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The Factor Content of Trade

A Survey of the Literature*

Preliminary Version

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1. Introduction

The foundations for modern trade theory were set with the work of Ricardo (1817), who through the development of the notion of comparative advantage showed how international trade could be mutually beneficial even if one country was more productive than its trade partner in all goods.[1] In this model a country can consume outside of its production possibility frontier by specialising in producing the good it is best at and trading its surplus production with a second country. The reason for beneficial exchange in the Ricardo model was differences in technology between countries. While Ricardo's notion of comparative advantage is elegant and provides invaluable insights in to the determinants and gains from trade, it is also limited in a number of ways. In particular, a theory that suggests complete specialisation is at odds with observed behaviour. Moreover, since the model is based on the assumption of a single factor of production it doesn't allow one to say anything about the effects of trade on the distribution of income across factors. Of most importance for the discussion that follows however is the assumption that trade is driven by exogenously given technology differences, which is unappealing for a number of reasons, most notably because technology itself is a tradable "commodity" and because we would expect that other factors, such as differences in factor endowments, may help explain determinants of a country's comparative advantage. Given these shortcomings alternative theories of trade were sought, with that of Hecksher (1919) and Ohlin (1924) becoming the dominant theory of international trade throughout much of the twentieth century.[2]

The model developed by Hecksher and Ohlin (HO in what follows) is set in a two-country, two-good, two-factor world and returns to the assumption of identical technologies across countries, but allows for differences in factor endowments. It is clear that in addition to differences in technology, countries also differ in their endowments of labour (of different skill levels), land and capital. The classical HO model of international trade looks to predict the pattern of trade in goods for countries with different endowments, holding technology constant.[3] The main result of the HO model is that each country will export the good that uses its abundant factor intensively. Vanek (1968) amongst others extended the simple HO model to allow for more goods and more factors with the result that comparative advantage still works, but predicts trade in factor services rather than in goods. As such, capital-abundant countries should be a net exporter of goods that embody capital, i.e. goods that have a high *factor content* of capital.

When taken to the data the predictions of the HO model and its extension to more goods and factors – the Hecksher-Ohlin-Vanek (HOV) model – are usually not confirmed.[4] This can be seen by the seminal contribution of Leontief (1953) who showed that in 1947 the US exported relatively labour-intensive goods and imported relatively capital-intensive goods. Such results were replicated for different years and countries and seemed to reject the HO model. These early studies generated a great deal of debate, with later studies criticising the methodology of the early

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[1] The theory of comparative advantage and the subsequent development of international trade theory is covered in all international trade textbooks, good examples being Markusen et al (1995), Borkakoti (1998), Feenstra (2004) and Rivera-Batiz and Oliva (2004).

[2] With respect to factor content studies technological differences as determinants of (factor) trade have been reintroduced in the 1990s as we will see below.

[3] Grossman and Helpman (1991) study the HO model in a dynamic setting combining endogenous growth and trade theory.

[4] As discussed by Baldwin (2008, pp. 56-59), Ohlin himself was sceptical of the validity of his model when taken to actual data.

factor content studies and developing alternative tests of the theory. It is only relatively recently that a literature has developed extending the HO model to allow for such things as technology differences, intermediate trade and alternative assumptions on preferences across countries. These changes to the strict theoretical HO model have been more successful in determining the pattern of trade. Other important aspects of trade such as intra-industry trade and scale economies are easily introduced in these models, as in the monopolistic competition models of the new trade theory (see for example Helpman, 1981). Firm heterogeneity has recently been introduced with the seminal contribution of Melitz (2003) being a prime example.

In this paper we provide a survey of the theoretical and empirical literature on the factor content of trade. The paper begins by describing the initial theory of Hecksher and Ohlin before looking at extensions of this theory. This involves a discussion of the model of Vanek extension to more goods and more factors as well as the more recent literature extending the HO model to allow for technology differences, intermediate goods trade and so on. The paper then surveys the empirical literature on the factor content of trade beginning with the seminal study of Leontief (1953).

The remainder of this paper is set out as follows. Section 2 begins by discussing the two-good, two-factor, two-country model of Hecksher and Ohlin (Section 2.1) before extending the model to allow for more goods and factors (Section 2.2). The section concludes by discussing the importance of the strict assumptions upon which this model is based and the implications of relaxing these assumptions. Section 3 proceeds to discuss the empirical literature testing the model of Hecksher and Ohlin. The section begins (Section 3.1) by discussing the early literature, which tended to find little support for the Hecksher-Ohlin model. We then discuss extensions of the literature that discuss methodological and interpretational problems with this early literature (Section 3.2) before discussing extensions that relax many of the assumptions on which the Hecksher-Ohlin model is based (Section 3.3). Section 4 concludes.

2. The Hecksher-Ohlin-Vanek Model of International Trade

In this section we summarize the theory of international trade that is relevant for the discussion of the factor content of trade. We will begin this section by briefly discussing the simple $2 \times 2 \times 2$ model of Hecksher and Ohlin (Section 2.1[5]), in which we assume that there are two goods, two countries and two factors of production. This model is based upon a number of additional restrictive assumptions. An important shortcoming of the simple $2 \times 2 \times 2$ model is that generalisations to more goods, more factors or more countries are not straightforward. In Section 2.2 we introduce the model of Vanek (1968) who tackled some of these problems by focussing on the factor content of trade allowing for more goods and more factors of production. An important conclusion from this latter piece of work is that in a world of more than two goods and factors it is no longer possible to predict the pattern of trade in goods, but that countries abundant in a particular factor of production should export goods that embody more of that factor. As a response to this theoretical result, but also motivated by earlier empirical research including Leontief (1953), researchers have looked to compute the factor content of a country's trade (i.e. the amount of capital, labour and land embodied in the exports and imports of a country) and examine whether this is consistent with what one would expect given that country's

[5] The discussion of the two good, two country, two factor model draws on Falvey (1994).

factor endowments. This is the empirical literature that is reviewed in detail in later sections. Section 2.3 discusses the importance of some of remaining assumptions and extends the models of Sections 2.1 and 2.2 by relaxing some of these assumptions.

2.1. The $2 \times 2 \times 2$ HO model

The Heckscher-Ohlin model is based on a number of restrictive assumptions, many of which are also made in the Ricardian model of comparative advantage. The following is an exhaustive list of assumptions which are usually made when specifying the basic HO model. In Sections 2.2 and 2.3 we will discuss the implications of relaxing some of these assumptions below.[6]

Assumptions of the $2 \times 2 \times 2$ HO model:

1. There are two countries, which we will call H and F
2. There are two goods, which we will call 1 and 2
3. Each country is endowed with two homogenous factors of production, which we will call capital (K) and labour (L)
4. The two goods are produced according to the production function $Q_j = F_j(L_j, K_j),\ j = 1,2$, which are assumed identical in the two countries. This is one of the most important departures from the Ricardian model of comparative advantage and rules out the possibility that trade is based on variations in production technology across countries
5. The production functions for goods 1 and 2 are assumed to be increasing, concave and homogenous of degree one in the inputs (L_j, K_j), implying that there are constant returns to scale in the two goods
6. The production functions for goods 1 and 2 differ in their use of capital and labour
7. The quantities of the two factors in each country are fixed
8. The two factors are perfectly mobile across industries within a country and perfectly immobile across countries
9. The two goods are traded freely
10. There are no market distortions (e.g. taxes, subsidies, imperfect competition, etc) that may affect consumption and production decisions
11. Preferences in the two countries are taken to be identical and homothetic. This assumption rules out the possibility that comparative advantage is driven by differences in demand behaviour. We will discuss whether the HO theorem still holds if we relax this assumption in Section 2.3
12. Countries are assumed to differ in their relative factor endowments. This is a second main departure from the Ricardian trade model, and given the assumption of identical technologies and preferences across countries provides the only real difference between the two countries
13. There are no Factor Intensity Reversals (FIR) and Factor Price Equalisation (FPE) holds. A factor intensity reversal occurs when the comparison of factor intensities changes at different factor prices. We will discuss the implications of this assumption in Section 2.3. It can be shown that as long as both countries are not specialised in production and if trade equates relative product prices internationally, technologies are identical across countries and factor proportions

[6] An extensive treatment is beyond the scope of this contribution. See Dixit and Norman (1980) and Wong (1997) for an extensive treatment.

are different across countries FPE will hold. This is a fairly strict assumption and inconsistent with real world data and we will discuss below the outcome if FPE doesn't hold

14. Trade is balanced (i.e. the value of imports and exports are identical)

Given these assumptions it is clear that on the production side producers of each good (in both countries) will choose the input mix that minimises the costs of producing their chosen level of output. The assumption of constant returns to scale further implies that this cost-minimising input mix depends only on relative factor returns and is independent of the level of output. Given this, we can write:

$$a_{i_j} = a_{i_j}(w_L, w_K) \qquad i = K, L, \qquad j = 1,2 \tag{2.1}$$

where a_{i_j} denotes the number of units of factor i used to produce each unit of output j, which will depend upon the factor prices, with w_L being the wage and w_K being the rental rate[7] The unit cost of production for each product is then given by:

$$c_j = a_{L_j} w_L + a_{K_j} w_K, \qquad j = 1,2 \tag{2.2}$$

which is independent of the level of output. From equation (2.2) it is clear that the derivative of unit costs with respect to wages (rental rate) equals the labour (capital) needed for one unit of production.

The assumptions listed above also guarantee that the two factors of production in each country are fully employed (i.e. there is no unemployment), such that:

$$a_{L_1} Q_1 + a_{L_2} Q_2 = L \tag{2.3}$$

and

$$a_{K_1} Q_1 + a_{K_2} Q_2 = K \tag{2.4}$$

where Q_j is the quantity of good $j = 1,2$ produced. These can be used to solve for output in each country in terms of the factor proportions and endowments. The assumption of perfect competition ensures that in equilibrium the unit price of good j, p_j, is no greater than its average cost, that is:

$$c_j \geq p_j \qquad j = 1,2 \tag{2.5}$$

with (2.5) holding with equality if the good is produced.

On the demand side aggregate consumption is constrained by aggregate income. The budget constraint can be written as:

$$p_1 D_1 + p_2 D_2 = p_1 Q_1 + p_2 Q_2 \tag{2.6}$$

where D_j is aggregate demand for good j. Alternatively, we can express the budget constraint in terms of net exports as follows:

[7] In what follows we will not make this explicit, dropping the term in brackets from the equations.

$$p_1 NX_1 + p_2 NX_2 = 0 \quad (2.7)$$

where NX_j represents net exports of good $j = 1{,}2$.

Given this basic set-up we are in a position to consider the impact of trade between countries H and F, when allowing for differences in factor endowments between these two countries. Factor endowments are defined in terms of the ratios between the capital stocks and labour forces in the two countries. A country is thus relative capital-abundant if its capital-labour ratio is greater than that in the other country. In what follows we will assume that country H (F) is relatively capital (labour) abundant, such that $\bar{k}^H > \bar{k}^F$, where $\bar{k}^n$ is the endowment capital-labour ratio in country $n = H, F$, and that good 1(2) uses capital (labour) more intensively at all factor prices (Assumption 13).

Given the assumptions of identical relative prices and identical homothetic preferences the two goods 1 and 2 will be consumed in the same proportions in the two countries. Consumption of good j in the home country can then be written as:

$$D_j^H = \alpha\left(D_j^H + D_j^F\right) = \alpha\left(Q_j^H + Q_j^F\right), \qquad j = 1{,}2 \quad (2.8)$$

where Q_j^i is the quantity of good $j = 1{,}2$ produced in country $n = H, F$ and α is the home share of world income, that is:

$$\alpha = \frac{(w_L + w_K \bar{k}^H)L^H}{(w_L + w_K \bar{k}^H)L^H + (w_L + w_K \bar{k}^F)L^F} \quad (2.9)$$

where the returns to capital and labour are the same in the two countries given the assumed factor price equalisation. Defining the share of home output in total world output in the free trade equilibrium of good j as β_j, that is:

$$Q_j^H = \beta_j (Q_j^H + Q_j^F) \quad (2.10)$$

then we have:

$$\beta_j = \frac{(k_l^H - \bar{k}^H)L^H}{(k_l^H - \bar{k}^H)L^H + (k_l^F - \bar{k}^F)L^F} \qquad l, j = 1{,}2,\ l \neq j \quad (2.11)$$

Given (2.10) and (2.11) we can write an expression for imports of good j as:

$$M_j = D_j - Q_j = \left(\alpha - \beta_j\right)(Q_j^H + Q_j^F) \quad (2.12)$$

The home country therefore imports (exports) good j if $\alpha > (<) \beta_j$, or using equations (2.9) and (2.11) when,

$$\frac{\bar{k}^H - \bar{k}^F}{(k_i^H - \bar{k}^H)L + (k_i^F - \bar{k}^F)L^F} > (<) 0 \quad (2.13)$$

Making the assumption above that the home country is relatively capital-abundant ($\bar{k}^H > \bar{k}^F$) then $\beta_2 > \alpha > \beta_1$ and it will export (import) the relatively capital (labour)-intensive good. This is the (quantity version of the)[8] HO theorem which can be stated as:

> *If the conditions for FPE are met and both countries have identical homothetic tastes, then under free trade each country will export the product making relatively intensive use of its relatively abundant factor.*

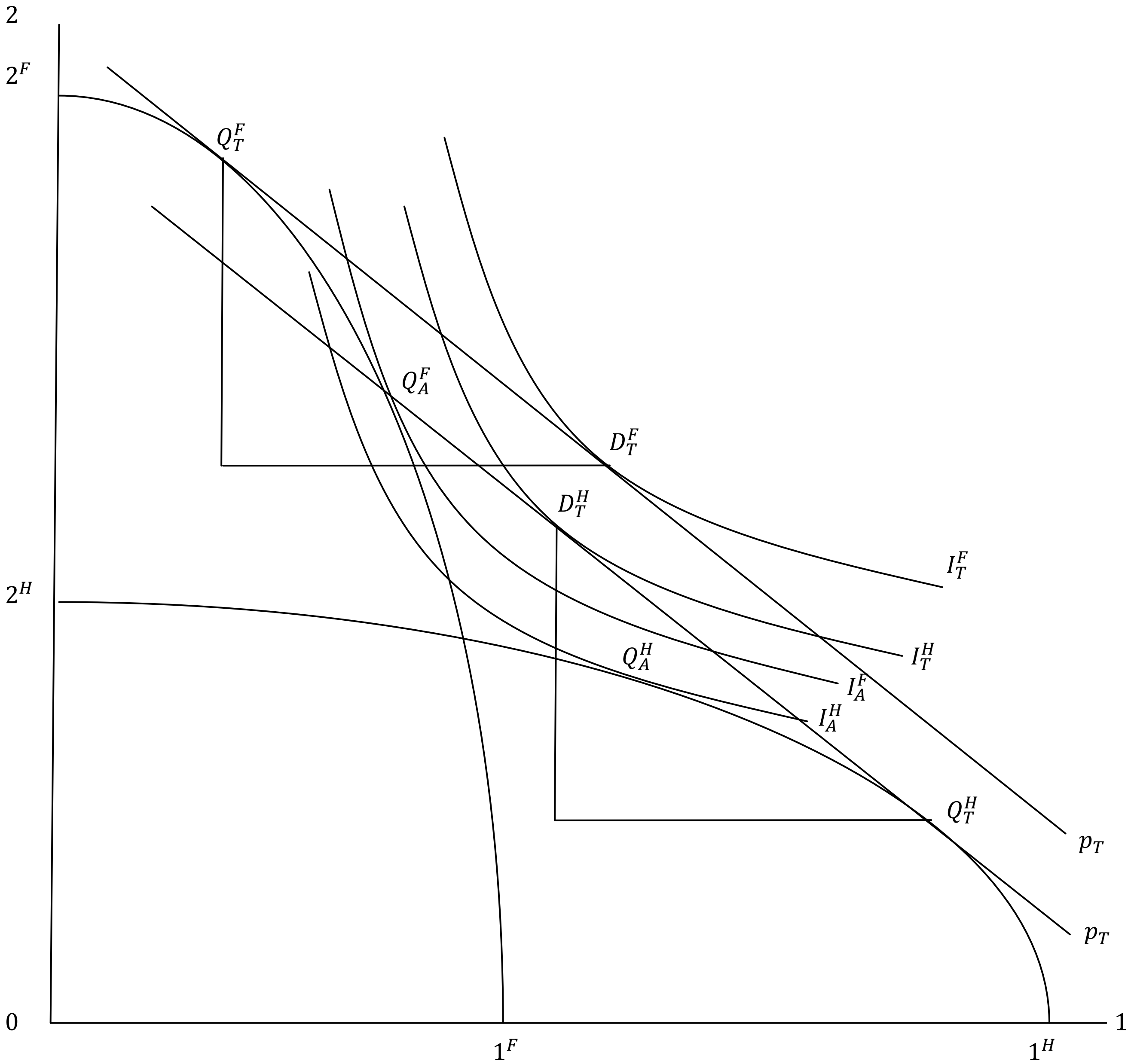
Intuitively, this states that for full employment to hold under the assumptions of identical technologies and factor prices (meaning that identical factor proportions will be used in each industry in the two countries) the relatively capital-abundant country will have to employ relatively more of its resources in the capital-intensive sector. With products consumed in the same proportions in each country, this implies that the capital-intensive product will be exported.

