$ . That is, this bilateral ranking within the favored part of the economy insures that either  $\hat{w}_2 > \hat{w}_n > \hat{p} > \hat{w}_1$  or that  $\hat{w}_1 > \hat{p} > \hat{w}_n > \hat{w}_2$ .

Somewhat the same procedure can be followed in the fixed-price part of the economy, with one exception. With  $\underline{n}$  large, more than two sectors comprise



this subset of the economy, so that a bilateral factor intensity ranking between just two sectors is no longer appropriate. Instead, a kind of "reduced" multilateral ranking is required, involving a comparison between  $\prod_{jj} \theta_{jj}$  over all industries in the fixed-price part ( $j \neq 1, n$ ), on the one hand, and  $\prod_{j \neq 1, n} \theta_{j+1, j}$ , on the other. To see this, follow the procedure used in obtaining equation (5), which revealed the ripple effect connecting the returns to the two edge factors. Substitution through the competitive profit conditions for sectors 2 through  $n-1$  reveals that

$$(11) \quad \hat{w}_2 = (-1)^{n-2} \frac{\prod_{j \neq 1, n} \theta_{j+1, j}}{\prod_{j \neq 1, n} \theta_{jj}} \cdot \hat{w}_n.$$

In cooperative models with an even number of sectors (or, more particularly, an even number of sectors in the fixed-price part of the economy), edge returns rise or fall together. What is crucial is which change in factor return lies closer to zero (the value of the commodity price change in the fixed-price part of the economy). By analogy with our remarks for a bilateral ranking in the favored part of the economy we would like to define edge factor 2 as used intensively in a multilateral sense in the fixed-price part of the economy (which includes sector 2) as compared with edge factor n (where sector n is not included in the fixed-price part of the economy) if  $\prod_{j \neq 1, n} \theta_{jj}$  exceeds  $\prod_{j \neq 1, n} \theta_{j+1, j}$ . As (11) reveals, if in this sense the fixed-price part of the economy uses factor 2 intensively,  $\hat{w}_2$  lies closer to the commodity price change (zero) than does  $\hat{w}_n$ .

Three factor intensity rankings have been considered: (i) The overall multilateral ranking in which we assume factors are numbered so that  $\prod_{jj} \theta_{jj}$  exceeds  $\prod_{j+1, j} \theta_{j+1, j}$  and thus factor j is used intensively in industry j; (ii) The bilateral comparison in the part of the economy consisting of neighboring

sectors  $\underline{1}$  and  $\underline{n}$  when they are the only sectors favored by a (similar) price rise; and (iii) The multilateral criterion in the fixed-price part of the economy, involving a comparison of reduced products  $\prod_{j \neq 1, n} \theta_{jj}$  and  $\prod_{j \neq 1, n} \theta_{j+1, j}$ . We now define these latter two rankings as "consistent" with the assumption that overall  $\prod \theta_{jj}$  exceeds  $\prod \theta_{j+1, j}$  if, for the favored part,  $\theta_{11}$  exceeds  $\theta_{1n}$  and, for the fixed-price part,  $\prod_{j \neq 1, n} \theta_{jj}$  exceeds  $\prod_{j \neq 1, n} \theta_{j+1, j}$ . More generally, the multilateral intensity ranking uniquely associates each factor with one of its neighboring sectors. When the economy is subdivided into two parts "consistency" follows if each edge factor is bilaterally intensive in the subdivision containing the sector with which it has the multilateral association.

Referring to solutions (7'), (8), and (9) it is clear that if intensity rankings in both sub-divisions of the economy are consistent with the overall ranking, the factor price response to a neighboring commodity price rise in sectors 1 and n is similar to that found in specific-factor models:<sup>6</sup>

$$(12) \quad \hat{w}_1 > \hat{p} > \hat{w}_n > \hat{w}_2 > 0 > \sum_{i=3}^{n-1} \theta^i \hat{w}_i.$$

The logic behind this ranking can perhaps be more readily revealed by noting that the only way  $\hat{w}_n$  can lie closer than  $\hat{w}_2$  to  $\hat{p}$ , (which it must do if  $\underline{n}$  is used bilaterally more intensively in the favored part than is  $\underline{2}$ ) and, simultaneously,  $\hat{w}_2$  lie closer than  $\hat{w}_n$  to zero (which it must do if  $\underline{2}$  is used more intensively in our "reduced" multilateral sense in the fixed-price part

<sup>6</sup> In the last term,  $\theta^i$  refers to the share of factor  $\underline{i}$  in the national income. That this weighted sum for changes in prices of factors used exclusively in the fixed-price part of the economy must be negative can be simply proved by considering the competitive profit conditions of change in sectors  $\underline{2}$  through  $\underline{n-1}$  (see equation (1)). Multiply each by the industry share of output  $\underline{j}$  in the national income,  $\theta_j$ , and add to obtain:

$$\{\theta_2 \theta_{22} \hat{w}_2 + \theta_{n-1} \theta_{n, n-1} \hat{w}_n\} + \left\{ \sum_{i=3}^{n-1} \theta^i \hat{w}_i \right\} = 0. \quad \text{Since with consistent rankings } \hat{w}_2 \text{ and } \hat{w}_n \text{ are positive, the last inequality in (12) must follow.}$$

than is  $n$ ) is for both to lie trapped between the two commodity price changes. The other factor price changes follow accordingly, since each commodity price change is flanked by factor price changes.

As we have used the term, there is no reason why these various factor-intensity concepts must be "consistent." We delay our analysis of the significance of possible alternatives to our discussion of a world model of internationally mobile, sector-specific capital--the case where  $n=4$ . First we turn to possible international trade interpretations of the simple cooperative model where  $n=3$ .

## II. Applications to International Trade Theory

The most straightforward application to trade theory involves a small open economy with more than two productive sectors and matching number of factors facing world-determined changes in its terms of trade. In section A we wish to compare the results obtained in such a case with those flowing from a more familiar class of models featuring specific factors and a single mobile factor. In section B we focus on two large open economies joined by commodity trade and international factor mobility. Finally, section C considers alternative interpretations of the case  $n=4$ .

