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by

P. J. Lloyd

Centre for Research in Economic Development and International Trade, University of Nottingham

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The Author

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Abstract

Past attempts to generalise the Stolper-Samuelson Theorem have used a matrix of real income terms which is sufficient but not necessary to define a change in utility. In contrast, one can define a second matrix of terms which are necessary and sufficient for a change in indirect utility. Using this matrix, the paper presents an extension of the Stolper-Samuelson Theorem to a model of any dimension and to households which have diversified ownership of factors. The theorem states that there is a positive and a negative element in every row and every column of the matrix showing how each household is affected by the changes in goods prices. The condition required is that there be sufficient diversity among households in their ownership of factors or preferences.

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INTRODUCTION

Even after its Golden Jubilee in 1991, there is still doubt about the generality of the Stolper-Samuelson Theorem (see Deardorff and Stern (1994)). This is unfortunate. The Theorem is one of the few comparative statics propositions in general equilibrium theory and it is the foundation of political economy models of tariffs and other taxes and government interventions. The importance of the theorem derives from its key message; goods price changes necessarily create conflict between households owning different factors.

This paper considers a general model of an economy with constant returns to scale. The introduction of diversification in households' ownership of factors changes the relationships between prices and real incomes fundamentally. Nevertheless, a generalisation of the Stolper-Samuelson Theorem that holds much more widely than earlier versions can be obtained.

Section I provides a brief history of attempts to generalise the original Stolper-Samuelson Theorem. The outcome is rather dismal. These extensions apply to models in which the households are completely specialised in their ownership of factors, as in the original Theorem and they require quite severe restrictions on the technology when they do hold. All of these generalisations are special cases of one generalised Stolper-Samuelson matrix. Section II develops the concepts of the change in real income, the generalised household income function and the imputed output vector of households which are necessary to extend the theorem. The criterion of real income allows the use of a matrix of real income terms which permits any dimensions and diversified household ownership of factors. The proof of the generalisation of the Stolper-Samuelson Theorem and some other extensions are provided in Section III. Section IV makes some concluding remarks.

I

Stolper and Samuelson (1941) stated a theorem which predicted the movement of real incomes of factors in an internationally trading economy that may protect an industry and, in effect, certain factor owners employed in the industry. At the heart of this version is a simple and strong relationship between goods prices and factor prices "that has nothing to do with factor scarcity or abundance and is independent of whether prices change because of protection or for any other reason" (Deardorff (1994, p. 12)). Deardorff called this the "essential" version and it is the version now used by most economists. It does, however, require an open economy so that the disturbance which causes the price change can originate in the rest of the world and one can maintain the assumption that the technology and the preferences of the country do not change with the change in price.

The Theorem was proven for an economy in which there were only two goods and two non-specific factors. The factors are called labour and capital and the goods 1 and 2. The factors are owned by separate groups of households. With constant returns to scale and both goods produced, there are zero profits. We are interested in the change in real incomes of the owners of the two factors when the prices of goods 1 and 2 change. As the criterion of real income, Stolper and Samuelson chose the income of a factor owner deflated by the price of good 1 or good 2. Since the factor endowments are fixed, income is proportional to the price of the owned factor.

Assuming all goods are produced, there is a one-to-one mapping from goods prices to factor prices which is given by the zero profit conditions alone. Differentiating these conditions in the manner introduced by Jones (1965), we get the equations

$$\begin{bmatrix} \theta_{L1} & \theta_{K1} \\ \theta_{L2} & \theta_{K2} \end{bmatrix} \begin{bmatrix} \hat{w} \\ \hat{r} \end{bmatrix} = \begin{bmatrix} \hat{p}_1 \\ \hat{p}_2 \end{bmatrix} \tag{1}$$

We follow the standard notation . (w, r) and (p_1, p_2) are the vectors of prices of the two factors and the two goods respectively. ^ denotes a proportionate change in a variable. θ is the transpose of the matrix of factor shares. In matrix form, $\theta\hat{\omega} = \hat{p}$ where $\hat{\omega}$ and $\hat{p}$ are the column vectors of changes in the prices of factors and goods.

Solving for the changes in factor prices, we have $\hat{\omega} = \theta^{-1}\hat{p}$ · If only one goods price changes at a time, we get the matrix showing the changes in real incomes in terms of prices of the good whose price has changed:

$$S = \begin{bmatrix} \hat{w}/\hat{p}_1 & \hat{w}/\hat{p}_2 \\ \hat{r}/\hat{p}_1 & \hat{r}/\hat{p}_2 \end{bmatrix} = \theta^{-1} \qquad (2)$$

This may be called the Stolper-Samuelson matrix. If an element is greater than +1, the real income of the factor must have increased and if it is less than 0, the real income of the factor must have decreased. This gives a criterion which is sufficient to determine the direction of change in real incomes independently of factor owners' preferences over goods.

It is easily shown that, after a suitable numbering of the columns and rows, the sign matrix must have the form of

$$\text{sign } S = \begin{bmatrix} + & - \\ - & + \end{bmatrix} \qquad (3)$$

If an element is positive, it is greater than unity. Hence, there is only one permissible sign pattern, that in which the diagonal elements are positive (and greater than unity) and the off-diagonal elements are negative. Moreover, the positive elements correspond to changes in the real incomes of the factors which are used intensively in the production of the good whose price has changed.