The HO model can also be represented graphically. Figure 1 depicts the production possibility frontier for the two countries, with that for H (F) – the relatively capital- (labour-) abundant country – being given by 02^H1^H (02^F1^F), i.e. country H is better at producing the relatively capital-intensive good 1. Also included in the figure are community indifference curves – that reflect the assumptions of identical and homothetic preferences. Under autarky the highest community indifference curve that country H can reach is I_A^H, with the associated price ratio given by the gradient at the point of tangency, while country F can reach indifference curve I_A^F. It is clear therefore that in autarky the price ratio (defined as p_1/p_2) of H is lower than that of country F.[9] These differences in autarky relative prices allow for gains from trade. When we allow for trade, residents in country F (H) will observe that good 1(2) is cheaper in country H (F) and will therefore import some of this good from the other country. The increase in demand for good 1(2) in country H (F) and corresponding decline in demand for good 1(2) will lead to a shift in production. This change in production will lead to a corresponding change in the price ratio, which will increase in country H and decrease in country F. Changes in production will continue until the excess demands and supplies of the two goods are satisfied in both countries, which will lead to the equalisation of the price ratio in the two countries (given by the lines p_T in Figure 1). This price equalisation occurs at points of equal slope on both production possibility frontiers (given by Q_T^H and Q_T^F in H and F respectively in Figure 1). An important implication of this result is that in general both countries will produce both goods, which is different to the Ricardian model and more in line with observed behaviour. Finally, for equilibrium, we require that the world excess demand and supplies of the two countries be zero, i.e. exports minus imports of each good sum to zero. This is shown in Figure 1 where the two trade triangles are equal. At the new equilibrium both countries consume on indifference curves that lie outside their production possibility frontiers and so both gain from trade. The figure also reveals that country H (F) produces more of good 1(2) than it consumes, implying that country H (F) exports good 1(2).

[8] There is also a price version of this theorem, which states that each country will have the lower autarky relative price of the product making intensive use of its relatively abundant factor, and will export that good in the trading equilibrium.

[9] It is also straightforward to see that these autarky relative prices would be the same regardless of the size of the country, since the equilibrium points at different country sizes would lie along the rays OQ_A^H and OQ_A^F for country H and F respectively. It is the relative factor endowments and factor intensities that are important.

Figure 1: The Hecksher-Ohlin Theorem



Two other important theorems are often related to the HO theorem, namely the Stolper-Samuleson and Rybczinski theorems. These are not directly relevant for the discussion that follows, but for completeness we will state them here. The Stopler-Samuelson (Stolper and Samuleson, 1941) theorem states that an increase in the relative price of a good will increase the real return to the factor used intensively in the production of that good and reduce the real return to the other factor (assuming constant returns to scale and incomplete specialisation),[10] while the Rybczinski theorem (Rybczinski, 1955) states that an increase in the supply of a factor will lead to an increase in the output of the good using that factor intensively and a decrease in the output of the other good (assuming that relative prices are constant and incomplete specialisation).

[10] Assuming no factor intensity reversals.

2.2. Extension to Many Goods and Factors – the Hecksher-Ohlin-Vanek (HOV) model

While the $2 \times 2 \times 2$ model is based upon a number of restrictive assumptions, the most restrictive assumption when taken to the data is the assumption of only two goods and two factors of production. During the 1960s authors such as Travis (1964), Melvin (1968) and Vanek (1968) extended the basic HO model to allow for more goods and factors.[11] Melvin (1968) for example showed that adding a third good to the model leads to a problem of indeterminancy of both production and trade if all three goods are produced. In such cases, the (relatively) capital-abundant country need not export the most capital-intensive good. Melvin (1968) showed that if we were to add a third good (good 3) to our analysis with $\frac{K_2}{L_2} > \frac{K_1}{L_1} > \frac{K_3}{L_3}$ it is possible that the relatively capital-abundant country would export goods 2 (as would be expected from the HO model) and 3 and import 1. Despite this, under balanced trade the HO model does generalise in another way however. Melvin (1968) showed that the bundle of goods exported by the capital-abundant country will be more capital-intensive, in the sense that it will embody a higher ratio of capital to labour than its import bundle (with the reverse being true for the labour-abundant country).

Travis (1964) and Vanek (1968) extended the HO model to the many-good, many-factor case, maintaining the other assumptions listed above (though any number of countries is possible). Vanek (1968) showed that it is possible to rank the endowments of a country by computing its share of each endowment in the global supply of that factor, with the most abundant factor being the one with the highest relative share. Given this ranking a factor is described as being abundant in a country if the country's share in that factor exceeds that country's share of global income. Computing the amounts of each factor that are used to produce the bundle of exports, imports and Gross National Income (GNI) leads to the Heckscher-Ohlin-Vanek (HOV) theorem on the factor content of a country's trade:

> *For an arbitrary but equal number of goods and factors, a ranking of the content of any factor in net exports divided by its content in total output will duplicate the ranking of relative factor endowments.*

In other words, comparative advantage still works, but predicts trade in factor services rather than in goods. The factor content theorem generalises for any number of factors and goods as long as the number of goods produced in each country is at least as large as the number of factors.

To discuss the extension to many goods and factors we will need to introduce some new terminology. Let F_i^n be the amount of any factor i ($i = 1, \ldots, I$) embodied in the vector of net exports of any country n ($n = 1, \ldots, N$), and a_{ji} be the amount of factor i needed to produce one unit of good j ($j = 1, \ldots, J$). In addition, let V_i^n be country n's endowment of factor i, V_i^W be the world endowment of factor i, and $s^n = (Y^n - NX^n)/Y^W$ be country n's GNI (Y^n) minus its net exports (or trade balance)[12] divided by world GNI. Since it is assumed that all

[11] Dornbusch et al (1977) formalised a model with a continuum of goods in a Ricardian framework, while Dornbusch et al (1980) do something similar in the HO framework.

[12] Or alternatively, country n's aggregate consumption $D^n = Y^n - NX^n$.

income is spent on goods and services, Y^W is also equal to the world's aggregate consumption of goods and services, D^W. This means that s^n is equal to the share of country n's consumption in total world consumption, and under balanced trade it is equal to the country's share of world GDP.

We can now write the vector of net exports for country n as $NX^n = Y^n - D^n$. The vector of the factor content of trade is then defined as $F^n \equiv ANX^n \equiv AY^n - AD^n$, where A is the matrix of factor requirements to produce one unit of each good, i.e. $A = [a_{ji}]$. For a particular factor i, F_i^n will be positive if the factor is exported and negative if the factor is imported. It is straightforward to see that AY^n is equal to the endowment of country n, which using the above terminology is written as $AY^n = V^n$. Given the assumption of identical and homothetic preferences the proportion of a country's total consumption expenditures spent on a particular good is the same in all countries, with differences in the amount of a particular good consumed across countries due solely to differences in the levels of overall consumption across countries. Making use of the above definitions and assuming full employment, which implies that world production exhausts the use of all factors of production, we can write $Y^n = s^n Y^W = s^n D^W = s^n V^W$. Given this, the basic HOV model can be expressed as:

$$F^n = V^n - s^n V^W, \tag{2.14}$$

and in terms of individual factors as:

$$F_i^n = V_i^n - s^n V_i^W \tag{2.15}$$

This latter equation states that if country n's endowment of factor i relative to the world endowment exceeds country n's share of world GDP $\left(\frac{V_i^n}{V_i^W} > s^n\right)$, then country n is abundant in that factor, and the factor content of trade in factor i should be positive ($F_i^n > 0$) for this country. Baldwin (2008) provides the following intuition for such a result. As mentioned above, the assumption of identical and homothetic preferences implies that the proportion of a country's total consumption spent on a particular good is the same in all countries. Similarly, given the assumptions of identical technologies, constant returns to scale, FPE and no FIRs all countries use the same amount of each factor per unit of output of each good (i.e. the a_{ji}'s are common across countries). As such, countries not only consume goods in the same proportion, but also the productive factors embodied in the goods. This further implies that a country whose endowment of a productive factor (V_i^n) is greater (less) than the country's consumption of that factor ($s^n V_i^W$) becomes a net exporter (importer) of that factor (embodied in goods). The result of Vanek further implies that the ordering of the ratios of a country's endowment of each factor to the world endowment of that factor is the same as the ordering of the trade in each factor to the world endowment of that factor. As such, the generalisation of the HO theorem by Melvin (1968) continues to hold: countries export (import) their relatively abundant (scarce) factors.

2.3. Extending the HOV model

As we will see in Section 3 the HO and HOV models in the form described above have found to perform poorly when confronted with data. This is the case both for the predictions of the model but also when testing the underlying assumptions directly (see Appendix C). As a response to this a number of studies have attempted to relax one or more of the highly restrictive assumptions to examine the implications with respect to theory, while others have introduced other extensions to the model to allow for such things as non-tradable and intermediate goods. This section briefly discusses the effects of these extensions on the HO and HOV model. This is done here in a purely theoretical manner, with the results from empirical applications of these extensions are discussed in Section 3.

Assumption 4 – Technology Differences

An important distinction between the Ricardian and HO model is the assumption of identical technologies across countries in the HO framework. It is clear that in the real world technology levels differ across countries, partly because countries undertake different levels of innovation and partly because the diffusion of technology across countries is not perfect. There is the obvious problem when relaxing this assumption and allowing for technology differences across countries that technology itself can be a reason for trade. The effect of relaxing this assumption is also likely to depend upon how technology differences are modelled. If technology differences are factor-augmenting, meaning that a factor in one country is uniformly more productive than the same factor in the other country (regardless of the sector), then such differences will act much like factor endowment differences. In such a case, the HO theorem will be maintained, but specified in terms of "effective" factor endowments. If however, technology differences are due to sectoral TFP differences, meaning that one country can produce a larger output from the same factor inputs in a particular sector, then it can be difficult to classify goods in terms of their factor intensities and the HO theorem breaks down. It can be shown however that if the capital-abundant (labour-abundant) country is (relatively) technologically advanced in the capital-intensive (labour-intensive) good then the HO theorem always holds. If, on the other hand, the capital-abundant (labour-abundant) country is (relatively) technologically advanced in the labour-intensive (capital-intensive) good the HO theorem need not hold. Whether the theorem holds will depend upon the extent of the technological difference: if the difference is not too large the HO theorem may hold. As we will see below, the extension of the HO and HOV models to allow for technology differences goes some way to help explain the poor performance of the models in predicting the factor content of trade.

Trefler (1993, 1995) introduces factor-augmenting productivity differences across countries into the HOV model, which he argues is the major reason for the lack of FPE.[13] To do this he defined $\tilde{V}_i^n = \pi_i^n V_i^n$ as the endowment of country n of factor i in productivity-equivalent units, with π_i^n being the productivity parameter. He further defined w_i^n as the price per unit of V_i^n and $\widetilde{w}_i^n$ the price per unit of $\tilde{V}_i^n$. Using these definitions Trefler notes that $1/\pi_i^n$ units of V_i^n provides one productivity-equivalent unit of service priced at:

$$\widetilde{w}_i^n = \frac{w_i^n}{\pi_i^n}$$

[13] Other studies that focus on a lack of FPE include Bardhan (1965), Deardorff (1979, 1982), Brecher and Choudhri (1982b), Woodland (1982) and Helpman, (1984).

Letting $\tilde{A}^n(\tilde{w}^n)$ be country n's technology matrix when factors are measured in productivity-equivalent units, with $\tilde{w}^n = (\tilde{w}_1^n, \dots, \tilde{w}_I^n)$ and assuming that $\tilde{A}^n = \tilde{A}^{n^*}$ for all country pairs n and n^*, Trefler shows that the FPE and HOV theorem hold, with V_i^n replaced by $\tilde{V}_i^n$ and w_i^n with $\tilde{w}_i^n$. More formally, this can be expressed as:

$$\tilde{F}_i^n = \pi_i^n V_i^n - s^n \sum_{p=1}^{N} \pi_i^p V_i^p \tag{2.16}$$

$$\frac{w_i^n}{\pi_i^n} = \frac{w_i^{n^*}}{\pi_i^{n^*}}, \qquad n, n' = 1, \dots, N \tag{2.17}$$

As we will discuss below other studies include alternative assumptions on technology, examples including Trefler (1995), Davis and Weinstein (2001a) and Lai and Zhu (2007).

Assumption 11 – Differences in Tastes across Countries

In order to isolate the effects of differences in factor endowments on the pattern of trade it was assumed that tastes were identical and homothetic in the two countries. It can easily be shown that if this assumption is relaxed the pattern of trade predicted by the HO theorem can be reversed. This would be the case for example, if the capital-abundant country had a sufficiently large taste bias towards the relatively capital-intensive good. In such a case the high demand for the capital-intensive good in the capital-abundant country leads to a relatively high demand for K so that the rental rate increases, and hence the supply price of the capital intensive good is high. Whether the HO theorem no longer holds will depend on the nature of the differences in tastes and the extent of such differences. If the difference in tastes is not too large however the HO theorem will still hold. If the capital-abundant country has a taste bias towards the labour-intensive good then the HO theorem will also continue to hold.[14]

Trefler (1995) introduces alternative assumptions on consumption into the HOV model. Firstly, he argues that the observed consumption shares (s) in developed and developing countries may be different to the actual ones (γ). This can occur because investment spending is not taken account of when calculating the observed consumption shares in the HOV model. This omission would be expected to result in the actual consumption share being less than the observed share in developed countries. Trefler begins by defining the trade balance as $T^n = Q^n - D^n - Z^n$, with Q^n being production and Z^n being the vector of investment goods, and γ^n determined from $D^n = \gamma^n D^W$. Then letting p be the output price vector he shows that $\gamma^n = \frac{(Y^n - NX^n - p'Z^n)}{(Y^W - \sum_{p=1}^{N} p'Z^p)}$, implying that heavily investing rich countries will have $\gamma^n < s^n$. He shows further that the HOV equation under this assumption is given by:

$$F_i^n = V_i^n - \gamma^n V_i^W + \mu_i^n \qquad \text{s.t.} \sum_n \gamma^n = 1 \tag{2.18}$$

where $(\mu_1^n, \dots, \mu_I^n) = A(Z^n - \gamma^n \sum_{p=1}^{N} Z^p)$. This same results hold if Z is interpreted as services and/or nontradables.

