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Definitions of Factor Abundance and the Factor Content of Trade

HENRY THOMPSON hthompsn@business.auburn.edu
Economics Department, Auburn University, AL 36849

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Abstract

This paper points out that the different definitions of factor abundance in the empirical trade literature are weaker than in the Heckscher-Ohlin model, which compares endowments of two factors across two countries. These different definitions in practice lead to different factor abundance rankings when there are three or more countries or factors. A lack of correlation between a weak measure of factor abundance and the factor content of trade provides no ground to claim that factor proportions trade theory fails. A working definition of factor abundance more in line with the traditional one is proposed.

Empirical tests of the factor proportions theory of trade look for correlation between the factor content of trade and some measure of factor abundance. Contributions include Leamer (1974), Harkness (1983), Maskus (1985), Brecher and Choudri (1988), Salvatore and Barazesh (1990), Stern and Maskus (1993), Trefler (1993), and Davis et al. (1997). Little consensus has emerged, with results depending on model specification, methodology, time period, countries, industries, and so on. It may not be generally appreciated that the definitions of empirical factor abundance are much weaker than the theoretical definition in the Heckscher-Ohlin model with only two factors and two countries.

Leamer (1980) examines the situation of many goods, and defines factor abundance as a high endowment of a factor relative to the world. Leamer presents a theoretical example with three factors and three goods in which a country "abundant" in capital is a net importer of capital embodied in trade.

In the "traditional" definition, endowment ratios are compared across a pair of countries. Leamer's comparison can be called "world abundance." The comparison that appears most in the literature can be called "share abundance," with a country's endowment relative to the world compared to the country's share of world income. These definitions of factor abundance are equivalent with two factors and two countries.

The present paper presents a bilateral definition of factor abundance for data with many factors and many countries. This definition is based on a series of bilateral comparisons, and is stronger than the other definitions.

1. Two factors and two countries

Comparing two countries with identical tastes, the local Heckscher-Ohlin theorem follows directly from the Rybczynski theorem. Ruffin (1977) starts with two identical countries producing two goods with two productive factors, the $2 \times 2 \times 2$ model. With free trade, factor price equalization (FPE) holds in the absence of both factor intensity reversals and complete specialization. If one worker migrates, the marginally labor abundant country will produce a higher ratio of the labor intensive good according to the Rybczynski theorem, and will export it. A comparison of country outputs and associated endowment points in the common production cone implies the global Heckscher-Ohlin theorem.

Vanek (1968) and Williams (1977) extend the Heckscher-Ohlin analysis to a comparison of two countries each producing any number of goods at least as great as the number of factors, the $r \times n \times 2$ model with $r \leq n$. If there are more goods than factors, $n > r$, factor price equalization FPE may not hold. Let v_{ik} be the endowment of factor i in country k. Begin with $r = n = 2$ and the abundance ranking

$$v_{11}/v_{21} > v_{12}/v_{22}, \tag{1}$$

where v_{ik} is the endowment of factor i in country k. In the $2 \times 2 \times 2$ model with free trade, FPE holds. National income in country k is $y_k = w_1 v_{1k} + w_2 v_{2k}$. Let s_k be the share of country k in world income, $s_k = y_k/(y_1 + y_2)$.

The cost minimizing factor inputs a_{ij} represent the amount of factor i used to produce one unit of good j. With linearly homogeneous production functions, the a_{ij} are functions of the vector of factor prices w. If each production function is the same worldwide, the a_{ij} are identical across countries given FPE. Let x_{jk} be the output of good j in country k. Full employment implies $\sum_j a_{ij} x_{jk} = v_{ik}$. The world output of good j is x_{jw}. The world endowment of factor i is $v_{iw} = \sum_j a_{ij} x_{jw}$. Given identical and homothetic demand, the two countries will consume goods in the same ratio, equal to the ratio of world outputs. The consumption of good j in country k is $c_{jk} = s_k(x_{j1} + x_{j2}) = s_k x_{jw}$. Each good is distributed across countries according to world income shares, $c_{j1}/c_{j2} = s_1/s_2$.