This proves that, when the price of one good increases, the real income of the factor used intensively in the production of this good must increase and that of the other factor must decrease. There is, therefore, conflict between the factor owners. One group of factor owners would support the increase in the price of one good and the other would oppose it.

When the number of goods and/or factors is greater than 2 and uneven, univalence breaks down. Attempts to generalise the theorem to higher dimensions, therefore, have been mainly confined to dimensions of nxn. It is usually assumed that there are no intermediate inputs. This can be relaxed to include intermediate usage of the produced outputs but pure intermediates can be admitted only if other produced commodities are omitted as this would otherwise upset the evenness of the model. But even this nxn case has proven extraordinarily difficult.

In this case, let $w = (w_1,...,w_n)^t$ and $p = (p_1,...,p_n)^t$ be the column vectors of prices of factors and goods respectively. Assuming again that all goods are produced, we have $\theta\hat{w} = \hat{p}$ and, hence, we have the nxn Stolper-Samuelson matrix

$$S = \begin{bmatrix} \hat{w}_1/\hat{p}_1 & .. & \hat{w}_1/\hat{p}_n \\ & & \\ \hat{w}_n/\hat{p}_1 & .. & \hat{w}_n/\hat{p}_n \end{bmatrix} = \theta^{-1} \tag{4}$$

A problem now is that there is no natural definition of factor intensity when the number of goods and factors is greater than 2. Hence, there is no natural way of characterising the sign matrix to represent generalisations of the Stolper-Samuelson Theorem.

Three principal generalisations have been proposed.[1]

1. The "strong" generalisation: Each of the diagonal elements is positive (and greater than unity) and each of the off-diagonal elements is negative.

2. The "weak" generalisation: Each of the diagonal elements is positive (and greater than unity).

3. The "basic" generalisation: In every column and every row there is at least one element which is positive (and greater than unity) and at least one which is negative.

The first two generalisations were proposed by Chipman (1969). The third was first considered by Meade (1968), Ethier (1974) and Jones and Scheinkman (1977).

[1] Others have been proposed but they are less interesting. For example, Inada (1971) proposed a sign matrix in which the diagonal elements are negative and all the off-diagonal elements are positive but this is a mathematical curiosity.

Both the strong and the weak generalisations involve an association between goods and factors which is mutually exclusive and exhaustive. For every good, there is one and only one factor associated with this good such that the increase in the price of the good must increase the real income of the associated factor. Hence, these generalisations preserve the identification of the particular factor which is associated with each good, as Stolper and Samuelson were able to do for the 2x2 case in terms of the factor intensities of the goods.

By contrast, the third generalisation does not associate factors with goods. If it holds, it might not be possible to array the elements so that every column has a positive element on the diagonal. It is, therefore, weaker than the "weak" generalisation in this sense, even though it does specify the presence of at least one negative element in each column whereas the "weak" generalisation does not. The column property means that when the price of any one good changes, at least one factor has an increase in real income as defined by Stolper and Samuelson, and at least one has a decrease in real income. There must be conflict between groups of factor owners. The row property states that, for every group of factor owners who derive their income solely from the factor in this row, there is at least one good whose price increase will raise their real incomes and at least one other good whose price increase will lower their real incomes. This generalisation is thus the minimal restriction that preserves the conflict features of the original theorem. It has the added advantage that it extends to non-square matrices when the number of goods and factors is uneven.

None of the three generalisations hold for the 3x3 version of the model without restrictions on the technology. Kemp and Wegge (1969) provided a factor intensity condition which is sufficient for the strong generalisation and Chipman (1969) provided a factor intensity condition in terms of a dominant diagonal which is sufficient for the weak generalisation. No condition which is sufficient (or necessary and sufficient) for the third generalisation has been provided to my knowledge.

Uekawa (1971) provides an example which is instructive in the present context. The matrix of factor shares and its inverse are:

$$\theta = \begin{bmatrix} 8/10 & 0 & 2/10 \\ 7/20 & 7/20 & 6/20 \\ 0 & 6/15 & 9/15 \end{bmatrix}, \qquad \theta^{-1} = \begin{bmatrix} 9/10 & 4/5 & -7/10 \\ -21/10 & 24/5 & -17/10 \\ 7/5 & -16/5 & 14/5 \end{bmatrix}$$

This case is a counter-example to each of the three generalisations. It is easily verified that the share matrix violates the Kemp-Wegge and the Chipman conditions.

Moreover, it has not been possible to derive conditions for the strong or weak generalisation which are sufficient (or better necessary and sufficient) when n > 3. And the third or basic generalisation does not hold either in this case. Ethier (1974) was able to prove the desired column property. Using this result, Jones and Scheinkman (1977) were able to prove that every row must have a negative element but could not prove that it had an element greater than unity. However, Ethier's proof requires the rather extreme assumption that all $\theta_{ij} > 0$, that is, all of the factors are used in all industries.

For the nxn case, Jones and Scheinkman showed that every column has a negative element under the weaker condition that every factor is used in strictly positive quantities by at least two industries and every industry employs strictly positive amounts of at least two factors. While this is not a very strict condition, the first part rules out industry-specific factors.

Some further results have been obtained by Jones and other co-authors (see Jones and Mitra (1995) and references therein). These involved other restrictions on the factor intensities between sectors using the benchmark share rib of factor shares.