[14] Linder (1961) emphasises differences in preferences as a reason for trade. Hunter (1991) discusses the possibility of non-homotheticity of preferences.

As an alternative, Trefler allows for a bias in preferences towards domestically produced goods, along the lines of Armington (1969). To do this he generalises the HOV demand assumption $D^n = s^n D^W = s^n Q^W$ by distinguishing between domestic (Q^n) and foreign ($Q^W - Q^n$) goods. Demand can thus be written as:

$$D^n = s^n[\varphi^n Q^n + \varphi^{n*}(Q^W - Q^n)] \quad (2.19)$$

where $\varphi^n > 1$ and $\varphi^{n*} < 1$ capture home bias. Premultiplying this by p imposes a balanced budget and yields:

$$\varphi^n \left(\frac{Y^n}{Y^W}\right) + \varphi^{n*}\left(1 - \frac{Y^n}{Y^W}\right) = 1 \quad (2.20)$$

World market clearing implies:

$$\sum_n s^n \left[(1 - \varphi^{n*})\frac{Y^W}{Y^n} V_i^n + \varphi^{n*} V_i^n\right] = V_i^n \quad (2.21)$$

Given the above equation the HOV equation implied by the Armington assumption is:

$$F_i^n = V_i^n - s^n \left[(1 - \varphi^{n*})\frac{Y^W}{Y^n} V_i^n + \varphi^{n*} V_i^n\right] \quad (2.22)$$

Assumption 12 – Relative Factor Endowments

One of the main differences between the HO model and the Ricardian model is the assumption that there are differences in factor endowments across countries in the HO model. It can be shown that the HO theorem will hold regardless of how big these differences are, but other results such as FPE and the Stopler-Samuelson and Rybczinski theorems need not.

Davis and Weinstein (2001b) argue that when endowment differences lead to a breakdown of FPE, then a set of equilibrium factor prices and the associated goods that can be competitively produced at these factor prices define a "cone" in factor space. FPE will then hold for countries whose endowments lie within the same cone, but it will not for countries in different cones. Considering the case of a country with intermediate capital abundance, Davis and Weinstein (2001b) note that such a country will trade with countries that are both more and less capital-abundant. The country should be a net importer of capital services from the countries more abundant than itself, and a net exporter of capital services to those countries less abundant in capital. Denoting the set of countries more [less] capital-abundant than n as $N^+(n)$ $[N^-(n)]$, and exports from [imports to] n to n^* as E^{nn^*} $\left[M^{nn^*}\right]$, then the factor content of trade of n with countries that are more capital-abundant than itself is given by:

$$\bar{A}^n \sum_{n \in N^+(n)} E^{nn^*} - \sum_{n \in N^+(n)} \bar{A}^{n^*} M^{nn^*} = \sum_{n \in N^+(n)} s^{n^*} V^n - s^n \sum_{n \in N^+(n)} V^{n^*} \quad (2.23)$$

with a similar condition holding for countries less capital-abundant than n.

Non-Tradable Goods

Davis and Weinstein (2001b) argue that it is straightforward to incorporate non-traded goods into the HOV model with FPE. Letting V^{nNT} be the amount of primary factors devoted to non-traded production in country n, then the residual endowments that will be available for production of exportables in country n will be given by $V^{nT} \equiv V^n - V^{nNT}$, and endowments available for exportables production in the world as a whole will be given by $V^{WT} \equiv \sum_n V^{nT}$. Davis and Weinstein (2001b) go on to show that the factor content of trade can be defined as $F^n = V^{nT} - s^n V^{WT}$, and that under the assumptions of FPE and free trade it is true that $V^{nNT} = s^n V^{WNT}$. Adding $V^{nNT} - s^n V^{WNT} = 0$ to the factor content equation above $F^n = V^n - s^n V^W$, which is the same as that for the standard HOV model without non-tradables (i.e. equation 2.14). As such, as long as there is FPE the presence of non-traded goods does not affect the factor content of trade theorem.

Intermediate Goods

Davis and Weinstein (2001b) introduce the use of intermediates into the theoretical model of HOV. In this case, the matrix A refers to the matrix of primary (or direct) factor inputs, with an additional input-output matrix $\acute{A}$ giving the unit input requirements of one good in the production of another. It is further necessary to distinguish between gross output Y^n and net output available for final demand, $\acute{Y}^n$. The relationship between net and gross output is given by $\acute{Y}^n = (\mathrm{I} - \acute{A})Y^n$, where I is the identity matrix. Since only net output is available for final consumption we can write $D^n = s^n Y^W$. Assuming that $(\mathrm{I} - \acute{A})$ is invertible, a matrix of total (direct and indirect) factor inputs can be written as $\bar{A} = A(\mathrm{I} - \acute{A})^{-1}$, and a statement of the HOV model in the presence of intermediates can be written as:

$$\bar{A}NX^n = V^n - s^n V^W \tag{2.24}$$

and in terms of individual factors as:

$$\bar{A}_i NX^n = V_i^n - s^n V_i^W \tag{2.25}$$

Allowing for the possibility of trade in intermediates Davis and Weinstein (2001b) note that if all countries use identical techniques, the standard HOV equations can be implemented because goods will always embody the same amount of factors regardless of where they are produced. In the case where FPE doesn't hold things become more difficult because all exports and imports embody a combination of domestic and foreign factors, with the factor content of trade depending on all of the input-output relationships and technological differences in all countries.

The approach of Davis and Weinstein (2001b)[15] implicitly assumes that all intermediates are non-tradable, since they impute the factor content of imported intermediates using domestic factor intensities in the presence of international technique differences. Reimer (2006) extends the approach of Davis and Weinstein to measure the factor content of a good that is produced using an input sourced from multiple countries, each of whom use different techniques.[16] The main change to the model of Davis and Weinstein is the construction of a global input-output matrix that distinguishes a good by country of final assembly. As such $\acute{A}$ becomes a global input-output matrix of dimension $(JN \times JN)$ where J is the number of goods and N the number of countries.

[15] See also Hakura (2001).

[16] See also Trefler (1996) and Trefler and Zhu (2000, 2010). These papers develop a framework allowing for both technique differences and traded intermediates in a model consistent with Vanek's original prediction.

This implies that the number of columns in the global matrix is scaled up by the number of countries examined.

Assumption 13 – Factor Intensity Reversals and Factor Price Equalisation

A central pillar of the HO theorem is the ability to characterise goods as either relatively labour- or capital-intensive. Relaxing this assumption and allowing for factor intensity reversals implies that for some factor return ratios each product is capital-intensive, while at others each product is labour-intensive. This raises the possibility that the relatively capital-intensive product in one country will be the same product as the relatively labour-intensive product in the other. Since both countries cannot export (or import) the same good in equilibrium, both must be exporting either their labour-intensive or their capital-intensive products and so one country must violate the HO theorem.

Davis and Weinstein (2001b) discuss the conditions under which FPE may fail to hold. They discuss the possibility of a so-called FPE club where members of the club share FPE, but countries outside the group need not. In such a case, club members share a common technology matrix. Letting $r \in R$ be a set of countries which share FPE, and $\bar{A}^r$be the common technology matrix, then the factor content equation for countries in the club is given by:

$$\bar{A}^r NX^r = V^r - s^r \bar{A}^r Y^W \quad (2.26)$$

Davis and Weinstein (2001b) go on to discuss the reasons for a breakdown in FPE. One such reason for a breakdown of FPE is due to a systematic correlation between country capital abundance and industry input usage in both tradables and non-tradables. In such a case, capital-abundant countries with high wages will use more capital-per-worker in non-traded sectors, implying that measures of excess factor supplies overstate how much of the abundant factor is available for production of exportables. Letting the appropriate technology matrix for country n in this case be A^{nH} the appropriate measure for this version of the HOV model is:

$$\bar{A}^{nH} Y^{cT} - \sum_{n^*} \bar{A}^{n^*H} M^{nn^*} = [V^n - s^n V^W] - [V^{nNT} - s^n V^{WNT}] \quad (2.27)$$

where T and NT refer to traded and non-traded goods respectively and M are imports by country n from country n^*.[17] Here the measured factor flows of trade are measured using the producer's technology. Predicted factor flows are also adjusted to take account of the fact that countries abundant in a factor tend to use that factor more intensively in non-traded production, thus leaving less available for the production of exportables.

3. Empirical Evidence on the HO and HOV models

There are a number of methods of testing the HO model and its extensions, which will be reviewed in this section. As Davis and Weinstein (2001b) note however, given the lack of an alternative framework relating endowments to trade it is not possible to test the HOV against a well-specified null hypothesis. As such, researchers often run a horse-race between various

[17] The superscript H stands for Helpman (1984) who proposed such an approach. Both Deardorff (1982) and Helpman (1984) argue that when techniques of production vary across countries, the factor contents should be measured using the producer's technology.

versions of the model choosing the one that best fits the data. Early studies, such as that of Leontief (1953) can be related directly to the HOV model, which – as we have seen – states that a country exports the services of the relatively abundant factors which are embodied as factor contents in the exported goods and imports the services of the relatively scarce factors which are embodied as factor contents in the imported goods. The method thus involves comparing the factor content – usually the capital-labour ratio – of exports to that of imports and examine whether the results are consistent with data on a country's factor endowments.

Bowen, Leamer and Sveikauskas (1987) amongst others have made use of two further tests of the HOV theorem. The sign test is a test of whether the sign of actual factor content of trade is the same as that on the predicted factor content of trade. The sign test can be written as $\text{sign}(F_i^n) = \text{sign}(V_i^n - s^n V_i^W)$. With I factors and N countries there are IN observations in total, with the relevant statistics being the percentage of these that have the same sign on both sides of the equation. A coin toss would be expected to give a 50 percent success rate so the test should give a significantly higher percentage in order to support the HOV model. Large outliers are thus unlikely to affect the results from this test, but countries with small predicted factor contents of trade may have many sign errors without indicating a major problem for the theory. Rank tests put a little more structure on the data by asking whether countries that are predicted to be large exporters (importers) of a factor are measured to do so. The rank test can be expressed as $F_i^n > F_l^n \Leftrightarrow (V_i^n - s^n V_i^n) > (V_l^n - s^n V_l^n)$. The rank test involves a pairwise comparison of all factors for each country so that there are $I(I-1)/2$ pairs for each of the N countries. If the computed factor contents of one factor exceed that of a second factor, we check whether the relative abundance of that first factor exceeds the relative abundance of the second factor. Once again, random assignment of factor abundance would imply that in 50% of comparisons, the rank test would be satisfied. The problem with this test arises when there are a large number of countries with similar predicted factor contents of trade. Kohler (1991) shows that the rank and sign tests can be formulated in different ways and that the different formulations of these tests may lead to different test results for a given data set, if these data do not satisfy the strict version of the model. A further test of the HOV theorem involves regression based tests which regress the actual and predicted factor contents of trade (i.e. the left and right hand sides of equation 2.15) and consider the slope coefficients and fit of the regression.

The remainder of this section reviews the main empirical results considering the factor content of trade. We begin in Section 3.1 by considering the first and most often cited study of Leontief (1953) who compared the factor content of exports to imports for the USA in 1947. His results were found to be inconsistent with the HO model, a result that came to be known as the Leontief Paradox. In particular, he found that US exports were labour-intensive, which goes against the conventional wisdom that the USA was a relatively capital-abundant country in 1947. Following this perverse result a number of subsequent studies sought to replicate Leontief's approach for different periods and countries. This early literature, which is based upon a strict interpretation of the HOV model, tended to find results at odds with the theoretical model, with capital-abundant countries being found to export labour-intensive goods. Section 3.2 considers various responses to this early literature that propose various methodological and interpretational improvements upon this early literature. Section 3.3 then considers the recent literature that relaxes the strict assumptions of the HOV model. This section does not cover the related literature that while not directly testing the HOV model relate to the implications of the HOV model. A number of papers for example relate information on factor endowments to a measure of trade at either the sector/industry or country level. A selection of these studies are summarised in Appendix B. We also do not review the literature testing the assumptions of the HOV model in this section. Appendix C however provides a brief overview of papers that relax some of the HOV assumptions.[18] Finally, Section 3.4 briefly discusses some of the more recent literature on the factor content of trade.

3.1. Early Studies of HOV

3.1.1. The Leontief Paradox

Early empirical studies of the factor content theory directly tested the theory by comparing the factor content of exports with that of imports and examining whether the resulting ratio was consistent with what would be expected given a country's factor endowments. The seminal study in this regard is that of Leontief (1953).[19] Starting from the conjecture that "[the United States] has a comparative advantage in the production of commodities which require for their manufacture large quantities of capital and relatively small amounts of labour" (pp. 332-333), Leontief sought to examine whether the data on the factor content of U.S. trade was consistent with this conjecture. Leontief (1953) based his analysis on input-output analysis, which he himself had helped develop as a leading member of the Harvard Economic Research Project, Studies in the Structure of the American Economy (1952).[20] Input-output tables show how each industry or sector depends on other industries, by taking account of the fact that the production of a good usually requires the use of primary factors of production (e.g. labour, capital, etc) as well as intermediate inputs from other industries. Such intermediates are also likely to have been produced using primary factors and intermediate goods. Using information from IO tables to calculate the direct input of capital and labour in an industry and the indirect capital and labour embodied in intermediates used in that industry allows one to compute the total labour and capital embodied in production in a given industry.

Leontief used the 1947 IO table for the United States to calculate the direct and indirect requirements of labour and capital required to produce 1 million dollars of output in each of 200 industries, which were eventually consolidated in to 50 industries, of which 38 engaged directly in international trade. Leontief then considered what would happen if the U.S. decreased both its imports and exports by 1 million dollars, under the assumption that the reduction would leave the composition of exports and imports unchanged. A problem with this approach is that while one can use the US input-output table to compute the factor content of US exports, in order to compute the factor contents of US imports one would require similar and consistent data on

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[18] There are alternative ways of splitting up this literature. An alternative would be to split the discussion of the factor content studies into partial and complete tests of the HOV model. Leamer and Bowen (1981) and Maskus (1985) for example emphasise that a complete test of the HOV model requires data on technology (A in our terminology), trade (B) and endowments (V). The vast majority of studies only use data on two of these three, meaning that they are partial studies of the HOV model. Few studies conduct complete tests of the HOV model by using data on all three of these variables.