### A. The Case of Three Factors and Three Goods

Imagine an economy containing an "enclave" producing two traded commodities,  $x_1$  and  $x_2$ . Factor  $V_2$  is used in both sectors, while factor  $V_1$  is used just to produce the first commodity and factor  $V_3$  is employed in the second sector, but not the first. Figure 2 illustrates this  $3 \times 2$  model. Now suppose the price of good 1 increases, and that of good 2 remains unchanged.

If there is no change in the overall availability of productive factors to this enclave, such a price change leads to:

$$(13) \quad \hat{w}_1 > \hat{p}_1 > \hat{w}_2 > 0 \quad (= \hat{p}_2) > \hat{w}_3 .$$

The return to "mobile" factor 2 is trapped between the price changes, which are themselves bounded by the returns to the "specific" factors.

Although the ranking (13) of factor price responses to this rise in the price of one commodity is firmly rooted in the intuitive logic of the 3x2 model, it is predicated on the absence of any changes in factor "endowments" to this enclave that may be induced by the price change. Such a condition would be violated, for example, if "mobile" factor 2 were (at least in part) supplied from a foreign source (e.g., foreign capital). Furthermore the "endowment" bundle  $(V_1, V_2, V_3)$  would no longer be constant if factors  $V_1$  and  $V_3$ , the "specific" factors in this example, actually possess alternative employment opportunities outside the "enclave" in which commodities 1 and 2 are produced. Such a possibility could be shown in Figure 2 if a third productive activity,  $x_3$ , were to be added, using factors  $V_1$  and  $V_3$ . Such a change converts the 3x2 structure of Figure 2 into a 3x3 neighborhood production structure.

Suppose  $V_1$  and  $V_3$  do have this alternative outlet and that  $x_3$ 's price is kept constant (say  $x_3$  is also a traded good). Then the increase in  $p_1$  raises, in cooperative fashion, the returns to both factors employed in the first sector, and must obviously thus push down the returns to the remaining third factor. The returns ranking shown in (13) becomes a necessity (despite endowment changes) if, in the neighborhood analogue, a factor intensity

ranking is imposed that guarantees that  $\hat{w}_1$  rises relative to  $\hat{w}_2$ . Factors 1 and 2 are both used in the fixed-price part of the economy (comprising sectors 2 and 3). Following our earlier remarks on the significance of bilateral intensity rankings,  $\hat{w}_2$  must lie closer to zero than does  $\hat{w}_1$  if factor 2's distributive share in that sector ( $\theta_{22}$ ) exceeds factor 1's share ( $\theta_{13}$ ).

This example serves to highlight a particular role for the model with a neighborhood production structure. An economy may consist in part of an "enclave" producing two traded commodities with the use of a factor common to both (and perhaps partially supplied from abroad) and two other factors each used in one sector but not the other. Thus the "enclave" represents a 3x2 specific-factors production structure in which, if factor supplies available to the enclave were to remain unaltered, a relative commodity price change would have intuitively appealing repercussions on factor prices: that (local) factor used only in the favored sector would experience a rise in its real return, the (local) factor used only in the other (non-favored) sector would suffer a real loss, while that factor used in both (and perhaps supplied in part from abroad) would find its return rising in terms of one commodity and falling in terms of the other. But suppose the two (local) factors each used specifically in a different industry in the enclave also are used jointly in a separate part of the economy to produce a third commodity. Then factor supplies to the enclave cannot be expected to remain constant if the enclave experiences commodity price changes, and these induced "endowment" changes would feed back to alter factor returns even further. Nonetheless, the familiar ranking provided by the 3x2 model with fixed factor supplies will emerge if the third commodity price is kept constant and, of the two local factors used in the enclave, the one used in the favored sector is

unintensively used in the non-favored part of the economy. Factor price changes associated with a model with more factors than commodities may be replicated in a model with the same number of each. And the latter model frees up factor returns from any further direct influence of factor endowments.

B. International Factor Mobility and the Case of  $n=4$ .

The specific-factors model has been used extensively in the theory of international trade, especially in a small-country setting in which commodity prices in two sectors are determined in the rest of the world, the nation's labor force is mobile between the two sectors, and two types of capital are specific in their use. Figure 3 provides a schematic illustration of a two-country world in which products from two industries are freely traded. Commodities  $\underline{X}$  and  $\underline{X}^*$  need not be identical, but they belong to the same X-industry and are characterized by the use in production of the same type of capital. Similarly, although the home country's Y-product may be differentiated by consumers from the foreign country's  $\underline{Y}^*$ , these two products are each produced by combining labor with a specific Y-type of capital. If, as in Figure 3, no factor is internationally mobile, a shift in world taste patterns away from products of the world's Y-industry towards X-type products has a readily-identified impact on factor prices: in each country the return to type-X capital unambiguously rises, that of type-Y capital falls, while wage rates in each country rise relatively less than the price of  $\underline{X}$  but improve in terms of  $\underline{Y}$ .

The possible international mobility of capital alters this scenario. Of particular interest here is the case in which both types of sector-specific

capital are internationally mobile.<sup>7</sup> The schematic representation in Figure 4 suggests that a trading world in which national labor forces are mobile within countries but immobile between, whereas capital is specific in its occupational use but footloose in world markets, provides a special example of a neighborhood production structure for  $n=4$ . Among the four producing sectors two types of commodities are distinguished: a world X-sector comprises products  $\underline{X}$  and  $\underline{X}^*$  while each country produces as well a product in the world Y-industry. World demands are such as to support an initial equilibrium in which all four products are produced.<sup>8</sup> As before, suppose tastes shift towards products of the world's X-industry. In particular, consider an equi-proportionate rise in world prices  $p_x$  and  $p_x^*$  (equal to  $\hat{p}_x$ ), at the expense of constant prices throughout the world's Y-industry.