The export of good j from country k is $t_{jk} = x_{jk} - c_{jk}$. Premultiply by $\sum_j a_{ij}$ to find $\sum_j a_{ij} t_{jk} = \sum_j a_{ij}(x_{jk} - c_{jk}) = v_{ik} - \sum_j a_{ij} s_k x_{jw} = v_{ik} - s_k v_{iw}$. Premultiply by w' to find the balance of trade vector $w'At_k = p_1 t_{1k} + p_2 t_{2k}$. Rescale prices of goods to unit value, and trade is balanced where $t_{ik} = -t_{2k}$. Postmultiply the factor cost matrix

$$\begin{bmatrix} w_1 a_{11} & w_1 a_{12} \\ w_2 a_{21} & w_2 a_{22} \end{bmatrix}$$

by $(t_{1k}\ t_{2k})'$ to find the content of factor i in the trade of country k,

$$t_{ik} = w_i a_{i1} t_{1k} + w_i a_{i2} t_{2k} = (1 - s_k) w_i v_{i1} - s_k w_i v_{i2}. \tag{2}$$

If $t_{ik} > 0$, country k consumes less than its value share of factor i in world output, and factor i is effectively exported. If $t_{ik} < 0$, country k effectively imports factor i. The endogenous share s_k is found, given balanced trade. When $t_{ik} = 0, s_{ik} = (1 + (v_{i1}/v_{i2}))^{-1}$. With two goods, a higher v_{i1}/v_{i2} implies factor i is exported by country 1.

Another way to write the traditional abundance in (1) is $v_{11}v_{22} > v_{12}v_{22}$. Country 1 is world abundant in factor 1 if

$$v_{11}/v_{1w} > v_{21}/v_{2w}, \qquad (3)$$

which can be written $v_{11}/(v_{11} + v_{12}) > v_{21}/(v_{21} + v_{22})$. It follows that $v_{11}v_{21} + v_{11}v_{22} > v_{11}v_{21} + v_{12}v_{21}$, which is equivalent to (1). World abundance is identical to traditional abundance in the $2 \times 2 \times 2$ model.

Country 1 has a share abundance in factor 1 if $v_{11} > s_1 v_{1w}$, or

$$v_{11}/v_{1w} > s_1, \qquad (4)$$

which implies $v_{11}/v_{1w} > (w_1v_{11} + w_2v_{21})/(w_1v_{1w} + w_2v_{2w})$. It follows that $w_2v_{11}(v_{21}+v_{22}) > w_2v_{21}(v_{11} + v_{12})$, which simplifies to (1). In the $2 \times 2 \times 2$ model, the three definitions of factor abundance are equivalent.

2. Two factors and three countries

The two factor, three country model is analogous to the situation in the data with many countries but fewer factors. If there are only two goods, the $2 \times 2 \times 3$ model, factor price equalization would hold. With more goods, prices would have to be consistent with production of the same two goods in all three countries for FPE. Horiba (1974) develops a method of applying bilateral concepts to a world with many countries.

The factor proportions model cannot apply directly since there are too many variables for the number of equations. In the two country model, the endogenous variables in (2) are t_{11} and t_{21}. With no loss in transit, $t_{11} = -t_{12}$ and $t_{21} = -t_{22}$, closing the model. The added country creates four endogenous variables, t_{11}, t_{12}, t_{21}, and t_{22}, with t_{13} and t_{23} implied by these four. There are, however, only two equations in (2), one for each factor. Some assumption has to be relaxed, perhaps FPE or balanced trade, and there would be no necessary links between factor endowments and the factor content of trade.

There is, however, a straightforward abundance ranking because there are only two factors,

$$v_{11}/v_{21} > v_{12}/v_{22} > v_{13}/v_{23}. \qquad (5)$$

The first inequality in (5) says that country 1 is abundant in factor 1 relative to country 2, $v_{11}v_{22} > v_{12}v_{21}$. The second says that country 2 is abundant in factor

1 relative to country 3, $v_{12}v_{23} > v_{13}v_{22}$. It follows that country 1 is abundant in factor 1 relative to country 3, $v_{11}v_{23} > v_{13}v_{21}$.

Ranking world abundance, there are two clear countries but one ambiguous country. Country 1 is world abundant in factor 1 and country 3 is world abundant in factor 2,

$$v_{11}/v_{21} > v_{1w}/v_{2w} > v_{13}/v_{23}. \tag{6}$$

Country 2 has an intermediate position, not necessarily world abundant in either factor, since v_{12}/v_{22} may be greater or less than v_{1w}/v_{2w}. Substitute $v_{i1}+v_{i2}+v_{i3}$ for v_{iw} in (6) to find $v_{11}v_{22} - v_{12}v_{21} > -(v_{11}v_{23} - v_{13}v_{21})$ and $v_{11}v_{23} - v_{13}v_{21} > -(v_{12}v_{23} - v_{13}v_{22})$. These two inequalities are weaker than (5) in which each of the differences on each side of the inequalities are positive. Given only world abundance in (6), the differences on the right side of these two inequalities might be negative. Traditional abundance implies world abundance, but the converse does not hold. As an example, consider the world factor endowment matrix

$$\begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \end{bmatrix} = \begin{bmatrix} 2.1 & 3 & 1 \\ 1 & 1 & 1 \end{bmatrix}. \tag{7}$$

