# On the bilateral factor content of trade with traded intermediates

Neil Foster and Robert Stehrer

The Vienna Institute for International
Economic Studies (wiiw)
Rahlgasse 3, A-1060 Vienna, Austria.
Email: Robert.Stehrer@wiiw.ac.at

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**Abstract**

In this paper we derive testable restrictions relating the factor content of bilateral trade to bilateral differences in technology and endowments. As an extension over previous research we allow for trade in intermediates, and in particular allow for differing intermediate input requirements across countries, which may arise due to aggregation for example. These restrictions are tested using the recently compiled WIOD dataset that allows us to track the supply and use of intermediate goods across countries and industries.

*Keywords:* bilateral trade, factor content of trade, intermediates

*JEL-classification:* F11, F14, F15

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## 1 Introduction

The Heckscher-Ohlin-Vanek (HOV) model of trade has been a centre-piece of trade theory for the last four decades or so. The model building upon the simple $2 \times 2 \times 2$ Heckscher-Ohlin model to allow for more goods and factors predicts trade in factor services, rather than trade in goods, such that a capital-abundant country 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 however, the model in its strictest form has been overwhelmingly rejected. This can already be seen in the seminal contribution of Leontief (1953) who showed that in 1947 the USA exported relatively labor-intensive goods and imported relatively capital-intensive goods. Other studies quickly followed with a number of studies (e.g. Leontief, 1956; Baldwin, 1971, 1979) confirming the results of Leontief (1953) and others providing more support to the HOV model (e.g. Tatemoto and Ichimura, 1959; Roskamp, 1963; Roskamp and McKeekin, 1968; ?). Later studies criticized the methodology of Leontief and proposed alternative tests of the HOV model, again with mixed results (e.g. Leamer, 1980; Maskus, 1985; Bowen et al., 1987). Overall, the results from these early tests of the HOV model did not provide a great deal of support for the model.

More recent research has looked to relax the strong assumptions of the strict HOV model by allowing for international differences in production techniques, a lack of factor price equalization, taste differences and the possibility of non-traded goods and intermediate goods trade (e.g. Trefler, 1993, 1995; Davis and Weinstein, 2000, 2001a,b). Relaxing such assumptions has been found to significantly improve the performance of the HOV model; see also Baldwin (2009) in this respect. An approach to modeling and testing the factor content of trade that has recently been developed empirically involves testing theoretical predictions that relate the factor content of bilateral trade to bilateral differences in factor endowments (e.g Choi and Krishna, 2004; Lai and Zhu, 2007, for recent empirical applications).[1] Such an approach has the advantage over much of the existing literature in that it doesn't rely on either FPE or on identical and homothetic preferences. Moreover, the approach can be extended to allow for technology differences across countries and for traded intermediate goods. The empirical model is based upon the theory of

[1] In the appendix we provide a technical overview over the relevant papers.

Helpman (1984), who built upon the work of Brecher and Choudhri (1982) 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:

$$(\mathbf{w}^r - \mathbf{w}^p)(\mathbf{t}_V^{rp} - \mathbf{t}_V^{pr}) \geq 0$$

where $\mathbf{w}^r$ and $\mathbf{w}^p$ are the factor price vectors in countries $r$ and $p$, and $\mathbf{t}^{rp}$ ($\mathbf{t}_V^{pr}$) is the vector of factor content imports of country $r$ ($p$) from country $p$ ($r$) measured with the technology matrix of the exporting country. This states that, on average, country $r$ is a net importer from country $p$ of factors that are cheaper in $r$ than in $p$, and country $r$ is a net importer from country $p$ of factors that are cheaper in $r$ than $p$. Helpman (1984) shows further that this implies that the factor content of exports from country $r$ to $p$ has, on average, a higher ratio of productive factors in which $r$ is relatively well endowed than does the comparable ratio of exports from $p$ to $r$.

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 plus indirect) factor content measures. 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 of Choi and Krishna (2004) uses data on direct input matrices and input-output matrices for each of eight countries to test the model. In addition, they collect data on two types of primary input factors, capital and (disaggregated) labor. To test the model Choi and Krishna rewrite the equation above as:

$$\frac{\mathbf{w}^p\mathbf{t}_V^{pr} + \mathbf{w}^r\mathbf{t}_V^{rp}}{\mathbf{w}^r\mathbf{t}_V^{pr} + \mathbf{w}^p\mathbf{t}_V^{rp}} \equiv \theta \geq 1$$