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<sup>7</sup> Some analyses, e.g., Brecher and Findlay (1983) and Jones and Dei (1983), consider the case in which one type of capital is internationally mobile. The effect in such a model of a rise in the world's relative price of commodity  $\underline{X}$  is similar to that just described when there is no international factor mobility. Both types of capital are internationally mobile in Caves (1971) and Jones, Neary, and Ruane (1983), models concerned with the phenomenon of cross-hauling of capital. In the latter paper one of the commodities is treated as non-tradeable so as to avoid the possible necessity of specialization in one traded good for a small country which accepts commodity prices and the rate of return to internationally-mobile capital as given from the rest of the world. In our present treatment this is not necessary since rates of return are endogenously determined and consumer tastes allow product differentiation within each industry, although each country uses the same industry-specific capital input.

<sup>8</sup> The world transformation surface in the space of the four commodities is strictly bowed out if, as we assume, techniques required to produce goods are different ( $|\theta|$  different from zero). Therefore there is some set of relative commodity prices that will support positive production of all four commodities. If this set includes values for which  $p_x = p_x^*$  and  $p_y = p_y^*$ , consumers might view products  $\underline{X}$  and  $\underline{X}^*$  in the two countries as identical (and similarly for  $\underline{Y}$  and  $\underline{Y}^*$ ). We adopt a more general stance:  $\underline{X}$  and  $\underline{X}^*$  can be members of the same industry, both requiring the same  $K_X^W$ , but differentiated in the eyes of the world's consumers, so that indifference surfaces may be strictly bowed in. Our assumption in any case is that initial equilibrium is at a price vector supporting positive production of all four commodities.

The simplification which the reduction of  $n$  to 4 introduces into our earlier analysis is that the "favored" and "fixed-price" parts of the economy each symmetrically comprise only two sectors. When the world prices of commodities  $X$  and  $X^*$  rise, the "favored" part of the world economy consists of sector  $X$  at home and sector  $X^*$  abroad. The factor "specific" to this part is  $K_X^W$ , the world's supply of capital used only in the world's X-industry. The two "edge" factors are the labor forces in each country,  $L$  and  $L^*$ . In the fixed-price part of the world economy, consisting of sectors  $Y$  at home and  $Y^*$  abroad, the "specific" factor is Y-type capital,  $K_Y^W$ . In the general case with many sectors ( $j = 2, \dots, n-1$ ) comprising the fixed-price part of the economy, a "reduced" multilateral factor intensity ranking between edge factors involves the comparison of  $\prod_{j \neq 1, n} \theta_{jj}$  with  $\prod_{j \neq 1, n} \theta_{j+1, j}$  (see equation (11)). In our present case this reduces to a comparison between  $\theta_{LY} \theta_{KY}^*$  and  $\theta_{LY}^* \theta_{KY}$ , a bilateral comparison of capital and labor shares in home and foreign Y-industries. Similarly, in the favored X-part of the world economy, the crucial bilateral intensity comparison is intra-industry (and inter-national), that between  $\theta_{KX}$  and  $\theta_{KX}^*$ .<sup>9</sup>

Our preceding remarks concerning Figure 3's illustration of trade between two 3x2 economies with internationally immobile capitals has suggested that when world price rises in the  $X$ -industry, it might be reasonable to suppose that the return to type-X capital rises by more than the price of  $X$ , the return to type-Y capital falls, while both national wage rate changes lie

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<sup>9</sup> Comparing value shares for the same industry between countries (say  $\theta_{KX}$  and  $\theta_{KX}^*$ ) is not the same as comparing physical capital/labor ratios, since wage rates are presumably different. For example, if the home country has a lower level of techniques, expressing itself in a lower wage rate, the home country may have its X-sector capital-intensive compared with  $X^*$  (in the sense of  $\theta_{KX}$  greater than  $\theta_{KX}^*$ ) but nonetheless employ a lower capital/labor ratio. Unless otherwise indicated, we always refer to factor intensities in the value sense imparted by distributive shares.



trapped between the two price changes. Indeed, our general discussion of neighboring price rises in a model of even  $n$  has provided the conditions sufficient to guarantee this result in the present case in which both types of capital are internationally mobile (Figure 4): the intensity rankings in each part of the economy be consistent with the overall multilateral factor intensity ranking.

In the general case we arbitrarily assumed that in a multilateral sense each industry used intensively that factor with the same number, so that  $\Pi_{jj}^{\theta}$  exceeds  $\Pi_{j+1,j}^{\theta}$ . The comparison of Figures 1 and 4 shows that such an assumption in our present interpretation with  $n=4$  implies that<sup>10</sup>

$$(14) \quad \theta_{KX}^{\theta} \theta_{LY}^{\theta*} \theta_{KY}^{\theta*} \theta_{LX}^{\theta*} > \theta_{LX}^{\theta} \theta_{KY}^{\theta*} \theta_{LY}^{\theta*} \theta_{KX}^{\theta*} .$$

This implies that in the neighborhood production structure there must exist the factor-intensity reversal phenomenon for multilateral rankings. If the home X-sector is (multilaterally) capital intensive, the foreign X\*-sector is (multilaterally) labor intensive. Both  $X$  and  $X^*$  share a common pool of capital, and they cannot both be intensive (multilaterally) in its use. Similarly, equation (14) states that the Y-sector at home is (multilaterally) labor intensive, but abroad  $Y^*$  is capital intensive.