When m > n, Jones and Scheinkman (1977) showed that the property that every column has a negative element and an element which is greater than unity held when θ is a positive matrix.

The specific factor model developed formally by Jones (1971) for the model of 3x2 dimensions and extended by Jones (1975) to (n+1)xn is an example of m>n and has been widely used in the political economy literature. In this model, every column does has an element greater than unity and an element less than zero. Moreover, if one considers the square sub-matrix excluding the row for the non-specific factor, this has the pattern of the strong generalisation. In effect, factor specificity is a form of association between the factor and the good. As with the Kemp-Wegge condition in the 3x3 model, it generates the pattern of the strong generalisation for these inputs and it identifies the input which gains when each price is increased.

But the row relating to the non-specific factor has neither an element greater than unity nor an element less than zero. Ruffin and Jones (1977) referred to the absence of an element greater than unity in this row as the "Neoclassical ambiguity". Thus, again, the main sticking point in the basic generalisation is the property that the row have an element greater than unity.

All of the results obtained above for the 3x3, nxn and 3x2 cases are special cases of the following generalised Stolper-Samuelson matrix

$$S = \begin{bmatrix} \hat{w}_1 / \hat{p}_1 & .. & \hat{w}_1 / \hat{p}_n \\ & & \\ \hat{w}_m / \hat{p}_1 & .. & \hat{w}_m / \hat{p}_n \end{bmatrix} \qquad (5)$$

Using a different real income criterion from Stolper-Samuelson and earlier writers, Cassing (1981) re-examined the case of nxn dimensions. He established the row property of the basic generalisation which Jones and Scheinkman could not establish. He did so without restricting the technology. This is an important but generally neglected paper. His criterion of real income change is employed below.

All of these results have assumed that all households own only one factor. Plainly, we want a proposition relating real income changes to price changes which holds much more generally. We now consider the possibility of extending the theorem for a much more general model.

II

Consider a small open economy. There are any number of goods (n) and factors (m) and households (H). Factors are fixed in supply but may be specific or non-specific.

There may be intermediate inputs used in the production of goods. Households own the national endowments of factors and a household may own any number of the factors. Let the goods by indexed by i = 1,...n, the factors by j = i,...,m and the households by h = 1,...,H. p is the vector of prices of goods and w is the vector of prices of factors. v is the vector of endowments for the economy.

On the supply side, there is a national product function, G(p,v) for a competitive economy with a technology that is non-joint and has constant returns to scale in all industries. It is well-known that $G_p = y(p,v)$ and $G_v = w(p,v)$. On the demand side, a household, say household h, has an indirect utility function, $V^h(p, I^h)$ where I^h is the income of the household. I^h is endogenous in the general equilibrium.

Let prices change only one at a time. Differentiating the indirect utility function with respect to the price of good i, one has the expression for welfare change

$$\hat{V}^h/\hat{p}_i \equiv (\partial V^h/\partial p_i)/(\partial V^h/\partial I^h).(p_i/I^h) \tag{6}$$

These expressions can be arrayed in an Hxn matrix

$$V = \begin{bmatrix} \hat{V}^1/\hat{p}_1 & \hat{V}^1/\hat{p}_n \\ \hat{V}^H/\hat{p}_1 & \hat{V}^H/\hat{p}_n \end{bmatrix} \tag{7}$$

The sign of the element ($\hat{V}^h/\hat{p}_i$) provides the criterion of change in real income of the household. If an element of this matrix is positive, the household concerned has a higher real income when the price of the good in the column increases. If the element is negative, the household concerned has a lower real income when the price of the good in the column increases. This criterion requires knowledge of the pattern of demand of each household. But there is no ambiguity; an element greater (less) than 0 is necessary and sufficient for an increase (decrease) in the real income (= utility) of the household.

The three generalisations of the Stolper-Samuleson Theorem can be restated in terms of this V matrix. The strong generalisation of the Stolper-Samuelson Theorem holds, for a square matrix, if and only if all elements on the diagonal are strictly positive and all off-diagonal elements are strictly negative. The weak generalisation holds, for a square matrix, if and only if all elements on the diagonal are strictly positive. The basic generalisation holds for a matrix of any dimensions if and only if there is a strictly positive and a strictly negative element in each row and column.

The matrix in Equation (7) differs from the Generalised Stolper-Samuelson matrix in Equation (5) in terms of the criterion of a change in real income and in the diversification of the income of households. It permits any pattern of diversification.

The analysis of the Theorem with diversified household ownership requires additional new concepts on the supply side of the model. These concepts are the generalised household income function and the imputed outputs of the household.

Household income is the income from the factors which the household owns, $I^h = wv^{ht}$ where v^{ht} is the column vector of factors owned by the household, the transpose of v^h. Utilising $w = w(p,v)$, the household income function is

$$I^h = w(p,v)v^{ht} = g^h(p,v,v^h) \tag{8}$$

These functions are homogeneous of degree +1 in p.