World abundance is identical to "rest of the world (ROW) abundance," a more intuitive comparison which has not appeared in the literature. Consider the world abundance ranking for country 1 in a three country world, $v_{i1}/v_{h1} > v_{iw}/v_{hw}$. Substituting for v_{iw} and v_{hw}, it follows that $v_{i1}v_{h2} + v_{i1}v_{h3} > v_{i2}v_{h1} + v_{i3}v_{h1}$, which is exactly the implication of $v_{i1}/v_{h1} > v_{i\mathrm{R}}/v_{h\mathrm{R}}$ where R represents ROW, every country except country 1.

Share abundance consists of two necessary conditions

$$v_{11}/v_{1w} > s_1 \quad \text{and} \quad v_{23}/v_{2w} > s_3, \tag{8}$$

analogous to (5) and (6). Given factor price equalization and rescaling factors so $w_i = 1$, the share of country k in world income is $s_k = (v_{1k} + v_{2k})/(v_{1w} + v_{2w})$. Using (5), the first condition in (8) reduces to $v_{11}v_{22} - v_{12}v_{21} > 0 > v_{13}v_{21} - v_{11}v_{23}$. The second reduces to $v_{11}v_{23} - v_{13}v_{21} > 0 > v_{13}v_{22} - v_{12}v_{23}$. Country 2 is not necessarily share abundant in either factor. The share abundance of country 2 depends on the sign of $(v_{11}v_{22} - v_{12}v_{21}) - (v_{12}v_{23} - v_{13}v_{22})$. If it is negative, $v_{12}/v_{1w} > s_2$; if it is positive, $v_{22}/v_{2w} > s_2$. Given (5) alone, country 2 could be share abundant in either factor. Substituting for v_{iw} in the two parts of (8), the two conditions associated with world abundance in (6) are derived. Share abundance and world abundance are equivalent conditions in the model with two factors and three countries.

The shortcoming of world abundance and share abundance is that they might hold for pairs of countries when the traditional abundance in (5) does not. By

(6) or (8), countries 1 and 3 would be classified as abundant in their respective factors, even though country 2 might have the strongest abundance.

3. Three factors and two countries

In the model with three factors and two goods, FPE does not hold and the analysis breaks down. The 3×2 model is developed by Thompson (1985) and others. In the even model with three goods, FPE would hold. If there are more than three goods, FPE is not necessary.

The key abundance variable with two countries becomes v_{i1}/v_{i2}. There is an unambiguous abundance ranking across the three factors, as developed by Jones (1956),

$$v_{11}/v_{12} > v_{21}/v_{22} > v_{31}/v_{32}. \tag{9}$$

Country 1 exports goods intensive in factor 1, starting at the front of the ranking, and imports goods intensive in factor 3 at the end of the ranking. Two conditions which describe abundance from (9) are $v_{11}v_{22} > v_{12}v_{21}$ and $v_{21}v_{32} > v_{22}v_{31}$.

World abundance in the three factor, two country model is written

$$v_{11}/(v_{11} + v_{12}) > v_{21}/(v_{21} + v_{22}) > v_{31}/(v_{31} + v_{32}). \tag{10}$$

The first inequality in (10) implies $v_{11}v_{21} + v_{11}v_{22} > v_{11}v_{21} + v_{12}v_{21}$, and the second implies $v_{21}v_{31} + v_{21}v_{32} > v_{21}v_{31} + v_{22}v_{31}$, which are identical to (9).

Turning to share abundance, the two conditions

$$v_{11}/v_{1w} > s_1 \quad \text{and} \quad v_{32}/v_{3w} > s_2 \tag{11a}$$

indicate that country 1 has a share abundance in factor 1, and country 2 has a share abundance in factor 3. The first inequality in (11a) implies $s_2 > 1 - v_{11}/v_{1w} = v_{12}/v_{1w}$, which indicates country 2 is not share abundant in factor 1. Similarly, $s_1 > v_{31}/v_{3w}$ from the second inequality indicates country 1 is not share abundant in factor 3. Both countries cannot be share abundant in factor 2. If $v_{21}/v_{2w} > s_1$, then $v_{22}/v_{2w} = 1 - v_{21}/v_{2w}$ must be less than $s_2 = 1 - s_1$. Suppose country 1 is share abundant in factor 2,