[19] The original paper published in the Proceedings of the American Philosophical Society was reprinted in Economia Internazionale in 1954. Some texts refer therefore to Leontief (1954).

[20] A comprehensive review of IO methods is Miller and Blair (2009). Dorfman (1954) was an early critic of the IO methodology.

production techniques in all foreign trading partners. This was not feasible in 1947, with this data even today only available for a subset of trade partners. To get around this issue Leontief calculated the capital and labour required to produce US goods that are similar to (or compete with) American imports.[21] As discussed by Markusen et al (1995) such an approach is valid if either: (i) the factor endowments model holds and international factor prices are equalised, with each country sharing the same techniques of production, or (ii) if productions functions exhibit fixed coefficients, or a constant ratio of capital to labour regardless of the factor-price ratio.

The main results of Leontief are reported in Table 3.1, which shows that the capital-labour ratio of competitive import replacements was larger than that for exports. In particular, the capital-labour ratio measured in terms of capital per worker year in the import replacement sector was found to exceed that in the export sector by around 30 percent, or as Borkakoti (1998) writes the α-index, defined as the ratio of the capital-labour ratio for import replacements to the capital-labour ratio for exports, is 1.30 (i.e. \$18,184 / \$13,991). Given the assumption that the USA was a capital-abundant economy (relative to the rest of the world) the finding that the capital-labour ratio in the import replacement sector exceeded that in the exports sector was surprising, and came to be known as the 'Leontief Paradox'. Leontief (1953) himself didn't actually argue that this was a paradox and explained the difference by arguing that the productivity of labour in the USA was three times as large as that in the rest of the world. If this were the case – and no evidence was provided to indicate that it was – then the USA would be considered labour-abundant in terms of efficiency units of labour. The argument of Leontief that the paradox was due to technological differences across countries has since been taken up by a number of researchers, most notably Trefler (1993, 1995).[22]

Table 3.1. Leontief's Results

	Capital (1947 prices)	Labour (worker years)	Capital/Labour ratio
Exports	$2,550,780	182,313	$13,991
Import replacements	$3,091,339	170,004	$18,184

In response to the paradoxical results of Leontief (1953) a series of papers looked to replicate the results of Leontief for different countries and time-periods. The results from some of these studies are summarised in Table 3.2 and discussed in more detail below.

A particularly troubling aspect of the Leontief study was the use of input-output tables for 1947. The HO model is an equilibrium concept and it is difficult to believe that the USA and more importantly the trade partners of the USA (e.g. Japan, Germany, France, the UK) were in

[21] This approach also implies that one need not be worried about the production techniques in all trading partners, since one considers total imports from the rest of world. This combined with the assumption of only two factors of production implies that Leontief's approach fits in with the standard two-good (i.e. exports and competitive import replacements), two-country (i.e. USA and the rest of the world), two-factor (i.e. capital and labour) model.

[22] Keesing (1967) and Gruber and Vernon (1970) amongst others adopted a regression approach (see Appendix B) and show that measures of R&D spending and the share of engineers and scientists in an industry's workforce – used as proxies for technology – are positively correlated with industry exports. Other studies using the regression approach have identified the importance of human capital (Kravis, 1956; Keesing, 1965, 1967; Kenen, 1965; Yahr, 1968) and scale economies (Hufbauer, 1970) for net exports. Vanek (1963) argued that introducing natural resources as a third factor of production may explain the Leontief paradox, though his own work (Vanek, 1968) and that of Travis (1964) dismissed this suggestion.

equilibrium at a time when the world economy was recovering following the end of the Second World War. Leontief (1956) therefore carried out an additional study using the same methodology, but using trade composition data from 1951. Leontief continued to use the 1947 IO table, but considered a broader sample of 192 distinct sectors. In addition, he also took account of capital replacement costs in this latter study. The results indicated a decrease in the capital-labour ratio in both the import competing and export sector, but the Leontief paradox remained, with the capital-labour ratio in the import-competing sector exceeding that in the export sector by 6 percent. Leontief was able to show however that when removing 19 resource-based industries from the sample of 192 sectors that the α-index fell below 1.0, consistent with the USA being a capital-abundant country.

A number of studies conducted in the wake of the original Leontief study considered different countries, asking whether the factor content of other country's imports and exports were consistent with the HO model.[23] Tatemoto and Ichimura (1959) for example replicated the Leontief (1953) study but used data from the 1951 input-output table for Japan. They obtained a value of the α-index equal to 0.64, consistent with Japan being a capital-abundant country. This result was also considered paradoxical, since in 1951 Japan would have been considered to be a relatively labour-abundant country. Tatemoto and Ichimura explained this apparent paradox by arguing that at the time Japan was a middle-income country, being neither developed nor developing. As such, Japan would have a comparative advantage in capital-intensive goods when trading with developing countries and in labour-intensive goods when trading with developed countries. Considering the composition of Japanese exports, Tatemoto and Ichimura argued that since only around 25% of Japanese exports went to developed (i.e. capital-abundant) countries it would be expected that Japan exported relatively capital-intensive goods. Tatemoto and Ichimura used this insight and compared the capital-labour ratio of Japan's exports to the USA with the overall capital-labour ratio and the capital-labour ratio of US exports to Japan with the overall capital-labour ratio for the US. They showed that the capital-labour ratio of Japan's exports to the US was lower than that for total exports, while the capital-labour ratio of exports of the US to Japan was greater than for total US exports. This interesting result therefore provided support for the HO model on a bilateral basis, with Japan's exports to the US being relatively labour-intensive and those of the US to Japan being relatively capital-intensive.

A further study using Japanese data is Heller (1976) who uses data for 1955, 1960 and 1970 and information on 60 sectors. Adopting the Leontief methodology and considering both capital and skill intensity Heller finds that Japan's exports to developing countries are more capital (and skill) intensive than its exports to developed countries. Considering changes over time Heller finds that Japan's export bundle shifted towards the capital intensive sectors.

Roskamp (1963) compared the capital-labour ratio of exports and import replacements for West Germany in the year 1954, expecting to find values somewhere between the values found for the US and Japan. Roskamp obtained a value for the α-index equal to 0.99, which lies – as expected - between the values previously found for the US (1.30) and Japan (0.64). Despite this, the results were against expectations in the sense that German exports were relatively more capital-intensive than those for the US. Roskamp and McMeekin (1968) reconsider the case of West Germany, but

[23] Examples not discussed here include Wahl (1961) for Canada and Stolper and Roskamp (1961) for East Germany.

include a measure of human capital as an additional factor of production. They find that the Leontief paradox disappears when this additional factor of production is taken into account.

Bharadwaj (1962) followed a similar approach to Tatemoto and Ichimura (1959) considering the HO model on a bilateral basis for the USA and India. In particular, he compared the capital-labour ratio of 1 million dollars of US exports to India with 1 million dollars of US import replacements from India, and similarly 10 million rupees of Indian exports to the US with 10 million rupees of Indian import replacements from the US. The α-index was found to be 0.55 for the US and 0.72 for India. As such, the results are consistent with expectations in that the exports of the US to India are relatively capital-intensive and those of India to the US relatively labour-intensive. At the same time, the results are against expectations in that the ratio for India is less than one. This is paradoxical because Indian exports to the US are relatively capital-intensive and the imports from the US to India are relatively labour-intensive (in the sense that the domestic production of the goods imported from the US would require more labour and less capital). As an explanation Bharadwaj (1962) argues that 1951 was an atypical year in that a large quantity of food grain was imported from the US in that year because of adverse climatic conditions. Since agriculture is relatively labour-intensive in India, the labour requirements to produce the competing import replacements may have been exaggerated.

Baldwin (1971) follows the approach of Leontief considering data for 64 sectors using 1962 trade figures and the 1958 IO table. Baldwin considers all sectors, but in turn also removes the agricultural and natural resource industries when making the factor content calculations. In addition, he extends the Leontief method by including a further factor of production, namely a measure of human capital (the total cost of education). The α-index was then calculated for the three different industry groups (total, total minus agriculture, total minus natural resources) and for the capital-labour ratio, the human capital-labour ratio and the total capital-labour ratio. The results indicate that the Leontief paradox continues to hold when the ratio of physical capital-labour is considered (regardless of the industry groups), but disappears if the human capital-labour ratio is considered. When the sum of the two capital stocks ratios are used the Leontief paradox remains, except in the case where natural resources are excluded. The results overall provided strong support for the importance of human capital in trade for the US.

Stern and Maskus (1981) also include a measure of human capital (discounted industry wage differential) in their calculation of the α-index for 79 sectors for the years 1958 and 1972. Similar to Baldwin (1971) they also sequentially excluded services industries, agriculture and natural resource industries when computing the factor endowments. For the year 1958 the Leontief paradox is found to exist for physical capital with the α-index being greater than 1.0 for all industry groups. When considering the ratio of human capital to the labour force the α-index was less than one in all cases, implying that the Leontief paradox disappears in this case. The results for 1972 indicate the Leontief paradox was not present in this year, with the α-index being negative for all industry groups and for both the physical and human capital-labour ratio.

To summarize, the literature that immediately followed the work of Leontief (1953, 1956) often found evidence in favour of the Leontief paradox, both for different countries and time periods, though the evidence from Stern and Maskus (1981) would indicate that the paradox was overturned in the USA by the mid-1970s. The results of Leontief were quickly criticised, with

Valavanis-Vail (1954), Ellsworth (1954), Swerling (1954) and Granick (1955) amongst others questioning the validity of the results. The criticisms raised by these papers are wide-ranging, but include issues related to the methodology, interpretation of results and the assumptions, many of which have been raised and addressed in the subsequent literature. These include the assumption of identical technologies across countries, differences in tastes across countries, the omission of natural resources and other factors of production, and factor intensity reversals. Ellsworth (1954) raises the further argument that the technology used to produce import replacements in the US should be more similar to the techniques used to produce exports, rather than the techniques used abroad. This is to say that countries do not produce import replacements by using large amounts of its scarce factor. The result of Leontief that import replacements use relatively more capital than exports is therefore likely to reflect the need for exceptionally great use of the cheap factor in order to offset the advantage derived by other countries from their cheap labour. Ellsworth (1954) also mentions the issue of protection, with many import competing sectors in the US at the time being protected. Ellsworth (1954) argues that many of these sectors would cease to exist even with capital-intensive methods if protection were removed.

3.1.2 Multi-Country, Multi-Factor Tests of HOV

Bowen, Leamer and Sveikauskas (BLS) (1987) examine the factor content of trade in a multi-country, multi-factor framework. They test the HOV model using the sign and rank tests by computing the amount of each of 12 factors embodied in the net exports of 27 countries in 1967, using the 1966 US technology matrix, and then comparing the factors embodied in trade with direct measures of factor endowments. In terms of the sign test BLS find that the proportion of sign matches is greater than 50% for 11 of the 12 factors, but greater than 70% for only four factors, implying weak support for a relationship between factor contents and excess factor shares.[24] The results from the Kendall rank correlation between the ranking of each country's net factor content and excess factor shares also provides weak support for the HOV model, with the correlation being significantly different in only four cases.[25]

BLS go on to examine three reasons why the HOV may not be exact, these being non-proportional consumption, measurement errors and technological differences. Testing these hypotheses using regression analysis, BLS find support for the view that the HOV model can be rejected in favour of a model that allows neutral productivity differences and errors in measurement of both trade and national resource supplies. Results based upon such adjustments however lead to some "peculiar estimates", which leads BLS to conclude that "[t]he Hecksher-Ohlin model does poorly, but we do not have anything that does better".

3.2. Methodological and Interpretational Critiques of Leontief

3.2.1. The Leamer Critique

Despite the criticisms of the approach of Leontief the approach continued to be a popular method of examining the factor of trade. In 1980 however, a much more damning criticism of

[24] Considering the sign test for countries rather than factors reveals that the sign matches exceed 50% for 18 countries and 90% for five countries. The proportion of sign matches is below 70% in 19 of the 27 countries however.

[25] Considering countries rather than factors the hypothesis of a zero rank is rejected for only 8 of the 27 countries.

the interpretation of the Leontief approach was made by Leamer. He argued that the Leontief paradox was just a simple misunderstanding and that in reality there is no paradox. He argues that it is wrong to suggest that a country is poorly endowed with capital relative to labour if the capital per worker embodied in exports is less than the capital per worker embodied in imports, except in the unlikely case that there are only two goods, with one good being exported and one imported and balanced trade. Leamer showed that if trade is not balanced, then a capital-abundant country that runs a trade surplus can export both capital and labour, with its imports being more capital-intensive than its exports.[26] In such situations the correct test is to compare the capital-labour ratio in net exports to that in consumption. Letting K_X, L_X, K_M, L_M, K_D, L_D, denote the capital (K) and labour (L) embodied in exports (X), imports (M) and consumption (D), Leamer (1980) shows that a country is revealed to be more endowed with capital relative to labour if and only if one of the following conditions hold:

$$K_X - K_M > 0, L_X - L_M < 0 \quad \text{(C1)}$$

$$K_X - K_M > 0, L_X - L_M > 0, \frac{K_X - K_M}{L_X - L_M} > \frac{K_D}{L_D} \quad \text{(C2)}$$

$$K_X - K_M < 0, L_X - L_M < 0, \frac{K_X - K_M}{L_X - L_M} < \frac{K_D}{L_D} \quad \text{(C3)}$$

Leontief's original proposition is thus true only if the net export of labour services is negative ($L_X - L_M < 0$) while that of capital is positive ($K_X - K_M > 0$). Leamer computed net exports of capital and labour using the data from Leontief (1953) and found that net exports of capital ($23.45 million) and labour (1.99 million worker years) were both positive. The relevant condition to consider therefore is thus C2. Leamer (1980) then used data from both Leontief (1953) and Travis (1964), defining consumption to be equal to production minus net exports, and found that the capital-labour ratio for both net exports and consumption was positive. As such, the results were consistent with C2, meaning that the USA was a capital-abundant country and the Leontief paradox disappears.

Following this critique, Stern and Maskus (1981) – as mentioned above – examined whether the Leontief paradox existed for the years 1958 and 1972. As an extension over Leamer (1980), Stern and Maskus considered three factors of production; capital, labour and human capital. Their results indicated that in 1958 the US was a net exporter of all three factor services, while in 1972 it was a net importer of all factor services. More importantly, the results of Stern and Maskus (1981) implied that the Leontief paradox was present in 1958, since $\frac{K_X - K_M}{L_X - L_M} < \frac{K_D}{L_D}$, thus violating C2. In addition, they showed that $\frac{H_X - H_M}{L_X - L_M} > \frac{H_D}{L_D}$, where H is human capital, implying a relative abundance of human capital relative to both physical capital and labour. For 1972 Stern and Maskus (1981) found that $\frac{K_X - K_M}{L_X - L_M} < \frac{K_D}{L_D}$ and $\frac{H_X - H_M}{L_X - L_M} < \frac{H_D}{L_D}$, which when combined with the result

[26] Casas and Choi (1984) computed the trade pattern that would have prevailed had trade been balanced in 1947. They concluded that the US would have exported capital-intensive goods in the balanced trade situation.

that the US was a net importer of all factor services in 1972 and C3 implied that the Leontief paradox disappeared in this period.[27]

3.2.2. The Modified Leontief Paradox

Brecher and Choudri (1982a) show that despite the results of Leamer (1980) a modified version of the Leontief paradox continues to hold.[28] What they show is that a country can be a net exporter of labour services if, and only if, the country's consumption expenditure per worker is less than that for the world, i.e. $L_X - L_M > 0$ if $\frac{D_W}{L_W} > \frac{D}{L}$, where D and D_W denote the country's and the world's consumption expenditure and L and L_W the country's and the world's labour endowment respectively. When taken to the data for the USA in 1947 they find that this condition is not satisfied, with expenditure per worker in the USA being substantially greater than that in the rest of the world, but the USA being a net exporter of labour services. This is the modified Leontief paradox.