The outputs imputed to a household, denoted by $\tilde{y}^h$, may be calculated in the same manner as outputs are determined for the national economy. (The concept of the imputed output of the household has been used by Lloyd and Schweinberger (1988, 1997).) Each household owns a given endowment of factors which will be fully employed. The household is assumed to possess the same technologies of producing each good as the nations' firms. Its output vector is given by

$$\tilde{y}^h = y_v v^h = \tilde{y}^h(p,v,v^h) \tag{9}$$

y_v is the nxm matrix of derivatives with respect to v of the output vector y(p,v). With this convention, the national output vector is the sum of the household vector. We may, therefore, regard $\tilde{y}^h$ as that part of the national output vector which can be imputed to household h. Moreover, the value of the household's output is equal to its income, that is, $p\tilde{y}^h = wv^{ht} = g^h(p,v,v^h)$ (see Lloyd and Schweinberger (1997)). As each household's expenditure is equal to its income, there is balance of payments equilibrium for the economy. Note that $g_p^h = \tilde{y}^h$.

The economic meaning of this imputation can be obtained from inspecting the imputed output by household of good i. By derivation, the i'th element of $\tilde{y}^h$ is

$$\tilde{y}_i^h = \sum_{j=1}^{m} \partial y_i/\partial v_j v_j^h \tag{10}$$

That is, the imputed output of good i by household h is the weighted sum of the inputs supplied by this household to the firms of the economy. The weights are the marginal effects of the change in the aggregate supply of this input on the aggregate economy output of each good. These can be termed the Rybczynski weights.[2] They may be positive or negative. Hence, the output of a commodity imputed to a household may be positive or negative. If the household's endowments lie outside the cone of diversification, one or more of the outputs imputed to the household will be negative. A household may produce more than the national output of a good if other households in the aggregate produce a negative output of the good. The household's output vector is merely the vector it would be required to produce if its endowments are to be fully employed and it uses the national technology. It is a notional concept which will enable us to obtain further results.

Finally, with this concept of the imputed outputs of households, we can now define the excess demand of household h for good i as $e_i^h = x_i^h - \tilde{y}_i^h$ where x_i^h is the demand by household h for good i. Now $\tilde{y}_i^h = \tilde{y}^h(p,v,v^h)$ and

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[2] In the nxn case the full employment conditions are $A(w)y = v^t$. Hence, the outputs are given by $y = [A(w)]^{-1}v^t$. If households have the same technology the household outputs are given by $\tilde{y}^h = [A(w)]^{-1}v^{ht}$.

$x_i^h = x_i^h(p, g^h(p,v,v^h))$. Therefore, $e_i^h = {}_i^h(p, v,v^h)$. From the derivation of imputed household outputs, we have, for each good, $\sum_h e_i^h = e_i$, the excess demand in the economy for good i.

This definition of the excess household demand can be related to the change in the utility of a household when the price of a good changes. Using Roy's Identity and the derivative property of the household income function ($g_p^h = \tilde{y}^h$) in Equation (6) yields

$$dV^h/dp_i = (\tilde{y}_i^h - x_i^h)\,\partial V^h/\partial I^h \tag{11}$$

$$>(<)\ 0 \quad \text{as} \quad (\tilde{y}_i^h - x_i^h) > (<) 0$$

since $\partial V^h/\partial I^h > 0$. A household gains or loses from an increase in the price of a good, depending on whether it is an implicit net seller or buyer of the good.[3] Alternatively, this result can be expressed in terms of proportionate changes

$$\hat{V}^h/\hat{p}_i = \hat{I}^h/\hat{p}_i - \phi_i^h$$

$$= \gamma_i^h - \phi_i^h \tag{12}$$

where $\gamma_i^h = p_i \tilde{y}_i^h / \sum_i p_i \tilde{y}_i^h$ is the share of the income earned from the imputed production of good i, $\phi_i^h = p_i x_i^h / \sum_i p_i x_i^h$ is the share of the expenditure of household h on commodity i. Using Equation (12), we may write the matrix V as

$$V = \gamma - \phi \tag{13}$$

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[3] This generalises a result which has been known to apply to an exchange economy (see, for example, Jehle (1991, p.350)) to an economy with production. It also extends to the household unit a result which is known to apply to a small price-taking nation which trades with other nations.

where γ is the Hxn matrix of terms (γ_i^h) and ϕ is the Hxn matrix of terms (ϕ_i^h).

In Equations (11) and (12), the welfare effect of changes in the price of a single good contains two terms, one of which measures the effect of the price change on the household as an income-earner and one of which measures the effect on the household as a consumer. The criterion of real income used by Stolper and Samuelson and the subsequent literature neglects the second term.

The concept of imputed output can be used to verify the original Stolper-Samuelson Theorem for the 2x2 model and other earlier results. The Rybczynski equations relating commodity outputs to factor endowments are

$$a_{L1}(w,r)y_1 + a_{L2}(w,r)y_2 = L$$

$$a_{K1}(w,r)y_1 + a_{K2}(w,r)y_2 = K \qquad (14)$$

The solution to these equations is, for given commodity and factor prices,

$$y_1 = [a_{K2}L - a_{L2}K]/D$$

$$y_2 = [a_{L1}K - a_{K2}L]/D \qquad (15)$$

where $D = a_{L1}a_{K2}-a_{L2}a_{K1}$ is the determinant of the system of equations. Hence the Rybczynski weights are

$$R = \begin{bmatrix} \partial y_1/\partial L & \partial y_2/\partial L \\ \partial y_1/\partial K & \partial y_2/\partial K \end{bmatrix} = \begin{bmatrix} a_{K2}/D & -a_{K1}/D \\ -a_{L2}/D & a_{L1}/D \end{bmatrix} \qquad (16)$$

For household h, the i'th element of the vector $\tilde{y}_i^h$ is $\tilde{y}_i^h = \sum_{j=1}^{2} \partial y_i/\partial v_j v_j^h$. In each column and row of the matrix of Rybczynski weights, R, there is one positive and one negative element. Thus, when the stock of one factor increases, the output of the good which is intensive in this factor increases and the output of the other good decreases.