$$v_{21}/v_{2w} > s_1. \tag{11b}$$

The three conditions in (11a) and (11b) are not necessarily equivalent to (9), but factors can be renumbered to arrive at a traditional abundance ranking. Share abundance in (11a) and (11b) is consistent with v_{11}/v_{1w} being either greater or less than v_{21}/v_{2w}. The traditional abundance, however, implies $v_{11}/v_{1w} > v_{21}/v_{2w}$ which reduces to $v_{11}v_{22} > v_{12}v_{21}$. Share abundance implies traditional abundance, at least up to some ordering of factors, and traditional abundance unambiguously implies share abundance. In a model with only two countries, the concept of share abundance is unnecessary since a traditional ranking can be found by renumbering factors.

4. Three factors and three or four countries

In the $3 \times n \times 3$ model, each country has the potential to be abundant in a particular factor and to export the good which uses that factor most intensively. The factor endowment matrix is written

$$\begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{bmatrix}. \tag{12}$$

The idea behind factor abundance is that the ratio of one factor to other factors in a country is greater than the same ratio for all other countries.

In the three factor, three country model, country 1 is abundant in factor 1 in this strong sense if

$$v_{11}/v_{21} > v_{12}/v_{22}, v_{13}/v_{23} \quad \text{and} \quad v_{11}/v_{31} > v_{12}/v_{32}, v_{13}/v_{33}. \tag{13a}$$

Country 2 is abundant in factor 2 if

$$v_{22}/v_{12} > v_{21}/v_{11}, v_{23}/v_{13} \quad \text{and} \quad v_{22}/v_{32} > v_{21}/v_{31}, v_{23}/v_{33}. \tag{13b}$$

Country 3 is abundant in factor 3 if

$$v_{33}/v_{13} > v_{31}/v_{11}, v_{32}/v_{12} \quad \text{and} \quad v_{33}/v_{23} > v_{31}/v_{21}, v_{23}/v_{33}. \tag{13c}$$

The three sets of inequalities in (13) lead to a simple statement of abundance. The first inequalities in (13a) and (13b) together imply

$$v_{11}/v_{21} > v_{13}v_{23} > v_{12}/v_{22}, \tag{14a}$$

a more familiar looking expression. The first inequality in (13c) and with the second in (13a) lead to

$$v_{11}/v_{31} > v_{12}/v_{32} > v_{13}/v_{33}. \tag{14b}$$

Finally, the second inequalities in (13b) and (13c) imply

$$v_{22}/v_{32} > v_{21}/v_{31} > v_{23}/v_{33}. \tag{14c}$$

The three rankings in (14) provide a more traditional definition of factor abundance for the $3 \times n \times 3$ model. These bilateral rankings do not have to hold, but if they do it would make sense to test for correlation with the factor content of trade. The method behind the bilateral rankings in (14) generalizes to models with many factors and countries.

An unambiguous world abundance ranking occurs if $v_{ii}/v_{iw} > v_{ki}/v_{kw}$, for $k \neq i$. In other words,

$$v_{11}/v_{1w} > v_{21}/v_{2w}, v_{31}/v_{3w}, v_{33}/v_{3w} > v_{23}/v_{2w}, v_{13}/v_{1w}, \quad \text{and}$$
$$v_{22}/v_{2w} > v_{12}/v_{1w}, v_{32}/v_{3w}. \tag{15}$$

Country i is world abundant in factor i, $i = 1, 2, 3$. These three sets of conditions are weaker than the abundance in (14). For instance, $v_{11}/v_{1w} > v_{21}/v_{2w}$ implies $v_{11}v_{22} - v_{12}v_{21} > -(v_{11}v_{23} - v_{13}v_{21})$. From (14a), $v_{11}v_{22} - v_{12}v_{21} > v_{11}v_{23} - v_{13}v_{21} > 0$, which might not hold given only world abundance. On the other hand, bilateral abundance in (14) implies all of the weaker conditions in (15).

Given FPE and the rescaling of factors to unit value, the share of country k in world income is $s_k = \sum_i v_{ik}/\sum_i v_{iw}$. An unambiguous ranking of share abundance occurs if $v_{11}/v_{1w} > s_1$, $v_{22}/v_{2w} > s_2$, and $v_{33}/v_{3w} > s_3$. Each of these conditions leads to an inequality weaker than implied by the bilateral abundance in (14). For instance, $v_{11}/v_{1w} > s_1$ implies

$$(v_{11}v_{22} - v_{12}v_{21}) + (v_{11}v_{23} - v_{13}v_{21}) + (v_{11}v_{32} - v_{12}v_{31}) + (v_{11}v_{33} - v_{13}v_{31}) > 0. \tag{16}$$

Under (14), each of the expressions in parentheses is positive. Share abundance only requires their sum be positive.