A further contribution making use of the results of Leamer (1980) is that of Maskus (1985). Assuming that any two factors are exported on net, Maskus makes use of C2 and the fact that given that all income is spent on goods and services output will equal consumption to derive the sufficient condition:

$$\frac{(K_X - K_M)}{K} > \frac{(L_X - L_M)}{L} \qquad (3.1)$$

which reveals that K is more abundant than L. This condition holds if the two factors are net imported, and implies that a factor can be ranked according to its relative abundance measured by the factor's total content in net exports $(F_X - F_M)$ relative to that in production (F). Using data for 1958 and 1972 with information on 79 sectors, Maskus (1985) ranks five factors, namely high-skilled labour, unskilled labour, other labour, physical capital and human capital, finding for 1972 that skilled labour is most abundant and unskilled labour most scarce. Comparing physical capital with total labour, Maskus finds that labour is relatively more abundant than physical capital, implying that the Leontief paradox returns for 1972, in contrast to the results of Stern and Maskus (1981).

3.2.3. Aggregation Bias

Feenstra and Hanson (2000) argue that one of the reasons for the poor performance of the factor content theorem when taken to the data may be the aggregation of the data. In order to obtain information on indirect factor requirements researchers are usually forced to consider information from an input-output matrix, which usually have a relatively small number of industries. Calculation of factor contents will then require information on net exports, output and

[27] Maskus (1985) adopted the Leamer methodology for the US in 1958 and 1972 and found that the Leontief paradox was present in both years, a result which he termed "the Leontief commonplace". Davis and Weinstein (2001a) and Bowen, Leamer and Sveikauskas (1987) also find evidence in favour of the Leontief paradox, though Trefler (1993) finds no evidence using 1983 US data.

[28] Casas and Choi (1984) show a further paradox in the data. They show the domestic income of a scarce factor will be larger than the world level. Such a scarce factor may be exported in the presence of a surplus, but the assumptions of the HOV model implies that domestic absorption per unit of that factor will be lower than the world level. Evidence for the US however, indicates that both domestic income and absorption per worker in the US were considerably higher than in its major trade partners even though labour services were exported.

direct factor contents also to be aggregated to this level. The use of domestic outputs as weights in this aggregation is necessary to preserve the full-employment condition, but can be shown not to preserve the value of the factor content of trade. Feenstra and Hanson (2000) calculate the factor content of trade (net exports and gross exports and imports) using two-digit SIC data (around 20 industries) and approximately four-digit SIC data (on 371 manufacturing industries) and show that using the more disaggregated data results in an increase in both production and non-production labour embodied in net exports.

Recently, Feenstra (2010) has returned to this issue. Feenstra argues that Schott (2003, 2004) has shown that there is a great deal of heterogeneity between goods at a very disaggregate level, implying that such goods if produced in a country would require diverse technologies. Constructing the factor requirements at the more aggregate level involves using averages of the requirements of the underlying goods, meaning that a large part of the heterogeneity in factor use and technologies is lost. Feenstra proposes a solution to the aggregation problem based on the approach of Baldwin (1971), who regressed net exports across industries on their factor requirements. The solution involves running Baldwin-style regressions at the more aggregate level reported in IO tables and then using the resulting coefficients at the disaggregate level also. As such, this allows one to infer what domestic factor requirements would have to be to produce highly disaggregated traded products in the domestic economy. Feenstra goes on to derive the aggregation bias and shows that if there is no correlation between net exports and factor input requirements within each aggregate group, then there is no aggregation bias in computing the factor content of trade. In general however, we would expect some correlation between net exports and factor input requirements, consistent with the HO model that would suggest that trade is related to industry factor endowments. Using an IO table from 1982 for the USA, which includes 371 manufacturing industries Feenstra implements this method. In particular he runs the Baldwin-type regressions on these 371 industries and uses the coefficients from these regressions on 7-digit tariff schedule data prior to 1989 and 10-digit HS level trade data after 1989. The results for 1982 indicate that when using the 7-digit data the production workers imported increased by about 50 percent, while the non-production workers exported falls slightly. The impact of trade on the effective factor endowment ratio increases for later years, and in 2000 the implied import of production workers exceeds their employment in US manufacturing, which as noted by Feenstra will have a significant impact on factor prices. While the discussion in Feenstra concerns the importance of trade for factor prices, the approach is potentially interesting to examine the factor content of trade and the HOV theorem.

Richard Gift and William Marxsen (1984) consider an alternative form of aggregation, namely the aggregation of factors of production. They show that the method of aggregation can affect the HOV predictions. In particular, they are able to show that any linear aggregation that is consistently applied to home and world endowments and trade flows will yield HO behaviour. They move on to test the conjecture of Leontief that the USA was human capital abundant. They note that their results imply that any arbitrary way of measuring human capital is consistent with the HO model, and choose to equate earnings with human capital. Adjusting Leontief's calculations to account for human capital they find increased labour abundance of around 10 percent, a figure too small to solve the Leontief paradox.

3.2.4. Bilateral Studies

A further approach to modelling and testing the factor content of trade in the absence of FPE was developed by Helpman (1984), who built upon the work of Brecher and Choudrhi (1982b) and Deardorff (1982). Helpman assumes that two countries do not produce in the same cone of diversification and thus have unequal factor prices. He then derives the bilateral trade relationship that the flow of factor services in trade should be toward the country with the higher price of the factor. Helpman shows that if instead of importing the factor services, the higher priced country had produced them domestically (assuming identical technologies) then the cost of these goods would have been at least weakly greater than the import bill for these goods. From this insight, Helpman (1984) derives the following relationship:

$$\left(w^{n^*} - w^{n}\right)\left(F^{n^*n} - F^{nn^*}\right) \geq 0 \qquad (3.2)$$

where w^n and w^{n^*} are the factor prices in countries n and n^*, and F^{nn^*} (F^{n^*n}) is the gross import vector of factor content of country n^* (n) from country n (n^*) measured with the technology matrix of the exporting country. This states that, on average, country n is a net importer from country n^* of factors that are cheaper in n^* than in n, and country n^* is a net importer from country n of factors that are cheaper in n than n^*. Helpman (1984) shows further that this implies that the factor content of exports from country n to n^* has, on average, a higher ratio of productive factors in which n is relatively well endowed than does the comparable ratio of exports from n^* to n.[29]

Davis and Weinstein (2001b) discuss the possibility of taking this equation to the data, but note that it is crucial to have information on all factors of production – unlike with other approaches that test the HOV model on a factor-by-factor basis – and that one must be able to measure the factor returns in each country with confidence. Staiger (1986) has shown further that in the presence of traded intermediate goods, when implementing the Helpman (1984) model with common production functions, but no FPE one should only use direct (as opposed to direct and indirect) factor content measures when constructing 3.2.[30] Despite the problems in implementing this test of the HOV model Choi and Krishna (2004) employ this bilateral test for eight OECD countries in 1980. The study uses actual technology data on each of the eight countries and it is assumed that there are two types of primary input factors, capital and (disaggregated) labour. To test the model Choi and Krishna rewrite the equation above as:

$$\frac{w^{n^*}F^{n^*n} + w^{n}F^{nn^*}}{w^{n}F^{n^*n} + w^{n^*}F^{nn^*}} \equiv \theta \geq 1 \qquad (3.3)$$

The calculated value of θ then has a useful interpretation. A value of θ of 0.5 for example would imply that, on average, costs could be 50% lower if domestic production were substituted for bilateral imports. The calculated values of θ are found to be greater than one in 21 of the 28 country pairs in the sample, thus providing strong support for this version of the HOV model. In four of the seven cases where θ is less than one the value is above 0.99. The results using alternative measures of capital and labour give similar results, while accounting for measurement error of factor prices is actually found to improve the results. Given that many of the calculated

[29] Choi and Krishna (2004) discuss extensions of this model to allow for technological differences across countries.

[30] This implies that when intermediates are traded freely, Helpman's measure of the bilateral factor content of trade needs to be modified to exclude the factor content of traded intermediate goods.

θ's are close to one indicates the importer's and exporter's costs of production are similar. Choi and Krishna consider whether such evidence is consistent with FPE, but reject such a hypothesis since wage rates and returns to capital are found to differ a great deal across countries and the calculated values of θ are often found to be quite different from one at the industry level.

Lai and Zhu (2007) extend the approach of Choi and Krishna (2004) deriving testable restrictions relating the factor content of bilateral trade to bilateral differences in technology and endowments. The major differences compared to the study of Choi and Krishna (2004) are the larger sample – Lai and Zhu consider 41 developed and developing countries – and by allowing technology differences to be country- and industry-specific (i.e. the approach allows for Ricardian technology differences). The approach adopted leads to two testable hypotheses: Firstly, that, on average, a country imports the content of those factors that are cheaper in its trading partner and exports the content of those factors that are more expensive for its trading partner, and secondly that capital-abundant countries embody a higher capital-labour ratio than the exports of labour-abundant countries. Splitting the sample into a labour- and a capital-abundant group the authors find that when introducing Ricardian technology differences the sign test is satisfied in 96% of cases when one country is capital-abundant and one is labour-abundant. The test is satisfied in more than 80% of cases for pairs of capital-abundant and labour-abundant countries. Considering the second hypothesis that relates the factor content of bilateral trade to endowment ratio differences the authors find that endowment differences cannot fully explain trade between capital-abundant countries, though the model performs remarkably well for country pairs involving one labour- and one capital-abundant country. The results therefore indicate that the model works better for country pairs with substantially different endowments, a result consistent with Debaere (2003) – as we will see below.

3.3. Relaxing the Assumptions of the HOV Model

In the past two decades a couple of interesting extensions and generalisations of the HOV model and its empirical implementation have been published most following the influential studies of Trefler (1993, 1995) who emphasises the importance of technology differences across countries.

3.3.1. Reintroducing Technology Differences in HO and HOV: The Trefler Studies

In a couple of papers Trefler (1993, 1995) criticises the assumption of internationally identical technologies, arguing that this may provide an explanation for the Leontief paradox, thus returning to the original conjecture of Leontief (1953).[31] In both papers, Trefler extends the HOV model to allow for international technology differences, which he argues is the reason for the lack of observed FPE. In general, Trefler follows the approach of Section 2.3 and assumes that technology differences are factor-augmenting. This approach implies that one can express

[31] Earlier empirical studies also considered the possibility of differences in technology across countries. To account for such differences authors introduced variables reflecting a country's or industry's innovation – such as the proportion of expenditure on R&D or the share of engineers and scientists in an industry's workforce – into their analysis. Keesing (1967) and Gruber and Vernon (1970) for example both found that (relative to the total exports of all countries) the exports of US industries were strongly correlated with the relative importance of innovation in these industries.

factors of production in terms of their "productivity-equivalent" unit, thus adjusting country input coefficients to account for differences in productivity of factors across countries.[32]

In his 1993 paper Trefler argues that very few studies have examined the explanation offered by Leontief for the apparent paradox, namely technology differences across countries.[33] Using data from 1983 on 33 countries and 10 factors of production he calculates the factor content of trade for all countries using the US technology matrix.[34] Allowing the productivity parameters to vary across factors Trefler shows that the measured factor supplies can be adjusted upwards or downwards so that the HOV equation 2.16 fits by definition exactly, which allows him to calculate the productivity parameters, π_i^n, algebraically. Concentrating on capital and labour – the two variables for which Trefler has factor price data – Trefler finds that labour in the US is more productive than in other countries, consistent with the hypothesis of Leontief.[35] More generally, the results indicate that the ratio of the productivity parameter of capital and labour to that in the US tend to be lower the lower the country's per capita GDP. Moreover, the results indicate a large correlation between these productivity ratios and the ratios of factor returns, as would be expected from theory (see equation 2.17, which states that the productivity parameters ought to be proportional to factor price differences).[36] The lack of factor price data for the other factors makes it more difficult to examine the reasonableness of the π_i's. Trefler considers four criteria: (i) they must be non-negative, (ii) given that the US is among the countries with the highest productivities of each factor the distribution across countries of π_i's for the different factors should be less than unity, (iii) an absence of outliers, (iv) for the labour data a regression of the ratio of the productivity's (to that in the US) on the ratio of per capita GNI to that in the US should produce non-negative coefficients, given the positive correlation expected between an occupation's wage and per capita GNP. The results obtained provide strong support to the HOV model given these four criteria: only 10 of 384 π_i's are negative, and the suspicious results concerning the distribution and outliers are largely explained by a possible classification error for administrative workers. Overall the close correspondence between the productivities and factor returns provides support to a modified version of the HOV model that allows for factor-augmenting international technology differences and the implied international factor price differences.

Consistent with Leamer (1984), Trefler (1993) finds that developed countries tend to be scarce in all factors and developing countries tend to be abundant in all factors, a result at odds with the

[32] More generally, we may expect that productivity differences depend upon other factors. For example, the productivity of labour is likely to be determined in part by the amount of capital that labour has to work with.

[33] He notes that a number of studies have disaggregated labour by skill classification, while maintaining the assumption that within classifications no international productivity differences exist (examples being Leontief, 1956; Travis, 1964; Keesing, 1965, 1966; Baldwin, 1971; Stern and Maskus, 1981; Maskus, 1985; Bowen et al, 1987). Disaggregating has been found to partly explain the paradox, but cannot explain the overall poor performance of the HOV model.

[34] While this is open to criticism it should be noted that the technology data is modified in a country-specific, technologically non-neutral fashion, as discussed in Section 2.3.

[35] Though for 1983 the differences were nowhere near the three times more productive that Leontief argued

[36] The results don't however seem to support the theoretical prediction that the ratio of productivity-terms and the ratio of factor returns are equal, for labour at least. In particular, wages in the poorest countries are under-predicted and those in the richest over-predicted. One explanation put forward is that wage data pertain to non-agricultural wages. Agricultural wages tend to be lower than non-agricultural ones, while employment in agriculture tends to be proportionately larger in developing countries. These two facts bias upwards the developing country data and downwards bias the developed country wage data.

spirit of the HOV theorem that relies on relative factor abundance. The obvious explanation for this is that developed countries have a more productive relationship between endowments and output than developing countries and so need less of all endowments for a given output share (in total world output). Considering factors measured in productivity-equivalent units Trefler finds that developed countries tend to be capital-abundant, consistent with the link between development and capital formation.

Trefler (1993) goes on to consider the Leontief paradox specifically by looking at data for 1947 and computing the factor endowment ratios, which for factor f is given by V_f^{US}/sV_f^W, where V_f^{US} is the US endowment of factor f, V_f^W is the world endowment and s is the share of US consumption in world consumption. As such, a factor is deemed to be scarce (abundant) if this ratio is less (greater) than one. Trefler finds that in 1947 both capital and labour were scarce (the ratios are 0.71 and 0.54 respectively). When considering factors in terms of productivity-equivalent units however the ratios of both factors rise (being 0.96 and 0.97 for labour and capital respectively). As such, the productivity of labour can go a long way to explaining the Leontief paradox, though according to these results labour was still scarce since the factor abundance ratio was still less than one.