Suppose now that there are two households (or groups of households), one of which owns the labour supply of the economy and the other of which owns the capital stock. Let the household which owns labour be household 1 and that which owns capital household 2. Let the good which is intensive in the factor labour be good 1 and the other be 2. Using Equation (15) above, the implicit outputs of the households are y_1^1 $=\partial y_1/\partial L.L$, $y_2^1 = \partial y_2/\partial L.L$, $y_1^2 = \partial y_1/\partial K.K$, and $y_2^2 = \partial y_2/\partial K.K$. Each household produces a positive quantity of the good which uses intensively the factor with which it is endowed and a negative quantity of the other. Since the sum of the values of the outputs of the two goods by a household is equal to its income, the household which has a positive imputed output of the good has an imputed income from the production of this good which is greater than its household income. Consequently, this household has a value of $(\tilde{y}_i^h - x_i^h)$ which must be positive no matter what proportion of the budget of this household is spent on the good. The corresponding term for the other household must be negative no matter what its expenditure pattern. This proves the original Stolper-Samuelson Theorem by a quite different approach.

As a second example of a known pattern of real income effects, consider the specific factor model developed by Jones (1971). This is an important example as the model is uneven; there are three factors and only two goods. Jones also assumes that there are three completely undiversified factor owners, each of whom owns all of the nations' stock of one of the three factors. The non-specific factor is called labour, L, and the specific factors are the capital specific to industry 1, K_1, and the capital specific to industry 2, K_2. The Rybczynski (full employment) equations relating the outputs of the two goods to the endowments of the three factors are given by

$$\begin{aligned} a_{L1}(w,r_1,r_2)y_1 + a_{L2}(w,r_1,r_2)y_2 &= L \\ a_{K1}(w,r_1,r_2)y_1 \qquad\qquad\qquad &= K_1 \\ a_{K2}(w,r_1,r_2)y_2 &= K_2 \end{aligned} \tag{17}$$

where r_1 and r_2 are the prices of K_1 and K_2 respectively. The factor prices as well as the outputs, y_1 and y_2, are unknown. Consequently, as is well known, the determination of the outputs requires the two equations which relate factor prices to output prices. This gives five equations to determine the five unknowns (y_1, y_2,w,r_1, r_2). The Rybczynski weights can now be obtained by differentiating totally the five equations. This matrix has the sign pattern[4]

$$\text{Sign}\begin{bmatrix} \partial y_1/\partial L & \partial y_2/\partial L \\ \partial y_1/\partial K_1 & \partial y_2/\partial K_1 \\ \partial y_1/\partial K_2 & \partial y_2/\partial K_2 \end{bmatrix} = \begin{bmatrix} + & + \\ + & - \\ - & + \end{bmatrix} \tag{18}$$

Using this matrix in Equation (10), one sees immediately that a household which owns a specific factor produces a positive output of the good which use this specific factor and negative output of the other good whereas the household owning the non-specific factor produces both goods positively. Furthermore, a household owning one of the specific factors actually produces more than the national output because the Rybczynski weights are greater than the terms $(1/a_{Ki}) = y_i$ in Equations (18). In this model, an increase in the stock of a factor causes the factor price to decrease and this in turn increases the input of this factor at the margin. Hence, the square sub-matrix in the second and third rows of the V has precisely the same sign pattern as the original Stolper-Samuelson 2x2 model.

These results for the 2x2 and the 3x2 models and the use of imputed outputs generally can be explained by the Reciprocity Relation. For a competitive equilibrium such that all goods are produced and all factors fully employed, as we have been assuming, the Reciprocity Relation states that $y_v = w_p$. That is, $\partial y_i/\partial v_j = \partial w_j / \partial p_i$ for all i and j. This explains why the imputed outputs are linked to the terms $(\hat{w}_j/\hat{p}_i)$which appear in the S and V matrices.

III

Consider the small open economy described in Section II with any number of goods and factors and households and no restrictions on the technology of production other

4 The easiest way to obtain the Rybczynski terms is to use the Jones hat calculus in the manner suggested by Jones (1975).

than constant returns to scale.[5] In particular, households may have diversified endowments.

The introduction of diversified household ownership changes the properties of the model fundamentally. Consider the case in which $v^h = \beta v$, that is, each of the H households owns an equal fraction ($\beta = 1/H$) of the nations' endowment vector, and all households have the same preferences.[6] Hence, all households are equally (and completely) diversified, though some may own a larger share than others. There is then no diversification in either the pattern of factor ownership or the pattern of consumption. In Equation (13), the term $\gamma_i^h = \hat{I}^h / \hat{p}_i = \hat{Y} / \hat{p}_i$ where $\hat{Y}$ is the change in national income. Every term in each column of γ is identical. Similarly, every term in each column of ϕ is identical. Therefore, V is a matrix in which all terms in a column have the same sign. This holds for all θ.