World abundance implies share abundance, but not the other way around. For instance, world abundance implies $v_{11}v_{22} - v_{12}v_{21} > -(v_{11}v_{23} - v_{13}v_{21})$ and $v_{11}v_{32} - v_{12}v_{31} > -(v_{11}v_{33} - v_{13}v_{31})$, which implies (16). Starting with (16), however, these two conditions do not follow. Share abundance is the weaker condition, and might hold when neither world abundance nor bilateral abundance hold. Bilateral abundance implies both world abundance and share abundance.

In the factor endowment matrix

$$\begin{bmatrix} .5 & .4 & .1 \\ .1 & .5 & .4 \\ .2 & .3 & .5 \end{bmatrix}, \tag{17}$$

both world abundance and share abundance hold, but bilateral abundance does not. Neither world abundance nor share abundance implies the unambiguous bilateral abundance ranking in (14). In the endowment matrix

$$\begin{bmatrix} .4 & .3 & .3 \\ .5 & .4 & .1 \\ .2 & .3 & .5 \end{bmatrix}, \tag{18}$$

neither bilateral abundance nor world abundance holds, but share abundance does. Share abundance is the weakest condition.

The potential of bilateral abundance to generalize is illustrated by the $3 \times n \times 4$ model. Adding the fourth country to (13), $v_{11}v_{21} > v_{14}v_{24}$ and $v_{22}/v_{32} > v_{24}/v_{34}$ in (13a), $v_{22}/v_{12} > v_{24}/v_{14}$ and $v_{22}/v_{32} > v_{24}/v_{34}$ in (13b), and $v_{33}/v_{13} > v_{34}/v_{14}$ and $v_{33}/v_{23} > v_{34}/v_{24}$ in (13c). By renumbering if necessary, country 4 also has a bilateral abundance in factor 3, $v_{34}/v_{14} > v_{31}/v_{11}, v_{32}/v_{12}$ and $v_{34}/v_{24} > v_{31}/v_{21}, v_{32}/v_{22}$. Following the methodology which leads to (14), bilateral abundance implies

$$\begin{aligned} &v_{11}/v_{21} > v_{13}/v_{23}, \quad v_{14}/v_{24} > v_{12}/v_{22}, \\ &v_{11}/v_{31} > v_{12}/v_{32} > v_{14}/v_{34} > v_{13}/v_{33}, \quad \text{and} \\ &v_{22}/v_{21} > v_{21}/v_{31} > v_{24}/v_{34} > v_{23}/v_{33}. \end{aligned} \tag{19}$$

Both world abundance and share abundance can hold, while bilateral abundance does not, as in

$$\begin{bmatrix} .4 & .3 & .2 & .1 \\ .3 & .4 & .2 & .1 \\ .1 & .2 & .4 & .3 \end{bmatrix}. \tag{20}$$

Share abundance can hold when neither world abundance nor bilateral abundance hold, as in

$$\begin{bmatrix} .39 & .41 & .1 & .1 \\ .3 & .4 & .2 & .1 \\ .2 & .3 & .3 & .2 \end{bmatrix} \tag{21}$$

Share abundance is the weakest condition.

5. Conclusion

The factor content theory of trade will ultimately be judged with data in which there are many countries and fewer factors. Trefler (1995) claims that factor content theory has failed. In Trefler's measure of factor abundance, some of the most developed nations (Finland, Norway, Sweden, Switzerland, US, West Germany) are rated as abundant in the fewest factors, while some of the least developed nations (Indonesia, Pakistan, Sri Lanka) and other unlikely ones (Columbia, Greece, Panama, Uruguary, Yugoslavia) are abundant in every factor. This outcome raises questions about the usefulness of the share abundance measure.

Leamer (1984) makes the point that an independent measure of factor intensity, an equally tricky task with many goods, is required to test factor proportions theory. The arbitrary nature of national boundaries suggests nations might be aggregated into more meaningful trading "countries."

The Heckscher-Ohlin model itself applies only to comparisons of two countries, and even then special care must be taken to clarify factor abundance when there are three or more factors. The present paper proposes a bilateral definition factor abundance, closer in spirit to the original. In cases where it holds, tests of the factor content theory would have meaning. It should not be claimed that the factor proportions model has failed based on correlations of the factor content of trade with weak definitions of factor abundance.

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