Trefler (1995) uses a similar set of data to his 1993 paper, but now includes information on only 9 sectors. He compares the actual quantities of net exports of a factor (i.e. F_i^n in equation 2.15) with the predicted quantities of net exports of that factor (i.e. $V_i^n - s^n V_i^W$ in equation 2.15), which leads to a number of interesting results. Firstly, the correlation between F_i^n and $V_i^n - s^n V_i^W$ is only 0.28 (though it is significant). Secondly, when performing the sign test of BLS he finds that the proportion of sign matches is just 49.8 percent, thus consistent with the results of BLS.[37] Thirdly, he finds that actual net exports are much smaller than those predicted by the HOV model, a result he terms the "mystery of missing trade".[38] Fourthly, he found – as in his 1993 paper – that poor countries tend to be abundant in all factors, in the sense that the ratio of a country's endowment of a factor to the world endowment of that factor is greater than the ratio of the country's consumption to world income. Such a result is consistent with factor endowments being less productive in developing countries, and was termed by Trefler the "endowment paradox".

Trefler (1995) proceeds to try and improve upon the HOV model by relaxing some of the key assumptions. As in his 1993 paper Trefler considers international productivity differences as an explanation for the poor performance of the HOV model. To do this he adopts the approach of his 1993 paper introducing factor-augmenting technology differences. A problem with this approach is that attempting to estimate equation 2.16 with a cross-section of data results in a perfect fit because there are as many parameters as observations (i.e. IN observations and parameters). Trefler adopts two approaches. Firstly, he assumes that that there is a single productivity coefficient for each country across all of its factors (i.e. he replaces π_i^n with δ^n). In addition, he allows for neutral technological differences between developed and developing

[37] Weighting the sign statistics to attach more weight to observations with large net factor contents of trade gives a statistic of 71%, implying that the sign HOV hypothesis performs better when net factor service trade flows are large.

[38] Both Davis and Weinstein (2001a) and Helpman (1998) argue that the measured factor content of trade is likely to be biased towards zero.

countries, i.e. poor countries share one set of productivity parameters and rich countries share a different set.[39] Trefler (1995) also introduces the possibility of non-identical consumption across countries (as we discussed in Section 2.3) by allowing for investment (or equivalently non-tradables and services) in to the HOV model or by allowing for home bias in consumption.[40] Considering the assumption of productivity differences across countries in isolation Trefler finds that the proportion of (un-weighted) sign matches increases from 50 to 62 percent. Moreover, the model based upon international technology differences does a better job of fitting the data than does the unmodified HOV model. Considering alternative assumptions regarding consumption (see section 2.3 above) Trefler finds that including investment in the model results in coefficients that can reverse the endowments paradox, but the results in general are barely better than the standard HOV model. Considering the possibility of home bias in consumption – by distinguishing between domestic and foreign goods – Trefler finds significant support for home bias, with the preference for domestic goods being very large in some cases.[41] The model accounting for home-bias also performs better than the standard HOV model. Finally, Trefler combines the assumption of differences in international productivities with the assumption of home bias in consumption, and obtains a value for the sign test of 72 percent. Based on a comparison of the different models according to a number of criteria,[42] Trefler concludes that a model that allows for Armington home bias and neutral technology differences dominates the standard HOV model. He also finds however that no model predicts well when the predicted factor content of trade is small, that is, when a country's endowment is similar to the world endowment (in a cone of diversification sense). The model does best when the predicted factor content of trade is large, while theory would predict they do best when such predictions are small.

The Trefler studies received considerable (critical) attention. The method of introducing productivity differences by Trefler (1993) for instance has been criticised, most notably by Gabaix (1997). Gabaix (1997) showed that Trefler's adjustment to factor productivity merely reflects differences in the ratio of GDP to a particular factor. Given the correlation between factor prices and GDP per unit of a factor it is to be expected that the measured productivity parameters would be correlated with factor prices – as found by Trefler (1993) – and should therefore not be used as evidence in favour of HOV. To see this we make use of the missing trade phenomenon of Trefler (1995), which indicates that the measured factor contents of trade are generally small relative to the predicted factor contents of trade, and essentially zero. Such a result implies that we can write from equation 2.16:

$$0 = \tilde{F}_i^n = \pi_i^n V_i^n - s^n V_i^{W^*} \Leftrightarrow \pi_i^n = s^n \frac{V_i^{W^*}}{V_i^n} = \frac{Y^n}{Y^W}\frac{V_i^{W^*}}{V_i^n} = \frac{Y^n}{V_i^n} R \qquad (3.4)$$

where $V_i^{W^*} = \sum_{p=1}^{N} \pi_i^p V_i^p$ and $R = V_i^{W^*}/Y^W$, and are independent of country n. In the case of labour therefore the estimated productivity of labour would equal GDP per worker, and it is therefore no surprise that there is a correlation between productivities and factor prices and

39 This is introduced by setting $\pi_i^n = 1$ for developed countries and $\pi_i^n = \varphi_i$ for developing countries.

40 Hunter and Markusen (1988) show how to allow for non-homothetic tastes, something not considered by Trefler (1995).

41 Trefler (1995) also considers a linear expenditure system, but this performs worse than the home bias model.

42 These being (i) the correlation between actual and predicted factor trade, (ii) the sign HOV test, (iii) the endowments paradox and (iv) the case of missing trade.

Trefler's approach offers no independent validation for the empirical success of his productivity modification of HOV.

Conway (2002) examines the results of Trefler (1995) and considers alternative explanations for the results indicating a discrepancy between theory and the empirical evidence. Conway (2002) notes that the unsatisfactory results can be split in to two groups: (i) the missing trade and prediction error mysteries are statements about the poor predictive power of the HOV model on the volume of trade, and (ii) the sign HOV and endowments paradox mysteries are evidence of the poor predictive power of the HOV theory on the pattern of trade. In terms of the first group, Conway argues that sluggishness in reallocating productive factors within each country is an alternative hypothesis for explaining the lower-than-predicted volume of trade. In terms of the second group, Conway criticises Trefler' use of OLS arguing that the use of maximum score estimation will provide a consistent estimator. Using such a method improves the performance of the HOV model in predicting the pattern of trade. Conway proceeds to argue that the productivity parameters included in Trefler's preferred model may simply reflect error in measurement of the consumption share variable. Using consumption shares based on Purchasing Power Parity (PPP) expenditure shares from Summers and Heston – as opposed to data based on official exchange rates as in Trefler (1995) – Conway finds improved results from the standard HOV model, though none of the mysteries are removed. Conway argues further that the assumption of home bias in the work of Trefler (1995) leads itself to some mysteries, in that six countries have estimates indicating that more than 100 percent of consumption is on home goods, with the level of home bias being large in general. Conway suggests that the home bias parameter may in part at least reflect unbalanced trade rather than home preference, and presents arguments consistent with the importance of the trade balance in explaining the estimated parameters. Rather than the assumption of international productivity differences and home bias, Conway suggests that a combination of imperfect labour mobility across domestic industries and adjustment of the observed consumption shares for mis-measurement may provide a better explanation for the divergence between theory and empirics.[43] He tests this hypothesis using the J-test and finds that the Trefler specification adds nothing to the specification that includes imperfect labour mobility and consumption shares, but these add something to Trefler's specification, thus providing support to the hypothesis of Conway. As a final comment, Conway (2002) notes that there is a strong regularity in the covariation of errors (i.e. differences between the actual and predicted net factor content of trade) across factors within a country. This he argues is consistent with the amendment of the HOV model by Kenen (1965) who argued that capital be treated as a factor used only to improve other factors.

Commenting on the results of Trefler (1995) and Conway (2002), Davis and Weinstein (2001b) argue that given the result of Trefler (1995) that the measured factor content of trade is small – and essentially zero – what both Trefler and Conway look to achieve is to shrink the predicted factor content of trade to match the measured factor content of trade. In the case of Trefler, this is achieved by technology differences and a home bias, while Conway achieves it by introducing imperfect labour mobility and mis-measurement of consumption shares. According to Davis and

[43] Conway (2001) also shows that the partial internal immobility of factors is a significant component of the explanation of net trade flows among countries.

Weinstein (2001b) neither approach provides information on the economics underlying missing trade however.

Hakura (2001) also introduces international differences in production technology, comparing the performance of the basic and modified HOV model. Hakura considers a two country world and derives the following modified version of the HOV model:

$$F^1 - \alpha F^2 = V^1 - \alpha V^2 + \left[A^2(I - A'^2)^{-1} - A^1(I - A'^1)^{-1}\right] \cdot D^1 \quad (3.5)$$

where $F^i = A^i(I - A'^i)^{-1}NX^i$ for $i = 1,2$, A is the matrix of primary factor endowments and A' gives the unit input requirements of one good in the production of another and D^i is final consumption of country i. The vector $Z = \left[A^2(I - A'^2)^{-1} - A^1(I - A'^1)^{-1}\right] \cdot D^1$ then shows how differences in production techniques across countries modify the usual HOV relationship. It gives the difference in factor usage between two countries that would be required to produce country one's consumption. Adding the assumption of identical technology would cause the term Z in 3.5 to drop out, returning the model to the original HOV model.[44] Hakura employs the sign and rank test to compare the original and modified HOV model. Considering data on four of the six original members of the European Community (EC) in 1970 and 1980 and 23 industry categories, Hakura uses the actual IO matrix of countries thus allowing for unrestricted differences in production techniques across countries. Results from the sign test indicate that for the original (unmodified) HOV model the sign match is supported in around 58% and 47% of cases in 1970 and 1980 respectively. When the modified HOV model is considered the sign matches are found to be 94% in 1970 and 86% in 1980. The results indicate that when the country-specific IO matrix is used to measure and predict factor trade the model has strong predictive power, but this is not the case when the same IO matrix is applied to different countries, thus isolating the role of international differences in production technology as an important explanatory variable in predicting factor trade.

3.3.2. Stepwise Generalisations and Extensions of the HOV Model

Davis and Weinstein (2001a) introduce technological differences, a breakdown of FPE, the existence of nontraded goods and costs of trade and show the HOV model is consistent with data from 10 OECD countries and a rest of the world aggregate. Using comparable production data from the OECD allows Davis and Weinstein (2001a) to test production specifications of their models in addition to the trade specification. Similar to the test on the factor content of trade, this involves examining the difference between the predicted and measured factor content of production. Results using a common technology matrix indicate that neither the production specification nor the original HOV trade model performs well. Introducing factor-augmenting productivity differences in a manner similar to Trefler (1993, 1995) has only a limited impact on the results for the factor content of trade, but does improve the fit between the actual and predicted factor content of production. Noting results of Dollar et al (1988) who show that capital and labour usage across countries is correlated with country capital abundance, suggesting

[44] When constructing the factor content of trade Hakura adopts the Leontief definition of the factor content of trade, being defined and measured in terms of total domestic input requirements (direct and indirect). She notes however that a better method would be to calculate the factors actually used in the production of traded goods wherever they took place. This would require tracing the production history of all traded goods as well as the intermediate inputs used in their production, as is done in Reimer (2006).

that capital-labour ratios are not fixed across countries, Davis and Weinstein (2001a) proceed to introduce non-neutral differences in input techniques. Davis and Weinstein argue that one reason for the observed differences in input usage by industry across countries is due to aggregating goods of heterogeneous factor content within industry categories. They further argue that the presence of non-tradables can downward bias the factor content of trade. In the presence of non-tradables and a lack of FPE capital-abundant countries use more capital per worker in non-traded sectors, which leaves the residual available for production of tradables diminished and so lowers the predicted factor content of trade. Davis and Weinstein thus take into account not only factor-augmenting productivity differences but also country differences in capital-labour endowment ratios. Rather than using data on actual productivity differences Davis and Weinstein estimate a regression equation for each factor-industry pair (68 regressions in total, given 34 industries and two factors) to obtain estimates of the productivity parameters.[45] The estimates for the productivity parameters seem plausible, with the US (Italy) being most (least) productive. Moreover, industry capital-labour ratios seem to move in line with country capital-labour ratios. Based on the Schwarz criterion the preferred model is one with neutral productivity differences and no FPE. Using the estimated productivity parameters for each specification Davis and Weinstein compare the measured factor content of production (and trade) with the predicted factor content of production (and trade), finding that models accounting for technology differences, and a lack of FPE improve over the standard HOV model. Using these productivity estimates to calculate the factor content of trade and production, Davis and Weinstein find that the signs of the predicted and actual factor content of trade are the same in 86 percent of cases, which is significantly higher than that usually found. The results on the factor content of production are not significantly better than those from introducing just factor-augmenting productivity differences however, while the results have little impact on the mystery of missing trade.

Davis and Weinstein (2001a) also move away from the assumption of frictionless trade, to examine how much of the missing net factor of trade is due to the low volume of product trade. To achieve this, the authors make use of the fitted values from a gravity equation rather than the true trade data when predicting the factor content of trade. Incorporating this in to their model they find that measured factor trade rises to roughly 80 percent of that predicted.