Diversity is a departure from equal ownership of factors and equal consumption shares among households. With any diversity, the terms in a column will cease to be equal. With small diversity in household ownership of factors and/or preferences, the terms in the columns of V will be the same sign for all i.

Evidently, the assumption that each household owns only one factor that is not owned by any other household, which is built into the previous literature, is extreme diversity in factor ownership and produces atypical results. All of the results reported in Section I hold because of the combination of the assumed restrictions on technology <u>and</u> the restriction of household ownership to the extreme case of completely undiversified ownership.

We need to take diversification into account as the reality is that most households today are at least partly diversified in endowments.

5 The model can be extended to some situations with economies of scale which are external to the firm and joint production (see Lloyd and Schweinberger (1997)). It can also be extended to a labour-leisure choice, using the concept of full income and to ad valorem commodity taxes which maintain a fixed wedge between producer and consumer prices and to ad valorem factor taxes.

6 This result could be generalised to households which own fixed, but not necessarily equal fractions of the nation's endowments but it would require the restriction of homotheticity of preferences.

Theorem

Consider an economy in which at least some households are diversified in terms of their ownership of factor endowment. In the Hxn matrix of terms showing the change in real income (= utility) of households in response to changes in the prices of goods one at a time,

$$V = \begin{bmatrix} \hat{V}^1/\hat{p}_1 & \hat{V}^1/\hat{p}_n \\ \\ \hat{V}^H/\hat{p}_1 & \hat{V}^H/\hat{p}_n \end{bmatrix}$$

(i) there is at least one strictly positive element and at least one strictly negative element in every row, and

(ii) there is at least one strictly positive element and at least one strictly negative element in every column, if and only if there is sufficient diversity among households in their ownership of factors and/or their preferences.

Proof of the Row Property

The household real income is given by $V^h(p, g^h(p,v,v^h)) = W^h(p,v,v^h)$. W^h is homogeneous of degree 0 in p since V^h is homogeneous of degree 0 in p and g^h, and g^h is homogeneous of degree +1 in p. Applying Euler's Theorem and expressing the results in proportionate changes, we have

$$\sum_{i=1}^{n} \hat{W}^h / \hat{p}_i = 0 \tag{19}$$

The terms $(\hat{W}^h/\hat{p}_i)$ are the elements in the i'th row of the matrix of V. From Equation (19), there is at least one strictly positive element and at least one strictly negative element in every row.

Proof of the Column Property

(i) Necessity

If there is zero diversity in both factor ownership and preferences, $V = \gamma - \phi$ and every element of a column must have the same sign. Some diversity among households in factor ownership and/or preferences is necessary for the change in a goods price to affect households differentially.

(ii) Sufficiency

In an open economy, $e_i = \sum_h e_i^h \gtreqless 0$ with the strict inequalities > and < holding for goods which are imported and exported by the nation respectively. In the case of an import good, there must be at least one element which is positive and, in the case of an export good, there must be at least one element which is negative.

For any technology and any set of household preferences, there exists a distribution or distributions of the national endowments among households which yields the column property of the theorem. Consider a column of V. For a household with multiple factor ownership, $(\hat{I}^h/\hat{p}_i) = \sum_j a_j^h (\hat{w}_j/\hat{p}_i)$ where the weights a_j^h are share of income earned from each factor. Substituting this expression in Equation (6), we have

$$\hat{V}^h/\hat{p}_i = \sum_j a_j^h (\hat{w}_j/\hat{p}_i) - \phi_i^h \quad \sum_j a_j^h = 1; \quad h = 1,...,H \tag{20}$$

Take two households, one of which owns a factor with $(\hat{w}_j/\hat{p}_i) > 0$ and one of which owns a factor with $(\hat{w}_j/\hat{p}_i) < 0$. Call these households s and t. For any set of ϕ_i^h, we can increase the weight attached to the positive term $(\hat{w}_j/\hat{p}_i)$ for household s and decrease that attached to a negative term $(\hat{w}_j/\hat{p}_i)$ for household t until $(\hat{V}^s/\hat{p}_i)$ is positive and $(\hat{V}^t/\hat{p}_i)$ is negative.

It follows immediately from Equation (12) that a change in the price of any good must make at least one household better off and at least one worse off. Q.E.D.

The best interpretation of the conflict among households in the columns of V is to regard households which gain and those which lose as being on opposite sides of the market (see Equation (11) above). It is possible for all households to be on the same side of the market and consequently for conflict between households to be absent when the price of the good changes. However, a strong presumption of conflict between households remains in an economy with diverse individual households. This must occur if there is sufficient diversity among households.

Sufficient diversity may come either from diversity of endowment proportions or of preferences. Consider the case in which the H households are equally diversified in terms of endowments. Then $V = (\hat{Y} / \hat{p}_i) - \phi$ where $(\hat{Y} / \hat{p}_i)$ is the matrix in which every element in column i is identical as all share equally in the change in national income (Y). It requires only a limited variation in the preferences of some households to ensure that there is a positive and a negative element in every column. Conversely, if all households have identical preferences, diversity in factor ownership will create diversity in $(\hat{I}^h / \hat{p}_i)$ across households in each column. In this case, what diversity is sufficient will vary with the technology.

The Ethier (1974) and Jones and Scheinkman (1977) versions of the nxn Heckscher-Ohlin model and the specific factor model, with each household owning only one factor, can be shown to have households on opposite sides of the market.