"Consistency" for the experiment in which the prices of both X-sectors alone rise in unison requires that if (14) reflects the multilateral ranking, it is also the case that

<sup>10</sup> This comparison is equivalent to one among physical capital/labor ratios:  $\frac{k_x}{k_y} > \frac{k_x^*}{k_y^*}$ . But with reference to the preceding footnote, the ranking

$k_x > k_x^*$  need not imply that  $\frac{\theta_{KX}}{\theta_{LX}}$  exceeds  $\frac{\theta_{KX}^*}{\theta_{LX}^*}$  since  $w$  differ between

countries. Similarly, a comparison of  $k_x$  with  $k_y$  within a single country need not correspond to the share comparison since each sector uses a different kind of capital. Recall that in the neighborhood production structure two sectors jointly employ at most a single factor.

$$(15) \quad \theta_{KX} \theta_{LX}^* > \theta_{LX} \theta_{KX}^* \text{ and } \theta_{LY} \theta_{KY}^* > \theta_{KY} \theta_{LY}^*$$

or, more briefly, that  $\theta_{KX}$  exceeds  $\theta_{KX}^*$  and  $\theta_{KY}^*$  exceeds  $\theta_{KY}$ . Indeed, one could start with the separate bilateral rankings: consistency requires that neither country have both its sectors more capital-intensive than the other country in a bilateral sense. If the X-industry at home is (in a bilateral value sense) more capital intensive than its counterpart abroad and the Y-industry at home less capital intensive than is  $Y^*$  abroad, as portrayed in (15), the ranking shown in (12) for the general case of such consistency reduces to (16):

$$(16) \quad \hat{r}_x > \hat{p}_x > \hat{w}^* > \hat{w} > 0 (= \hat{p}_y) > \hat{r}_y$$

This is the ranking associated with the specific-factors model with the extra detail provided by the ordering of national wage rate changes, both trapped within the bounds set by commodity-price changes. Ranking (16) shows that  $\hat{w}^*$  lies closer to  $\hat{p}_x$  than does  $\hat{w}$  (reflecting  $X^*$ 's intra-industry labor-intensity ranking vis-a-vis  $X$  in (15)) while, at the same time,  $\hat{w}$  lies closer to  $\hat{p}_y$  (equal to zero) (reflecting  $Y$ 's intra-industry labor-intensity vis-a-vis  $Y^*$  in (15)).

Although this ranking has intuitive appeal in connection with the specific-factors model, it is not a necessary outcome, and will be violated if one country's capital share exceeds the other's sector by sector. To pursue the analysis, note that both wage rate changes either lie trapped between the price changes or they both lie outside, since within each disaggregated part of the world economy the changes in both wage rates must lie on opposite sides of the commodity price change than does the change in the common return to

that type of internationally-mobile capital. Therefore it is useful to concentrate on the behavior of wage rates, where national labor forces are the "edge" factors in this case.

The procedure we now follow is familiar from our general treatment. Favored world X-production consists of home and foreign production, and the pair of competitive profit conditions in these sectors provides a relationship between "edge" returns  $\hat{w}$  and  $\hat{w}^*$ :<sup>11</sup>

$$(17) \quad (\theta_{KX}\theta_{LX}^*)\hat{w}^* - (\theta_{LX}\theta_{KX}^*)\hat{w} = (\theta_{KX} - \theta_{KX}^*)\hat{p}_X.$$

Similarly, in the fixed-price Y-part of the world economy,<sup>12</sup>

$$(18) \quad -(\theta_{KY}\theta_{LY}^*)\hat{w}^* + (\theta_{LY}\theta_{KY}^*)\hat{w} = 0$$

Figure 5, showing these relationships between wage changes, is drawn under the twin assumptions both that the multilateral ranking in (14) holds (whereby  $\underline{X}$  is capital intensive and  $\underline{X}^*$  labor intensive), as well as the consistent pair of bilateral rankings provided by (15). If there were to be no price change in the X-sectors of the world economy, the returns to national wage rates would be restricted to the  $\underline{XX}^*$  locus. That is, any increase in home  $\underline{w}$  would drive down the world's return to type-X capital, and thus raise foreign  $\underline{w}^*$ . That this line is flatter than the 45o line reflects the assumption that in a bilateral intra-X-industry comparison  $\underline{X}^*$  is labor intensive, requiring  $\hat{w}^*$  to lie closer to the price change (zero along  $\underline{XX}^*$ ) than does  $\hat{w}$ . Similarly the  $\underline{YY}^*$  locus, drawn for a constant price of  $\underline{Y}$ , shows  $\underline{w}$  and  $\underline{w}^*$  moving up or down

<sup>11</sup> The general competitive profit conditions of change in the favored sector are shown in (10). In the present case translation requires factor 1 to be type-X capital, factor 2 to be home labor, and factor  $\underline{n}$  to be foreign labor. Similarly, commodity 1 is the home X-sector and commodity  $\underline{n}$  the foreign  $\underline{X}^*$ -sector. Compare Figures 1 and 4.

<sup>12</sup> This corresponds to equation (11) in the general case.

together. Since we are assuming  $\underline{Y}$  to be bilaterally labor-intensive compared to  $Y^*$ , this line must be steeper than the 45o line so that  $\hat{w}$  lies closer to  $Y$ 's price change (zero) than does  $\hat{w}^*$ . The relationship of each locus to the 45o line thus reflects the bilateral rankings in (15), while the fact that  $YY^*$  is drawn steeper than  $XX^*$  is reflective of the multilateral ranking in (14).

An increase in the world price of  $\underline{X}$  shifts the  $XX^*$  locus upwards to  $(XX^*)'$ ; equation (17) confirms this result if the home country's X-sector is bilaterally capital-intensive relative to that abroad, as assumed. (This intensity condition thus serves double duty: it implies that  $XX^*$  is flatter than the 45o line and that an increase in  $p_x$  shifts the locus upwards). The amount of the shift,  $(\theta_{KX} - \theta_{KX}^*)\hat{p}$ , is smaller than the price rise. The latter,  $\hat{p}$ , is shown by the vertical distance to point  $\underline{B}$  where  $(XX^*)'$  intersects the 45o line; if  $\hat{w}$  and  $\hat{w}^*$  are equal at a point ( $\underline{B}$ ) along  $(XX^*)'$ , they must each equal  $\hat{p}$ . The position of point  $\underline{A}$ , where the  $\underline{X}'$  and  $\underline{Y}$  loci intersect, confirms the specific-factors type of result shown in ranking (16) whereby both wage rates rise, but not by as much as the world price of  $\underline{X}$ , as well as the intra-industry intensity comparisons whereby  $\hat{w}^*$  exceeds  $\hat{w}$ .