Trefler and Zhu (2000) criticise Davis and Weinstein (2001a) for not distinguishing between trade in final goods and trade in intermediates. The HOV theorem is based upon trade in final goods, yet a great deal of actual trade is in intermediate goods. Trefler and Zhu develop an alternative formulation based on IO identities (see Trefler 1996). Trefler and Zhu implement this model on data for Belgium, France, Germany, the Netherlands and the USA, using land, capital and aggregate labour as factors and integrating investment into A (i.e. investment is a depreciable intermediate input) by using the 1982 US capital flows table to allocate each country's industry level investment to the industries that use the investment. Using their model and the assumption of no intermediates trade Trefler and Zhu find substantial improvement in the model as judged by correlations of factor content of trade with the predicted factor content. Davis and Weinstein (2001b) respond to Trefler and Zhu (2000) arguing that the theory that they use has no economic

45 Trefler (1996) shows that under certain assumptions using actual technology differences can lead to an identity between the factor content of trade and a country's relative endowments.

implications, other than the equation used holding under certain conditions. They argue further that the measure of final goods trade is likely to overstate the importance of intermediates trade

3.3.3. Development and the Factor Content of Trade

Davis and Weinstein (2000) quote the discussion of Krugman (1981) who notes that much of world trade is between countries with similar factor endowments, with a large part of trade being intra-industry trade (IIT). Factor endowments are not likely to be important for determining such trade between rich countries therefore. Davis and Weinstein (2000) thus examine the role of factor endowments in North-North trade adopting a similar methodology to Davis and Weinstein (2001a) allowing for factor-augmenting technology differences. Endowment differences are said to be important for North-North trade if factor service trade among countries of the North is systematically related to endowment differences and the magnitudes of factor service trade are economically large. Davis and Weinstein find that both criteria are met, with the implication being that IIT is one of the principal conduits of factor service trade for countries in the North. Davis and Weinstein (2000) define a variable called "matched intra-industry trade" for bilateral trade as $G_i^{nn^*} \equiv min\{X_i^{nn^*}, M_i^{nn^*}\}$, as well as a variable NX^{+nn^*} (NX^{-nn^*}) equal to the level of net exports where this is positive (negative) and zero otherwise. From this they can write net exports as $NX^{nn^*} = NX^{+nn^*} + NX^{-nn^*}$. Using this definition they define the factor content of trade for country n as:

$$F_i^n = A_i^{US} NX^n + \varepsilon^{NX} + \varepsilon^{NM} + \varepsilon^{MIT} \quad (3.6)$$

where the technology matrix used for all countries is that for the US. This equation shows therefore that the factor content of trade is equal to the standard measured factor content of trade using the technology matrix of a single country (i.e. the US) for all countries and three error terms. The first arises when the factor content of country n's net exports (NX) are incorrectly measured with the US technology matrix rather than the appropriate one for country n. The second arises due to the factor content of net imports (NM) are incorrectly measured with the US technology matrix rather than the correct one for country n^*. The final error arises because the use of any common technology matrix defines matched intra-industry trade (MIT) to have zero factor content, whereas the true factor content of trade must take account of the fact that even matched IIT will contribute to the net factor content, the level of which will depend upon the magnitude of matched IIT and the difference in techniques used in n and n^*. Davis and Weinstein (2000) go on to define the bilateral net factor content of trade for a particular factor as:

$$F_i^{nn^*} = s^{n^*} V_i^n - s^n V_i^{n^*} \quad (3.7)$$

which implies that country n will be a net exporter of factor i bilaterally if:

$$\frac{V_i^n}{s^n} > \frac{V_i^{n^*}}{s^{n^*}} \quad (3.8)$$

Using data for 22 countries and 34 sectors and data on the US technology matrix for all countries they show that the net factor content of trade conventionally measured is much smaller than the true net factor trade, and that if anything there is a negative relationship between the two. They show that when using the true technology matrix for each country rather than that of the US for all countries the results are broadly similar, implying that the mis-measurement is not simply due to the choice of a common technology matrix. They go on to consider their decomposition and examine how important IIT is in explaining the differences between the measured and predicted factor content of trade. Generally it is expected that for IIT to be important it must be the case that the technology differences are both large and systematic. In the case of specialisation of goods within industries and a failure of FPE however, IIT is likely to be an important conduit of factor service trade because even within industries goods are being produced with different factor proportions. Comparing the factor content of IIT to the factor content of trade they find that there is a systematic relationship between the two. The slope of the relationship indicates that more than 40 percent of net factor trade is carried out through IIT. Considering the data on individual countries they find that the ratio of the share of IIT in a country's total net trade in a factor is positive in 19 of 22 cases, with IIT being more important than inter-industry trade in the net export or import of factor services in half of the countries. Overall, endowments are found to be important in understanding bilateral trade even between countries in the North, which tends to be dominated by IIT.

Debaere (2003) develops a HOV type model that relates bilateral differences in country endowments to bilateral differences in factor contents. The model is an extension of the country-pair approach of Brecher and Choudhri (1988) and Hakura (1995) that introduces factor endowment ratios. Debaere uses data from Trefler (1995) and follows Trefler's approach of using the difference in GDP per capita between a country and the US to proxy for Hicks-neutral productivity differences. When considering countries with different endowments there is clear support for the HOV sign prediction. Thus countries with dissimilar endowment ratios also have very different factor content of trade differences as predicted by the HOV model. He finds that 70 percent of the more than 3000 country pairs support the sign prediction of the HOV model. Considering pairs of developed and developing countries that are very different in terms of capital-labour and skilled-unskilled labour ratios the sign test predicts correctly in around 80 percent of cases, while when explicitly including the factor content of North-South trade, the data match the sign prediction up to 90 percent of cases. Overall, he concludes that the HOV sign prediction is more likely to hold as country endowments are more different.

Lai and Zhu (2007) – similar to Debaere (2003) – derive testable restrictions relating the factor content of bilateral trade to bilateral differences in technology and endowments. The empirical model extends that of Choi and Krishna (2004) by allowing for country- and industry-specific technology differences (i.e. Ricardian technology differences). These restrictions are tested on data for 41 developed and developing countries with disparate technology and endowments. Similar to Debaere (2003) the factor content predictions perform best for country-pairs with larger endowment differences, as well as for trade between capital-abundant countries.

Maskus and Nishioka (2008) introduce a model based on Davis and Weinstein (2001a) and Maskus and Webster (1999) that allows for factor-specific productivities based on a Constant Returns to Scale (CRS) production function. Introducing this assumption thus allows one to avoid the problem raised by Gabaix (1997) that factor productivity differences merely reflect differences in the ratio of GDP to a particular factor. Introducing these assumptions raises the fit of the standard HOV sign tests from 46.6 percent to 72.4 percent. Consistent with other studies the results also indicate that the estimated productivities are strongly correlated with aggregate factor abundance in a relative sense.[46] Maskus and Nishioka argue that because the rapid growth of physical capital interacts differently with different types of labour, capital productivity and labour productivity evolve differently with the stages of economic development. Such findings raise important questions about applying strict HOV models in a relative (bilateral) sense because factor productivity interacts systematically with factor abundance. Debaere (2003) for example demonstrates that the HOV equation holds better for South-North country pairs than for North-North country pairs. But this raises the question of whether South-North factor productivity gaps or South-North factor abundance differences are driving such support for the factor content of trade.[47] Within Trefler's framework countries share identical production technologies at the productivity-equivalent level, making adjusted unit factor requirements across countries for each factor equal, i.e. $\tilde{a}_{ij}^{n} = a_{ij}^{US}$ for country n and factor i where $\tilde{a}_{ij}^{n} = \pi_i^n a_{ij}^n$. Following Davies and Weinstein (2001a) the productivity parameters are estimated by regressing the log of unit factor requirements on country fixed effects and common unit factor requirements. Initially Maskus and Nishioka allow for Hicks-neutral productivity differences implying that with CRS a single productivity parameter, π^n, augments each factor at the same rate, thus estimating:

$$\ln a_{ij}^{n} = \theta^{n} + \ln\bar{a}_{ij} + \varepsilon_{ij}^{n} \qquad (3.9)$$

where $\ln\bar{a}_{ij}$ is the log of the cross-country average of unit factor requirements, θ^n is vector of coefficients on country dummies and ε_{ij}^{n} is an error term. They then allow for the more general case of factor-augmenting productivity adjustments, by allowing the θ's to also differ across sectors within a country. The model to be estimated thus becomes:

$$\ln a_{ij}^{n} = \theta_i^{n} + \ln\bar{a}_{ij} + \varepsilon_{ij}^{n} \qquad (3.10)$$

In testing HOV using these estimated factor productivities they consider both the aggregate specification of Trefler (1993) and the pair-wise HOV model of Staiger et al (1987) and Hakura (2001). The primary advantage of the pair-wise HOV model is that the testing equation does not include world aggregates. The pair-wise HOV model with factor productivity adjustment is written as:

$$F^1 - \alpha F^2 = \Pi^1 V^1 - \alpha \Pi^1 V^2 \qquad (3.11)$$

where $F^1 - \alpha F^2$ is the measured relative factor content of trade (with the technology of country 1) and $\Pi^1 V^1 - \alpha \Pi^1 V^2$ is the (productivity-adjusted) predicted relative factor content of trade, with Π^1 is a diagonal $F \times F$ matrix with elements that are the corresponding productivity coefficients of country n estimated from equation (3.10).

Maskus and Nishioka employ data on 29 countries with two factors of production and 30 industrial sectors for the year 2000. The data covers 19 developed and 10 developing countries. The results indicate that the US has the highest labour productivity, while some developed and developing countries are found to have higher capital productivity than the US. The method of

[46] Workers in capital-abundant Japan for example are productive (relative to Japanese capital) because they have access to machines and computers that make them efficient. Such a result is consistent with Dollar, Wolff and Baumol (1988).

[47] Debaere and Demiroglu (2003) and Schott (2003) model the possibility of multiple specialization cones that can arise due to large endowment differences.

estimating technology differences works at least as well as Davis and Weinstein (2001a), while the estimated factor productivities are very similar to those obtained from Trefler (1993). When testing the HOV model the results strongly reject both the standard and Hicks-neutral HOV model. Once the estimated factor productivities are introduced performance improves with the sign fit improving to 72.4%. For developed countries the sign test improves from 36.8 to 73.7 percent. The results for the pair-wise model indicate that introducing the estimated factor productivities improves the sign test from 55.8 to 78.9 percent.

Maskus and Nishioka go on to discuss the implications of their results. They argue that the finding that workers in the US have the highest labour productivity could mean that: (i) workers in the US work harder than elsewhere, (ii) US workers have access to technologies that make them more efficient, (iii) the number of workers cannot account for the difference in each worker's efficiency occurring from educational attainment. Maskus and Nishioka concentrate on the notion that labour productivity correlates with capital abundance, since this characterises data between developed and developing countries, but not among developed countries. Maskus and Nishioka re-examine the conclusions of Debaere (2003) that the trade of South-North country pairs is consistent with HOV but that of North-North country pairs is not. They show that Debaere's result is caused not only by South-North differences in factor endowments, but also by South-North differences in factor productivity. The reason is that unskilled labour – the abundant factor in the South – has limited access to skilled labour and physical capital, implying that the productivity of unskilled workers there is systematically lower than that in the North. The sign match of country-pairs when picking one North and one South is 84.7%, while for North-North the figure is 47.4% and for South-South 28.9%. Adjusting endowments by factor productivities makes an important difference however, with the sign result for North-North country-pairs improving from 47.4% to 60.2%, with that for North-South pairs worsening from 84.7% to 41.1%. This reduction in success suggests implicitly that Debaere's finding was attributable to development-realted productivity biases: Factor productivities are inversely correlated with own-factor endowments and positively correlated with other factor endowments, which is consistent with the neoclassical trade model without FPE due to specialisation within different cones.

3.3.4. Other Literature

The recent literature on the factor content of trade has developed in a number of different ways. In this final section we briefly mention some of this recent literature.

Davis et al (1997) employ regional data on Japan to test the HOV model, considering the production and absorption (i.e. consumption) sides of the HOV model separately. They show that the HOV model performs very well for Japanese regional patterns of production.[48] Similar to Davis and Weinstein (2001a) they begin with a strict HOV model and relax assumptions one at a time to examine which were driving the results. They also used an approach that allowed one to make HOV predictions when only a subset of the world shared FPE. Considering the production side and assuming that the world shares the same input coefficients the HOV model finds little support, but when making the more modest assumption that all Japanese regions share a common set of input coefficients the results improve dramatically. These results were interpreted

[48] Moroney and Walker (1966) also introduce a regional test of the HO hypothesis.

as indicating that while theory was a powerful means of considering production within an FPE club, it worked poorly as a description of international production patterns. Turning to the consumption side, the authors consider Japanese regional absorption, which according to theory should be proportional to world net output. The HO model does well under this assumption: the assumption that Japanese consumption differed from the rest of the world performed no better than the standard prediction of homotheticity. Considering Japanese regions they move on to consider a full test of the HO theory of the net factor content of trade. Using data on endowments imputed to the world as if they had used the Japanese input coefficients they find that the results are a marked improvement on a model based on measured world endowments. Overall, they conclude that while HOV is a poor predictor of the international pattern of production and therefore of net factor trade, it is a useful theory of the location of production and the pattern of consumption (and therefore the net factor content of trade) of regions of Japan.

Schott (2003) argues that existing tests of the HO model that focus on models in which all countries producing all goods using the same technique may be misspecified. He argues that models with multiple cones, in which countries specialize in subsets of goods depending upon their relative factor endowments, may represent a better environment to test the relationship between trade and factor endowments. Using data on up to 45 countries across 28 industries in 1990 Schott finds that single cone model is rejected, with evidence indicating potential heterogeneity of output within industries across countries. He finds further that the capital intensity of industries varies substantially across countries, a result he argues signals intra-industry product variation. Schott then develops a technique to recast industries into more theoretically appropriate HO aggregates, i.e. a grouping of products that are close substitutes and manufactured with identical techniques, which when taken to the data provides strong support for the idea that country product mix varies with relative endowments.

Romalis (2004) integrates a many-country version of the HO model with a continuum of goods and the model of monopolistic competition of Krugman (1980) with transport costs. This leads to two main predictions: Firstly, that countries capture larger shares of world production and trade of commodities that more intensively use their abundant factors, and secondly, that countries that rapidly accumulate a factor see their production and export structures systematically shift towards industries that intensively use that factor. These hypotheses are tested using commodity trade data and estimates of factor abundance and intensity for the US trade with around 200 trading partners in 1998. The results strongly confirm the two hypotheses, with the role of skill abundance found to be particularly pronounced.

Similar to other recent literature, Cabral et al (2009)[49] modify the strict HOV model to allow for international productivity and technique differences. In addition, they concentrate on skill endowments rather than the usual distinction between capital and labour.[50] Using data for 27 middle-income and developing countries in 1995 they find that these adjustments provide strong support for the modified model. They then decompose total trade into inter- and intra-industry trade and further split intra-industry trade into its horizontally and vertically differentiated components. The modified HOV model is found to predict better for inter-industry trade than

[49] See also Cabral et al (2006).

[50] This can be justified by arguing that physical capital is now a relatively mobile factor internationally.

intra-industry trade, but within intra-industry trade there are found to be differences. In particular, the modified HOV model predicts poorly for horizontally differentiated goods, but explains well vertically differentiated products.

Bernhofen and Brown (2009) exploit the opening to trade of Japan in the 19th century to test the HO theorem as formulated by Deardorff (1982).[51] This model requires compatible data under both autarky and free trade, which Bernhofen and Brown (2009) argue is met by the case of Japan. Their preliminary tests confirm the general HO theorem arguing that relative factor scarcity predicts the pattern of trade.

4. Conclusions

The model of Hecksher and Ohlin and its extension by Vanek are elegant models determining the patterns of trade. The models are also empirically testable. Early studies that tested the implications of the HO and HOV model often found results at odds with expectations. Later studies that relaxed some of the more restrictive assumptions of the theory found stronger support for the HOV theorem. These results can be interpreted in a number of ways. Trefler (1995) argues that following the results of Leamer (1980) the paradox of Leontief cannot be considered a paradox, while even if one did exist the results of Maskus and Stern (1981) indicate that it disappeared from the data in the 1970s. An alternative reading of the literature is that despite the results of Leamer (1980) and Maskus and Stern (1981) many studies continued to find evidence inconsistent with the strict HOV theorem, and that only when the models strict assumptions were relaxed was support for the theorem found. Relaxing the assumption of international identical technologies does appear to be a crucial step in finding support for the model and a role for relative factor endowments.

Future research will no doubt continue to refine the HOV theorem with alternative assumptions regarding such issues as technology and preferences. The growing importance of trade in value-added and trade in tasks is likely to lead to further research on incorporating intermediates trade. In a recent paper Baldwin and Robert-Nicoud (2010) show that when trade is tasks as well as trade in goods is allowed that the HOV theorem no longer holds. They show further that a simple transformation that replaces actual endowments with shadow-migration-adjusted endowments restores much of the HOV theorem. As data becomes increasingly accessible for a larger number of countries we should expect to see future research addressing the HOV theorem for larger and more different countries, and would expect that researchers would make more use of highly detailed product-level trade statistics that are becoming increasingly available. On the theory side, empirical models that consider technology differences fail to include a theoretical model explaining why such technological differences exist. Models that allow for firm heterogeneity are also likely to be increasingly used. The increasing importance of Foreign Direct Investment (FDI) is also likely to be considered both theoretically and empirically. The results of Schott (2003) mentioned above indicating the importance of different technologies within industries across countries are also likely to lead to an increased focus on product differentiation within industries.