As another example, consider γ is the 3x3 matrix formed by taking the Uekawa matrix and there are three households each of which owns only one factor. This was a counterexample to the basic generalisation of the Stolper-Samuelson Theorem. In this case, V is

$$V = \theta^{-1} - \phi = \begin{bmatrix} 9/10 & 4/5 & -7/10 \\ -21/10 & 24/5 & -17/10 \\ 7/5 & -16/5 & 14/5 \end{bmatrix} - \begin{bmatrix} f_1^1 & f_2^1 & f_3^1 \\ f_1^2 & f_2^2 & f_3^2 \\ f_1^3 & f_2^3 & f_3^3 \end{bmatrix}$$

This matrix has the sign pattern required for the basic generalisation for any 3x3 non-negative matrix of consumption shares. Thus, the basic generalisation holds in terms of V. The upholding of the basic generalisation in terms of V but not S is another expression of the sufficiency but non-necessity of the Stolper-Samuelson criterion of real income change.

In all of these cases the extreme diversity in factor ownership alone coming from completely undiversified households is sufficient for the basic generalisation to hold in terms of V. It is also apparent that the required pattern would hold in these models if households endowments were only partially diversified.

A more general 3x3 example will demonstrate the role of imputed outputs in the determination of the patterns of factor ownership which yield the real income effects of the generalisation of the Theorem.

Example : 3x3 Heckscher-Ohlin model

It is convenient to use the Leamer Triangle. This Triangle has been used previously in the analysis of the Stolper-Samuelson Theorem by Jones (1992) and Lloyd and Schweinberger (1997). In this application, the triangle is applied to the endowments of the individual households within the national economy rather than the endowments of the nations within the world economy as in Leamer (1987). It is obtained by the intersection of the positive orthant of the 3-dimensional factor space with a unit value plane. The Triangle is then the unit simplex. The triangle represents graphically in 2-dimensional space the relative proportions of the three factors.

Thus, the endowment vectors of the individual households are points in the Triangle. For a household, the coordinates of these points are the shares of the income of the household from each factor (a_1^h, a_2^h, a_3^h). The endowment points of the households are distributed over the Triangle. A household which is completely diversified in that it owns a strictly positive quantity of each factor will have an endowment point in the interior of the Triangle. A household which owns two of the three factors will have an endowment point on a side of the Triangle and one which is completely undiversified will have it at a vertex.

We also plot in the Triangle the vector of cost-minimising input coefficients used in the production of each good, θ_i. The coordinates of these points represent the distributive shares of the factors, $(\theta_{1i},\theta_{2i},\theta_{3i})$. These vectors represent the technology.

For any technology, the Leamer Triangle can be partitioned into 7 zones showing the pattern of complete, partial or zero diversification in production by a household whose endowment point is in this zone. The zone of complete diversification is the area within the cone of diversification. If a household's endowment vector lies in this zone, the household will produce all three goods in strictly positive quantities. If it lies in another zone, it will produce positive quantities of one or two goods only. This partition holds for any technology. If θ lies on a side of the Triangle (because one of the factors is not used in the production of one good, good i), the zone in which only good i is produced positively reduces to the point θ_i.

Figure 1 provides an illustration. The technology in this figure is an example of a technology which satisfies the Chipman dominant diagonal condition. The points labelled θ_1, θ_2 and θ_3 show these sets of coefficients for goods 1, 2 and 3 respectively. The lines connecting these points form the familiar cone of diversification. For the technology given by the points θ_1, θ_2 and θ_3, the zones of zero, partial or complete diversification in the imputed outputs of households are shown. The goods produced in each zone are given in parentheses.

First assume, as in the original Chipman case, that there are three households which are completely undiversified in their factor ownership. Let households 1, 2 and 3 own the stocks of factors 1, 2 and 3 respectively. The endowments points of the three households are at the three vertices of the triangle. Then, households 1 and 3 produce only one good in positive quantities, good 1 and 3 respectively. These are the goods which use intensively the factor which the household owns. The other two goods are produced in negative quantities. Hence, the value of the imputed output of the respective good is greater than the income of these two households. These two households gain from an increase in the price of this good and lose from an increase in the prices of the other goods. Household 2 produces good 3 as well as good 2 in positive quantities and good 1 in a negative quantity. As θ_{22} dominates the other terms in the second column of θ, the value of the output of this good is larger than the income of household 2. The weak generalisation of the Stolper-Samuelson Theorem follows from Equation (12) and consequently the basic generalisation also follows.

Allowing diversification of household ownership of factors opens up a much richer variety of possibilities. One can find a region of household diversification which yields the basic generalisation. The patterns of diversification in this region will suffice for the generalisation, irrespective of the household preferences. First, for all sets of endowments in the zones marked (1), (2) and (3), the strong generalisation of the theorem holds. Since only one good is produced positively in each household, the value of the imputed output of this good exceeds its income and the household gains from an increase in the price of the good, irrespective of its preferences. For the other two goods, $\gamma_i^h < 0$ and, therefore, $(\gamma_i^h - \phi_i^h) < 0$. (These endowments are such that the strong generalisation holds even though the Kemp-Wegge condition does not hold.) The basic generalisation holds for all sets of endowments such that each household produces one good in value greater than its total output (income). This holds for any technology as represented by a θ.