Suppose, now, that the multilateral ranking shown by (14) remains valid, but that the difference between the intensities with which the home and foreign Y-sectors use labor and capital starts to diminish. The  $YY^*$  locus in Figure 5 would be shown rotated clockwise (around the origin) from its original position, so that as  $p_x$  rises the equilibrium changes in wage rates move from  $\underline{A}$  to  $\underline{C}$ . Factor intensity rankings are still "consistent," supporting again the rankings of returns shown in (16), but both  $\hat{w}$  and  $\hat{w}^*$  move closer to the price change in the X-sector,  $\hat{p}$ . Should home and foreign factor

intensity differences in the Y-industry completely vanish (leading to a  $YY^*$  schedule co-existent with the 45° line and an intersection with  $(XX^*)'$  at  $B$ ), both wage rates rise by the same relative amount as does the world price of commodity  $X$ . Identical value intensities within the world's Y-industry require that any wage change in one country be matched exactly by a comparable change abroad. With intra-industry factor intensities still assumed to differ in the X-part of the world economy, wage rate changes cannot be equal unless they both equal the change in the rate of return to X-type capital (and thus the price of  $X$ ).

This type of argument can now easily be extended to show how "inconsistent" intensity rankings must cause national labor forces to become "extreme" in the older Heckscher-Ohlin sense of reflecting an unambiguous improvement (or worsening) of real wages as a consequence of a price change. Suppose the home country's  $Y$ -sector now becomes more capital-intensive than a  $Y^*$  abroad, but with the difference less pronounced than in the world's X-industry. That is, in Figure 5 the  $YY^*$  locus is now flatter than the 45° line (but still steeper than the  $XX^*$  locus). Intersection is at a point such as  $D$ . The increase in the world price of  $X$  has raised both countries' wage rates by a more than proportional amount. With each foreign sector bilaterally more labor-intensive than its home counterpart,  $\hat{w}^*$  must lie closer both to zero and to  $\hat{p}$  than does  $\hat{w}$ , and thus must now fall short of  $\hat{w}$ . The return to the world's type of capital used exclusively in the favored X-part of the world economy cannot rise by as much as the price of  $X$ . Indeed, the return to X-type capital may actually fall.<sup>13</sup>

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<sup>13</sup> Equation (7) for the general case suggests the criterion for an actual fall in  $r_x$ : inequality (14) gets reversed when  $\theta_{KX}$  is deleted from the left-hand side and  $\theta_{KX}^*$  (smaller than  $\theta_{KX}$  by assumption) from the right. In extreme cases it appears that  $r_x$  may even fall by more than  $r_y$ .

The major results for this interpretation of the neighborhood model for  $n=4$  can now be brought together. When the prices of  $X$ -type goods rise throughout the world, the effect on returns to internationally-mobile but sector-specific capital and occupationally-mobile but country-specific labor depends crucially on the "consistency" of the bilateral intra-industry intensity rankings. The neighborhood production structure requires a multilateral factor-intensity reversal between countries: on a multilateral basis if  $X$  is capital intensive,  $X^*$  must be labor intensive (and  $Y$  must be labor intensive and  $Y^*$  capital intensive). We have defined "consistency" as the situation in which each intra-industry ranking conforms with the multilateral ranking, implying that each country possesses a sector which is bilaterally capital intensive relative to its counterpart in the other country. In such a case a rise in the world price of type  $X$  products leads to results familiar from specific-factor models:  $X$ -type capital unambiguously gains and  $Y$ -type capital loses, while each country's wage rate is trapped between the price changes. However, one country's wage will rise by more than the other, and the winner in this international wage comparison is the country in which the favored  $X$ -industry is labor intensive.

Lack of "consistency" in the neighborhood model is possible. It is associated with a situation in which one country has an intra-industry dominance in capital's distributive share in both sectors. In such a case relative price changes lead to unambiguous gains or losses to both countries' labor forces, a situation reminiscent of 2x2 Heckscher-Ohlin models. The key question centers on a comparison of the ratio of capital/labor shares in one industry and the other. If the favored industry has the larger intra-industry intensity spread (so that its bilateral ranking corresponds to the

multilateral factor intensity ranking), real wages in both countries unambiguously rise.<sup>14</sup> This rise is especially pronounced in the country which uses labor relatively unintensively in the favored sector.<sup>15</sup>

To stress the point that factor returns in this model are guided by world intra-industry intensity comparisons instead of the more typical intra-country comparisons of intensities between commodities in different industries, note that in the example shown in Figure 5 in which the YY\* schedule goes from the origin through point D it is possible for the X-sector to exhibit a higher capital intensity than the Y-sector in each country. For example, suppose

$$\frac{\theta_{KX}}{\theta_{LX}} > \frac{\theta_{KY}}{\theta_{LY}} > \frac{\theta_{KX}^*}{\theta_{LX}^*} > \frac{\theta_{KY}^*}{\theta_{LY}^*},$$

with, nonetheless, criterion (14) satisfied. Then despite the relative labor-intensity in each country of the industry (Y) which has suffered a relative decline in price, real wages in both countries unambiguously rise. The two crucial strands in the argument are: (i) the same country has a higher intra-industry capital share in each sector--this leads to unambiguous real wage changes, and (ii) the industry favored by the price rise exhibits a wider spread in techniques between countries than does the other industry--this requires wages more closely to approximate the price that has risen. Nowhere in the argument is appeal made to intra-country comparisons of techniques.

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<sup>14</sup> As the analysis in Figure 5 suggests, as the spread in the world Y-industry becomes smaller, for given spread in the world X-industry, wage rate changes must more closely resemble the change in the price of X (the favored sector).

<sup>15</sup> Indeed the same country will (in this inconsistent case) use labor less intensively sector-by-sector. In our example (point D in Figure 5), the foreign country's firms are labor intensive in both intra-industry comparisons, so that  $w^*$  is tied closer to both  $\hat{p}_x$  and  $\hat{p}_y$  than is  $\hat{w}$ . This implies  $\hat{w} > \hat{w}^*$  if wages rise generally more than prices.