[51] See also Bernhofen and Brown (2004, 2005).

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Appendix A: Factor Content Studies

Table 3.1: Direct Studies of the Factor Content of Trade

Study	Countries	Period	Trade	Technology	Factors Endowments	Method
Leontief (1954)	USA	1947 IO table and trade composition	Yes	US	No	Compared K/L ratio of exports and imports
Leontief (1956)	USA	1957 IO table; trade composition data from 1951	Yes	US	No	Compared K/L ratio of exports and imports
Tatemoto and Ichimura (1959)	Japan	1951 IO table	Yes	Japan	No	Compared K/L ratio of exports and imports
Bharadwaj (1962)	India; USA		Yes		No	Compared K/L ratio of exports and imports
Roskamp (1963)	West Germany	1954 IO table	Yes	West Germany	No	Compared K/L ratio of exports and imports
Roskamp and McMeekin (1968)	West Germany	1954 IO table	Yes	West Germany	No	Compared K/L ratio of exports and imports
Heller (1976)	Japan	1955, 1960, 1970 IO table Trade data: 1956-69	Yes	Japan	No	Compared K/L ratio of exports and imports
Bowen et al (1987)	27 countries	1966 IO table Trade data: 1967	Yes	US	No	Sign and rank test
Trefler (1993)	33 countries	1983	Yes	US	Yes	Allowed for productivity parameters
Trefler (1995)	33 countries	1983	Yes	US	Yes	Allowed for productivity parameters
Davis and Weinstein (2000)	10 countries	1985	Yes	10 countries	Yes	Used actual data on A^n
Davis and Weinstein (2001a)	10 countries	1985	Yes	10 countries	Yes	Estimated A^n from data
Hakura (2001)	4 countries	1970; 1980	Yes	4 countries	Yes	Allowed for productivity differences
Choi and Krishna (2004)	8 countries	1980	Yes	8 countries	Yes	Allowed for productivity differences
Maskus and Nishioka (2008)	29 countries	2000	Yes	29 countries	Yes	Estimated A^n from data

Notes: this is an expanded version of the table from Feenstra (2004, ch. 2).

Appendix B: Indirect Tests of HOV – Regression Based Studies[52]

A large number of studies, while not aimed at directly testing the HOV model contribute to the literature on the factor content of trade through regression analysis. These approaches quantify to what extent factor endowments affect actual trade flows. Two approaches in particular are relevant. The first involves considering a cross-section of commodities (or industries or sectors), and regresses a measure of trade performance on a number of theoretically suggested determinants of comparative advantage for specific time periods.[53] The second method considers cross-country regressions and involves regressing a measure of commodity characteristics (e.g. physical capital intensity) of a selected traded good on relevant country characteristics (e.g. physical capital abundance). Such a method is consistent with the comments of Leamer (1974) who argued that the fundamental theories of trade explain the variation of trade flows for particular commodities across countries and not the variation of trade flows of particular countries across commodities.

In terms of the former method Baldwin (1971) regresses adjusted net exports on the sectoral capital-labour ratio (accounting for both direct and indirect factor requirements), a measure of scientists and engineers in the labour force (accounting for innovation), six different occupation variables (measuring differences in human capital), a measure of scale and an index of unionisation. Net exports are adjusted by taking the difference between the values of exports and competitive imports after multiplying each sector's share of total exports and imports by one million dollars. The model was estimated using 1962 trade data and the 1958 IO table for the USA. The results indicate a significant negative relationship between net exports and the capital-labour ratio, a result which is considered a reconfirmation of the Leontief paradox. The measure of innovation is found to be positively related to net exports, and while the coefficients on most occupation levels are insignificant that on farmers and farm-workers is positive and significant. It is argued that this latter result is due to land be missing from the regression model.

Branson and Jutz (1971) regress sectoral net exports on capital per worker, human capital per worker and a measure of scale economies. The results indicate a negative relationship between the physical capital-labour ratio and net exports, with human capital displaying a positive coefficient. Branson (1971) adopted a similar approach but used the ratio of exports to gross trade as the dependent variable and found a similar set of results.

Harkness and Kyle (1975) use the dataset of Baldwin (1971), but define a binary dependent variable equal to one if the industry is a net exporter and zero if the industry is a net importer. The reason for considering this is that in a multifactor world the HOV model can only determine the direction of trade and not the volume. The independent variables are the capital-labour ratio, the share of the labour force divided in to four skill levels and a measure of resource intensity. The study initially considers 79 industries using 1962 trade data and the 1958 IO table for the

52 Much of this discussion is based on Borkakoti (1998).

53 This approach has been criticised by inter-alia Leamer and Bowen (1981) and Aw (1983) due to the lack of a theoretical basis for the approach. It has also been noted that the dependent variable in such studies should be scaled to normalise for world market size since no degree of comparative advantage will permit a country to export much of a good that nobody wants. This is not always done however. It is also possible that with more than two factors the signs of the regression coefficients do not duplicate the signs of the corresponding measures of factor abundance (see Feenstra, 2004, ch. 2).

USA, though in the final analysis a maximum of 58 industries are considered, with results for 45 resource-exclusive industries also being reported. The results indicate that the physical-capital labour ratio is a significant source of US comparative advantage of the 45 resource-exclusive industries.

Branson and Monoyios (1977) use data from Hufbauer (1970) on 1963 trade data and input data for 90 US sectors, regressing net exports on physical capital, human capital, and labour. The coefficient on capital is found to be negative – as is the coefficient on labour, as expected – while that on human capital is found to be positive. US exports are therefore found to be human-capital intensive, a result which lead Branson and Monoyios to conclude that it is inappropriate to add human capital to physical capital, as done by Kenen (1965) for instance. Branson and Monoyios also estimate the model with a binary dependent – consistent with the method of Harkness and Kyle (1975) – and find that both the physical capital stock and the physical capital-labour ratio have negative signs, results contrasting with those of Harkness and Kyle (1975).

Stern and Maskus (1981) also employ the cross-commodity method estimating regression models for each year between 1958 and 1976 for the USA. They regress sectoral net exports on physical capital, human capital and labour, with the number of observations ranging between 117 and 131. The results indicate that the coefficient on capital and labour are consistently negative, while that on human capital is positive. The negative coefficient on labour is taken as capturing relative scarcity of labour. Adopting a binary specification similar to Harkness and Kyle they find the capital and human-capital to labour ratios are both positive when natural resource intensive industries are excluded (though only significant for the human-capital-labour ratio), while when these industries are are included the coefficient on the physical capital-labour ratio turns negative and is occasionally significant.

While the vast majority of such studies have concentrated on the USA when adopting this approach, Stern (1976) adopted a similar methodology for West Germany using data on 25 sectors in 1962 and 1969. He finds results similar to those found for the US indicating a negative coefficient on the physical capital-labour ratio and a positive one on the human capital-labour ratio.

In terms of the cross-country approach Leamer (1984) considers the relationship between a country's factor supplies and factor demands using data on 47 countries and 10 factors of production in 1975. Estimates from this regression were taken as a measure of the link between endowments and trade. Leamer examines how these endowments relate to trade flows. A $1 million increase in the capital stock of the average country would reduce net exports of raw materials by $8,800 and of cereals by $4,300. It would increase net exports of animal products by $40, of labour-intensive products by $1,000, of capital-intensive goods by $16,500, of chemicals by $3,800 and machinery by $29,100. Overall the equations fit the data well and make sense, suggesting that factor endowments are an extremely important influence on comparative advantage. Interestingly Leamer finds that the US was abundant in dry land, coal and oil and scarce in lower-skilled labour and tropical land. At the same time the US was a large net importer of oil, suggesting that its tastes are biased heavily towards oil consumption in comparison with other countries. India however was well-endowed with many factors but had a small share of world GNP. It is argued that this reflects the very low productivity of inputs there, suggesting that production functions in India were significantly inferior to those in other countries in 1975.

Balassa (1979) introduces a two-stage cross-country analysis with a sample of 184 (4-digit SIC) product categories and 36 developed and developing countries. Comparative advantage is defined using 1972 trade data in terms of relative export performance, i.e. a country's share of world exports of a particular commodity or product category. For each country Balassa regresses export performance on (the sum of physical and human) capital intensity. Capital-intensity is expressed in terms of both stocks (the sum of the value of the physical capital stock and the value of human capital divided by the number of workers) and in terms of flows (value-added per worker). The coefficients using the stock concept are significant in 22 countries and in 29 countries using the flow concept. Balassa then regresses the estimated coefficients on countries physical and human capital endowment variables, and finds that both the physical and human capital variables are significant and positive.[54]

Hufbauer (1970) tests whether the α-index (that takes both direct and indirect inputs into account) decreases as the capital-labour ratio increases. He does this for 24 countries using the 1958 US direct capital and labour coefficients, and finds that capital per worker in 1963 manufactured goods exports is positively correlated with the estimated capital endowment per worker in the manufacturing sector and per capita GDP. For imports the correlation is negative, but insignificant. Baldwin (1979) uses capital and labour coefficients for the US (1963), EEC (1959) and Japan (1965) for the same 24 countries and finds that the correlations between the ratio of capital-labour content in import-competing to export production (i.e. the α-index) and the 1963 and 1969 per capita GDP are negative for the US, EEC and Japan (being significant for the US and EEC). This latter result supports the HOV model.

Bowen (1983) studied the changing patterns of resource supply in 34 countries over 1963-1975, estimating the changes in endowments of capital per worker and endowments of skilled labour. Bowen then examines whether the changes in resource endowments are associated with the changing patterns of comparative advantage in manufacturing goods by considering the sectoral exports and imports of 91 3-digit manufacturing sectors. The ratio of factor content in exports to that in imports is then computed for each of the 34 countries in the sample for each of five years (1963, 1966, 1969, 1972, 1975) using year-specific trade data but constant input coefficients (i.e. the 1963 US direct input coefficients). The results indicate a positive and significant relationship between resource endowments and the export-import factor content ratios.

Balassa (1986) introduces factor endowments, factor intensities and trade flows simultaneously in a multi-country multi-product econometric model. Net exports (scaled by total trade) are the dependent variable, while the independent variables include three factors of production (physical capital, human capital, labour), capital intensity, the stocks of physical and human capital and the flows of physical capital and human capital. Balassa uses 1971 trade and capital-intensity data for 38 countries covering 16 three- and four-digit SITC commodity categories. The results indicate that human and physical capital endowments explain a substantial part of the variations in the pattern of trade, lending support to the HOV theorem.

[54] As Bowen (1983) points out the Aw-Leamer-Bowen critique applies to this approach of first regressing a measure of comparative advantage on input intensity for each country and then using the estimated coefficients as dependent variables in a cross-country regression on countries' resources.

The results from these regression-based studies are often found to be consistent with the Leontief paradox, in that a higher capital-labour ratio in a sector in the US is associated with a decrease in net exports. The results further show the importance of human capital and technological inputs (e.g. R&D) in explaining the structure of trade however, which have often been ignored in factor content studies.[55] A further issue that has arisen from these studies is whether one should combine human and physical capital, or whether these should be treated separately.

[55] The search for additional explanatory variables other than the capital-labour ratio (e.g. skilled labour, R&D, human capital, etc) became known as the neo-factor proportions theory. See Chapter 20 of Borkakoti (1998) for further information on such studies.

Appendix C: Indirect Tests of HOV – Testing the Assumptions[56]

An alternative method of testing the validity of the HOV model is to examine whether the assumptions of the model are valid. Minhas (1962, 1963) for example tested the assumption of non-reversibility of factor intensities. If output (Q) is produced using capital (K) and labour (L), and α, β and A are technologically determined parameters we can write the CES production function as:

$$Q = \left(AK^{-\beta} + \alpha L^{-\beta}\right)^{-1/\beta}$$

Defining k and ω as the capital-labour ratio and the wage rental ratio (w/r) and noting that under perfect competition ω equals the Marginal Rate of Technical Substitution of capital for labour (MRTS) then we can write:

$$\log\omega = \log\frac{\alpha}{A} + (1+\beta)\log k$$

the constant slope $(1+\beta)$ is the reciprocal of σ, the elasticity of factor substitution. The test is based on the principle that the σ's vary between industries, so that the response of the capital-labour ratio to a change in the wage-rental ratio in the first industry can be much stronger than that in the second industry. Under such a situation (i.e. $\sigma_1 > \sigma_2$) the first industry which initially was relatively labour-intensive will become relatively capital-intensive as the wage-rental ratio tends to increase. Using data for 24 three-digit industries from 19 countries, Minhas estimates σ_i and $(\alpha/A)_i$. The real wage, w, equals the marginal product of labour under perfect competition, so that $w = \partial Q/\partial L$, which yields the following:

$$\log(Q/L)_{ij} = -\sigma_i \log\alpha_i + \sigma_i \log\omega_{ij}$$

Estimating this equation provides estimates for σ and α in industry i. Doing something similar for $r = \partial V/\partial K$ provides estimates of A for industry i.

Minhas (1962) plots seven crossover points for six industries[57] and argues that based on this the assumption of strong factor intensity condition is rejected. Leontief (1964) criticises the conclusions of Minhas and repeats the steps for 21 of the 24 industries and finds that the evidence supports the distinction between capital- and labour-intensive industries. Of the 210 possible crossover points only 17 are found, and these take place between curves that are very close and so may have identical capital-labour ratios. Lary (1968), Yahr (1968) and Philpot (1970) also rejected the Minhas results, though Naya (1967) finds evidence of factor intensity reversals between agriculture and other sectors. Yeung and Tsang (1972) use the variable elasticity of substitution production functions and find that factor-intensity reversals do occur.

Hunter and Markusen (1988) examine the assumption of homothetic preferences. They make use of a linear expenditure system, which allows for non-homothetic preferences in a simple way. A consumer's demand function is derived from a simple Cobb-Douglas utility function:

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56 This discussion is based on Borkakoti (1998).

57 He reports results for only 6 of the 24 industries.

$$U(C) = \prod_{i=1}^{n}(C_i - \bar{C_i})^{\beta_i}, \sum \beta_i = 1$$

where C_i is consumption of good i, $\bar{C_i}$ denotes a minimum consumption requirement for good i. The demand function for the ith good is derived from this utility function as:

$$C_i = \bar{C_i} + \beta_i\left(I - \sum p_j \bar{C_j}\right)/p_i$$

where Y is consumer's income, and the term $\left(Y - \sum p_j \bar{C_j}\right)$ is available income after having met the minimum consumption. Given that each consumer's demand is the same linear function the above equation can be aggregated up to the total economy Y and C_i can be interpreted as the economy's total income and consumption of good i (or in per capita terms if dividing by population). Rewriting the above equation gives the estimating equation:

$$p_i C_i = \sum_{i=1}^{n} \alpha_{ij} P_j + \beta_i Y$$

This is estimated for 11 goods and 34 countries using 1975 data. Units are chosen so that all US prices are set equal to 1. In each country the price of food (good 1) is taken as the numeraire. The empirical results show that the income elasticities of demand, evaluated at mean income and consumption levels, vary from a minimum of 0.452 for food to 1.741 for gross rent. Deviations from unity imply preference deviations from homotheticity and these tend to be significant, thus supporting the conclusion that non-homotheticity of preferences is prevalent.