Of course there are more than three households in an economy. With many households, all that is required for a generalisation to hold is that there be one household in each of the stipulated zones or areas.

These regions of factor ownership are sufficient for the theorem. With knowledge of the preferences of the households, there is a wider set of household distributions which is necessary and sufficient for the theorem. Even in the extreme case in which each household owns a fraction of the nation's endowments, all households will have the same endowment point in the cone of diversification but the theorem will hold if there is sufficient diversity in preferences.

IV

The theorem retrieves the spirit of the Stolper-Samuelson Theorem. It has not been stated previously to my knowledge. Cassing (1981) proved the row property for the restricted model with specialised factor ownership and nxn dimensions. If the numbers of households and goods and factors is n and every household owns only one factor and every factor is owned by one household, each household can be associated with a factor. Thus, households can be numbered in the same way as factors. Then, for any household h, $\hat{V}^h/\hat{p}_i = \hat{w}_h/\hat{p}_i - \phi_i^h$. The matrix of real income changes is $V = \theta^{-1} - \phi$. Since θ^{-1} and ϕ are both row stochastic, it follows immediately that the row sums of V are zero. Hence, there must be at least one positive and one negative element in each row of the matrix. Lloyd and Schweinberger (1988, p. 281) stated the general form of the row property in the theorem, using the household trade expenditure function.

The general proof of the row property derives from the use of a true index of utility rather than the Stolper-Samuelson criterion of real income change. In fact, it is the homogeneity property of the indirect utility function which produces the result that Cassing noted. This result is much more general than the special case of an nxn economy with undiversified households which Cassing considered. It applies to any household with a diversified factor ownership and it allows specific as well as non-specific factors and intermediate inputs. The column property has not been proven before.

Thus, it turns out that it is the row property which holds generally, not the column property. This is the opposite of the conclusion of Ethier (1974) and Jones and Scheinkman (1977) for the case of households which are completely undiversified in terms of the factor ownership and using the Stolper-Samuelson criterion of real income change.

The contrast between these results and those of earlier generalisations of the Stolper-Samuelson Theorem is the contrast between the two matrices in Equations (5) and (7). Equation (7) permits any pattern of diversification in factor ownership, uses the necessary and sufficient criterion for a utility change and is unrestricted in terms of the dimensions of the model .

The only restrictions which rule out a part of the gains from international trade is that the number of goods which are consumed is fixed and there are no economies of scale, unlike the models of Krugman, Helpman and others in which this number is endogenous and there are economies of scale. Even here, we can note that the consumers in the Krugman-Helpman models are identical in terms of their preferences (see, for example Helpman and Krugman (1985, especially chapter 9.5)). Again it is this lack of diversity which accounts for the result that all households may gain from trade, not the presence of economies of scale and product varieties.

In deriving the Stolper-Samuelson-type theorem above and the conditions for the strong and weak generalisations, the concept of the imputed outputs of a household is an expeditious method of extending the column property of the matrix of household changes in real income. However, the crucial step in the extension of the both the row and column properties of the Stolper-Samuelson theorem is the use of the true index of utility change. This provides a criterion which is necessary and sufficient for a price index to increase or decrease the real income of a household. The Stolper-Samuelson criterion was weaker and sufficient for the simple 2x2 Heckscher-Ohlin model. Stolper and Samuelson (1941) stated: "The vast majority of writers take it as axiomatic that a calculation of effects upon real income must take into consideration the behaviour of prices of commodities entering the consumer's budget." They saw their criterion which removed the index number problem as a great advantage. But the criterion was quite inadequate for more general models. It was too strict a test of real income change. Ironically, progress has been made in completing the row and column properties of a general version of the Theorem only by putting the consumption effect back into the criterion.

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Professor D. Greenaway - trade and development
Mr. R.C. Hine - economic integration, trade policy
Mr. K.A. Ingersent - agricultural trade, economic development
Dr. T.A. Lloyd - agricultural markets, econometric modelling
Dr. A. McKay - poverty, behaviour under rationing
Professor C.R. Milner - trade and development
Dr. C.W. Morgan - futures markets, commodity markets
Professor A.J. Rayner - agricultural policy and trade
Mr. G.V. Reed - international trade, commodity markets
Dr. P.W. Wright - employment implications of international trade

Research Fellows (External)

Professor V.N. Balasubramanyam (*University of Lancaster*) - trade, multinationals
Dr. K. Ekholm *(Research Institute of Industrial Economics)* - trade theory; multinationals
Professor G. Hansson (*Lund University*) - trade and development
Professor R. Lamusse (*University of Mauritius*) **-** labour economics
Dr. L. Lundberg (*IUI, Stockholm*) - intra-industry trade
Dr. M.McGillivray *(Deakin University)* - aid allocation, human development
Dr. J. Menon *(Monash University)* - trade and exchange rates
Professor D. Nelson *(Tulane University)* - political economy of trade
Dr. S. Pillay (*Universiti Sains Malaysia*) - trade shocks, commodity markets
Professor D. Sapsford (*University of Lancaster*) - commodity prices
Professor H.D. Smeets (*University of Dusseldorf*) - european integration, monetary economics
Professor P.K.M. Tharakan *(University of Antwerp)* - intra-industry trade
Dr. H. Vandenbussche *(University of Antwerp)* - European trade policy and antidumping.
Dr. H. White *(ISS, The Hague)* - Macroeconomic impact of aid.