### C. Alternative Interpretations (for $n=4$ )

Cornes and Kierzkowski (1981) provide an alternative interpretation of the case for  $n=4$ . Theirs is a small, price-taking open economy in which, say, commodities  $X^*$  and  $Y^*$  pictured in Figure 4 represent the production of intermediate goods (which can be traded). These goods are, respectively, used as inputs into  $X$  and  $Y$ .<sup>16</sup> The four productive activities are thus broken down into two stages; the first stage ( $X^*$  and  $Y^*$ ), and the second stage ( $X$  and  $Y$ ) are associated with what we have referred to as the foreign and home countries. Corresponding to this distinction is that between two types of local labor. Each type is trained only for use at a particular stage. Thus their stage-specificity for labor matches our national immobility of labor forces. Finally, in both interpretations capital is occupationally specific either to the  $X$ -industry or the  $Y$ -industry. Their model is used both to trace through one commodity price change at a time (such as in our general analysis, with compatible results) and to consider the effect of uniform changes in final goods prices on the one hand, or intermediate goods prices on the other. These latter exercises involve what we have called "neighboring price rises"; however, with different neighbors (e.g.,  $X$  and  $Y$ ) being aggregated, different bilateral factor intensity comparisons are required. That is, the standard comparisons between techniques used to produce the two goods,  $X$  and  $Y$ , either at the first or second stages, become important, whereas in our interpretation intra-industry intensities prove crucial.

The possibility of international capital mobility is also introduced in their model. However, if a small open economy (such as theirs) is presented with world-determined  $r_x$  and  $r_y$  as well as all commodity prices, some

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<sup>16</sup> This intermediate product feature does little to alter their model from the  $n=4$  case of the neighborhood production structure.



specialization in production patterns is to be expected. However, as they point out, the small country will continue to produce something in each stage (to avoid unemployment of stage-specific labor, as long as the implied "rent" on labor does not drop below zero).

A different interpretation of the neighborhood production structure for the case where  $n=4$  is associated with the model of trade in middle products as developed in Sanyal and Jones (1982) and applied in Jones and Purvis (1983). The central feature of this model is that international trade takes place in (middle) products that have already received value added in local production (e.g., the extraction of natural resources) but which will receive further value added locally after trade before being consumed (assembly costs, retailing, etc.). Productive activity in any country either takes place in an Input Tier, which combines labor and local (sector-specific) resources to produce middle products for the international (and local) market, or in the Output Tier, which combines middle products obtainable on world markets with national labor to produce final (non-traded) consumption goods.

Suppose, in Figure 4, the two productive activities shown for each country correspond to the Output Tier in each country. Thus  $\underline{X}$  and  $\underline{Y}$  are final (non-traded) goods at home, produced by combining labor with a particular middle product in each case. Let  $K_X^W$  now be interpreted as middle product  $\underline{A}$  and  $K_Y^W$  as middle product  $\underline{B}$ . In the Sanyal and Jones piece, the analysis was restricted to that of a small open economy in which prices of middle products are given from outside. The attraction of the neighborhood production structure is that it shows for a world made up of two such countries how middle product prices are dependent upon prices of final goods in each country.

As an example, suppose in each country consumer tastes are extremely flexible, as shown by two sets of linear indifference curves.<sup>17</sup> Then a natural subdivision of the world economy is suggested, this time consisting of two different industries in the same economy for each part. One country might "inflate" its final-goods prices relative to the other country, and the fall-out in terms of national wage rates and returns to internationally mobile capital analyzed. Furthermore, the Input Tier could explicitly be added to each country by letting part of each labor force be used in combination with specific factors (say  $V_A$  and  $V_B$  at home and  $V_A^*$  and  $V_B^*$  abroad) to produce A and B. With the two Output Tiers reflecting a world 4x4 model, the use of national labor forces in alternative (Input Tier) occupations exerts no independent effect on wage rates or middle product prices (except through effects on final goods prices).

These sketchy remarks are meant only to suggest that the neighborhood production structure for the case  $n=4$  might find useful applications not only in models of small open economies with more than two productive sectors but also in modelling large open-economy models linked by trade at input levels instead of (or in addition to) output levels.

### III. Concluding Remarks

There is no doubt that the two most heavily used simple general equilibrium models of production in international trade theory and other fields are the 2x2 model associated with the names of Heckscher, Ohlin, and Samuelson and the 3x2 specific-factors model. The former stresses the asymmetry in the proportions in which factors of production are utilized,

<sup>17</sup> This case, as well as the opposite extreme of right-angled (Leontief-type) indifference curves provided the basic building blocks in Sanyal and Jones for the more general case of imperfectly flexible taste patterns.

while the latter focuses upon a different asymmetry--that between the degree of intersectoral mobility possessed by each factor. It has been a relatively easy task to free the specific-factors model from its dependence upon a small number of commodities; the  $(n+1) \times n$  version of the model preserves most of the properties characteristic of the  $3 \times 2$  model.<sup>18</sup> But the  $2 \times 2$  model has not been generalized that easily. Some structure must be imposed on the  $n \times n$  model before many useful comparative statics properties can be obtained.<sup>19</sup>

The present paper suggests a route towards a manageable model in higher dimensions. The neighborhood production structure preserves much of the ease of analysis characteristic of the standard  $2 \times 2$  model by limiting the occupational alternatives which any factor of production possesses to two-employment in the two neighboring industries when a circular ranking can be devised such as Figure 1. As in any  $n \times n$  model the role of factor intensity comparisons is crucial in linking commodity price changes to the ranking of factor returns. Although in the neighborhood production structure no pair of industries shares the same pair of factors (except in the limiting  $2 \times 2$  version), a multilateral factor intensity ranking can be devised whereby each factor is intensively used in a different sector, and such a ranking insures that if the price of the commodity produced in that sector rises (alone), so will the return to the factor used intensively in that sector.

Our strategy was to utilize this model to analyze the effect on factor returns of a price rise common to two neighboring productive sectors, while the rest of the economy remained with prices fixed.<sup>20</sup> Such an exercise leads

<sup>18</sup> See, for example, the analysis in Jones (1975).

<sup>19</sup> Of course some properties are deducible even in general models. For example the lack of joint production imposes some restrictions. See Ethier (1974) or Jones and Scheinkman (1977) for further discussion.

to a clear categorization of productive factors: the factor used in both favored sectors is not used anywhere else, a set of  $n-3$  factors are used only in the fixed-price part of the economy, while a pair of factors (the "edge" factors) are used in both subdivisions of the economy. The distinctions are reminiscent of that made in the specific-factor model between specific factors and the mobile factor. The potential analogy between the two models prompted the question: Can the factor price rankings associated with neighboring price rises in the  $n \times n$  neighborhood productive structure approximate those associated with relative price changes in the specific-factors model? The answer was affirmative if factor intensity rankings in each subdivision of the economy proved "consistent" with the multilateral ranking.

Several applications of the neighborhood production structure were examined, with particular attention paid to the case in which world trade involves two large countries each with a national but intersectorally mobile labor force and making use of a common pool of internationally mobile but sector-specific capitals. This model fits the neighborhood production structure for the  $4 \times 4$  case, when the world economy is subdivided into two parts, each representing a particular industry located in both countries. Only if bilateral intra-industry factor intensity rankings are "consistent" will factor returns resemble the specific factors model, with an increase in the relative price of commodities in one industry serving to raise the return to the type of capital used specifically in that industry, lowering the return to the other type of capital, and having ambiguous real effects on wage rates in both countries. As was shown, such a "consistent" ranking is violated if one country employs more capital-intensive techniques than the other sector-

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<sup>20</sup> The same techniques could be used for any single subdivision of the economy, regardless of the number of sectors in the favored part.

by-sector (in a bilateral value sense).

As these remarks suggest, the neighborhood production structure is rich in the variety of its outcomes. Factor prices are freed from a direct dependence on factor endowments (arguably a useful characteristic in models with international factor mobility), and both specific-factor and Heckscher-Ohlin type of factor price rankings may be obtained. The distribution between the two rests upon a simple test of consistency of bilateral factor intensity rankings with the overall multilateral ranking. Further applications of the model may emerge, with room for more than two productive activities provided by the ease with which the neighborhood production structure handles higher dimensions.

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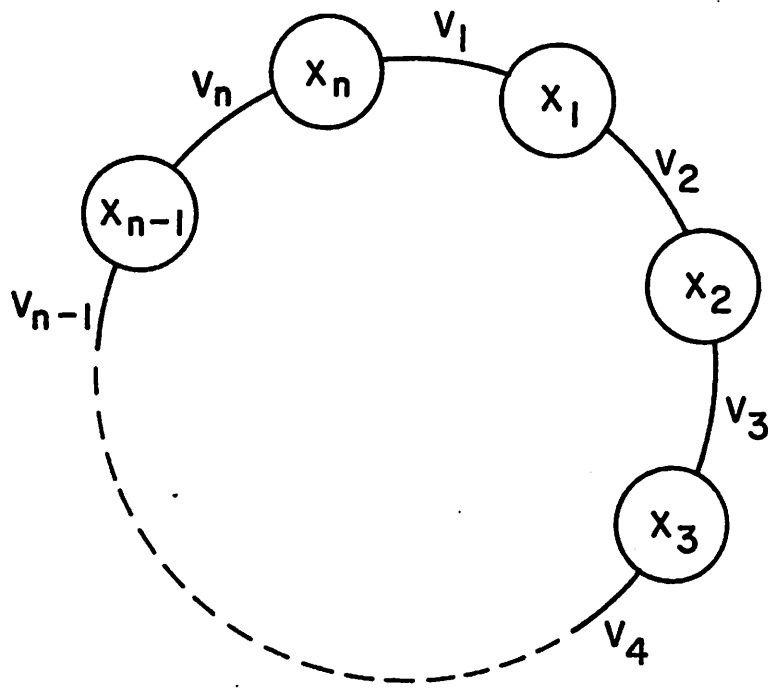


FIGURE 1

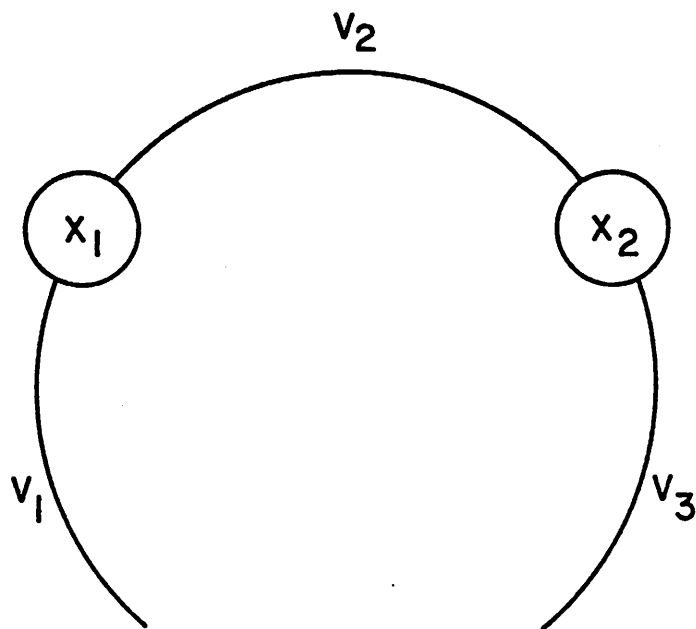


FIGURE 2

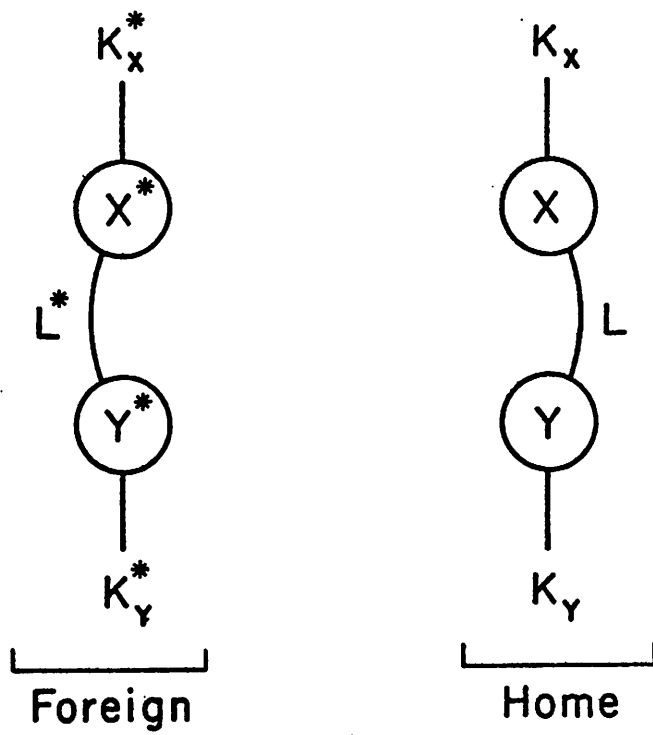


FIGURE 3

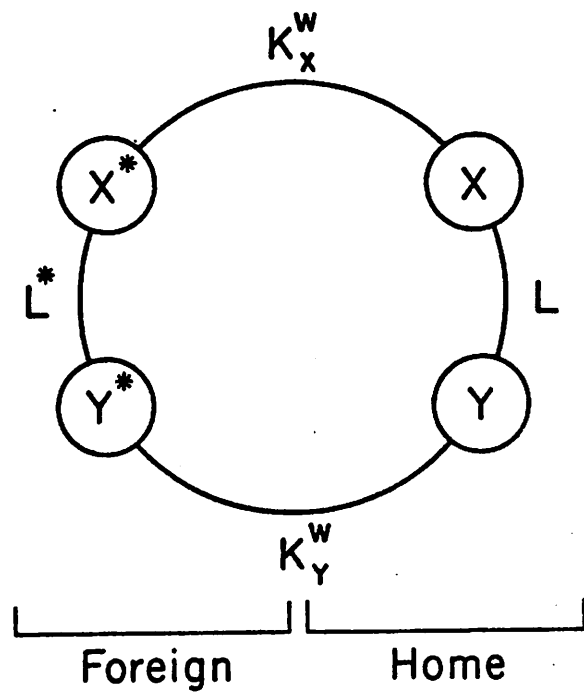


FIGURE 4



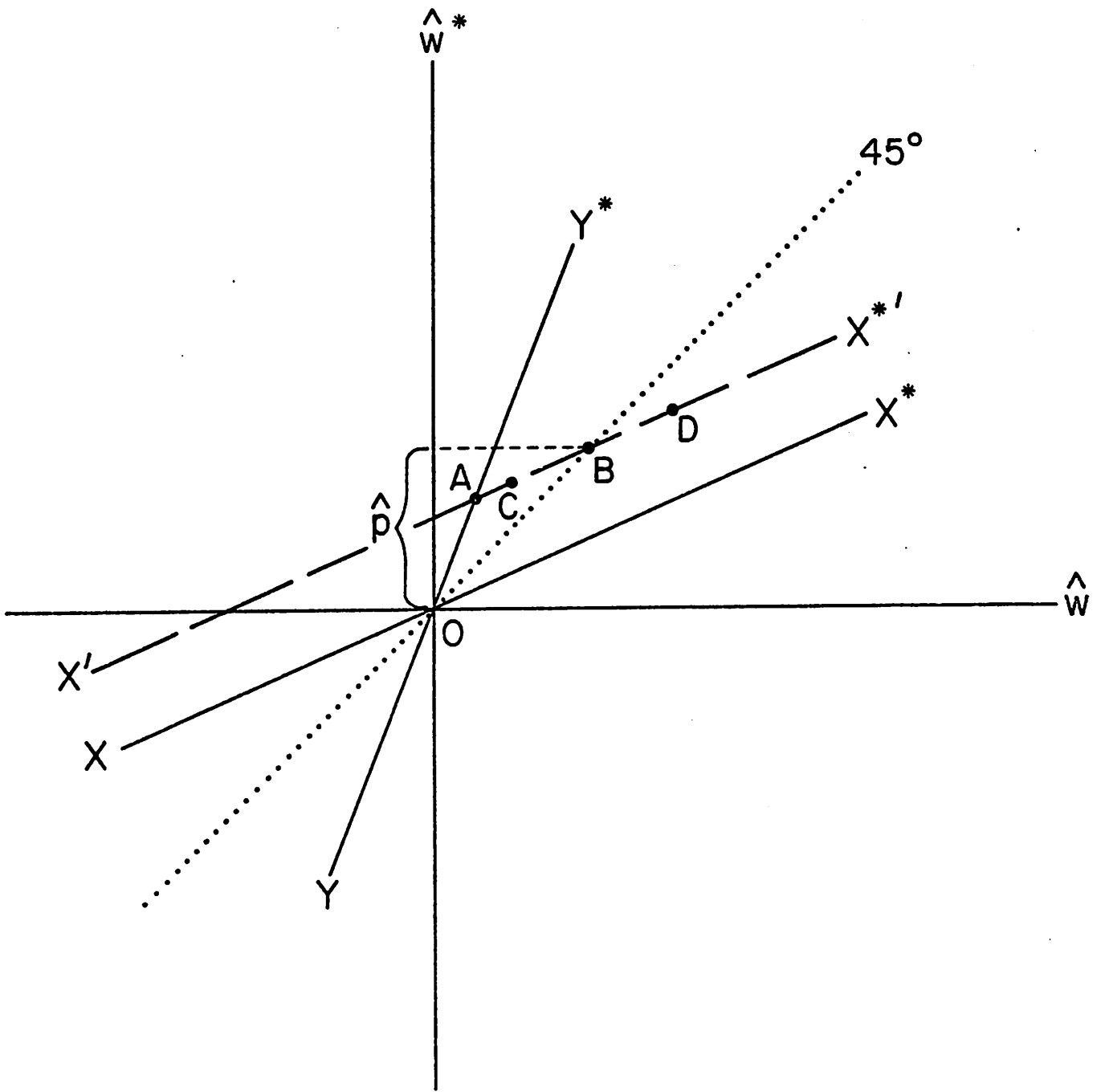


FIGURE 5

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