The calculated value of $\theta$ then has a useful interpretation. For any country pair, $r$ and $p$, with gross bilateral import flows of factors, $\mathbf{t}_V^{rp}$ and $\mathbf{t}_V^{pr}$, is the ratio of the sum of the importer's (hypothetical) cost of production (using the importer's factor prices and exporter's factor usage) to the total (actual) cost of production in the exporting countries (using the actual producer's factor prices and factor usage). A value of $\theta$ of 0.5 for example would imply that, on average, costs could be 50% lower if domestic production were substituted for bilateral imports. Such a value would represent a strong violation of the theory. The calculated values of $\theta$ 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 $\theta$ is less than one the value is above 0.99. The results using alternative measures of capital and labor give similar results, while accounting for measurement error of factor prices is actually found to improve the results. The result that many of the calculated $\theta$'s are close to one indicates that the importer's and exporter's costs of production are similar. Choi and Krishna consider whether such results are 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 $\theta$ 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) in a number of ways. The major differences when compared with Choi and Krishna (2004) are that Lai and Zhu employ a larger sample - Lai and Zhu consider 41 developed and developing countries - and allow for technology differences to be country- and industry-specific (i.e. the approach allows for Hicks-neutral, Ricardian technology differences). In addition, they derive from their theoretical model a second hypothesis relating the factor content of bilateral trade to relative factor abundance. In their theoretical model they assume that final goods are produced using primary factors and intermediate inputs, which are freely traded. They further assume that the requirement for intermediate inputs to produce a unit of a given good is identical across countries, and therefore that the cost of intermediate inputs is equal across countries.

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-labor ratio than the exports of labor-abundant countries. The restrictions are tested on a sample of 41 (developed and developing) countries. The dataset has information on two factors (capital and labor). Results for the first hypothesis indicate that the restrictions are satisfied in up to 99% of cases (depending on the assumptions regarding technology differences) when a country-pair includes one capital-abundant and one labor-abundant country. The restriction tends to be satisfied in more than 80% of cases for pairs of capital-abundant and labor-abundant countries (again depending on assumptions regarding technology differences). Results indicate that the restrictions are more likely to hold for countries with more disparate endowments. These results are not found to be sensitive to the assumption that intermediates are non-traded. 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 labor- 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).

This paper discusses the role of trade intermediates in these approaches. Traded intermediates are so far left out of the scene mostly based on the contribution by Staiger (1986). However this relies on the assumption that intermediates are traded freely and tariffs and transport costs do not matter. Thus, intermediates would not be a source of comparative advantages. We critically review this assumption and try to incorporate intermediates in bilateral factor content studies.

The paper goes as follows. In Section 2 we discuss two approaches, the one based on Lai and Zhu (2007) and the other more based on the approach as outlined in Helpman (1984) and extended by Choi and Krishna (2004). Section 3 provides an overview of the data used in the empirical application. These data are the recently compiled WIOD database (see www.wiod.org). In Section 4 we provide an overview over the empirical results following the methods as outlined in Section 2 as well an assessment to which extent intermediate input use differ across countries. Section 5 concludes.

# 2 Taking account of traded intermediates in bilateral FCT calculations

Based on the recent literature we discuss two approaches how to take account of trade in intermediates in bilateral factor content studies. The first approach follows the one as suggested in Lai and Zhu (2007) and the second is based on the contribution by Helpman (1984) and its extension by Choi and Krishna (2004).

## 2.1 Approach 1

In this section we derive theoretical restrictions on the factor content of bilateral trade and factor prices, allowing for different requirements for intermediate inputs across countries. The theory is a straightforward extension of that set out in Lai and Zhu (2007). Consistent with their approach and much recent literature in this area, our approach also allows for Ricardian technology differences. The assumptions of the model are similar to Lai and Zhu (2007) and Staiger (1986). There are $G$ goods which can be used as intermediates and final goods; goods are produced by primary factors and the intermediates. Production exhibits constant returns to scale, and all product markets are perfectly competitive. There are no barriers to trade in either final products or intermediate inputs. The model allows for technology to differ across countries and industries, and consistent with Lai and Zhu (2007) we assume that technology differences are factor-augmenting and Hicks-neutral. The major difference in our model when compared with that of Lai and Zhu (2007) is that we don't impose the assumption that the requirement for intermediate inputs is identical across countries (as assumed e.g. Staiger, 1986; Davis et al., 1997, as well). We drop this assumption since it is easy to think of examples in which a good is produced with different intermediate inputs in different countries (though this partly depends on the definition of a "product"). In this respect one has to note that the approaches are empirically assessed at the industry level. This necessary aggregation from product-level to industry-level is likely to create differences in intermediate input requirements across countries. As discussed by Reimer (2006) an industrial classification contains a range of goods differentiated both horizontally and vertically. Different goods within this range are likely to have different factor and intermediate input requirements. Countries are likely to specialize on a specific subset of goods within a particular industry and therefore the factor content as well as the intermediate input usage may differ across countries for a particular good (or industry). Furthermore, countries source their intermediates from different countries also depending on tariffs, transport costs and geographical distance.

Assume a number of goods $i = 1, \ldots, G$, a number of countries $r, p = 1, \ldots, N$. $\phi_i^r$ is the production function for good $i$ in country $r$, $\mathbf{d}_i^r$ is the vector of factors needed directly to produce one unit of good $i$ in country $r$, $\lambda_i^r$ is the productivity of industry $i$ in country $r$ (larger values indicating fewer inputs per unit of output), and $I_i^r$ is the vector of factor contents of intermediates used to produce one unit of good $i$ in country $r$. Let $\mathbf{w}^r$ is the vector of factor prices in country $r$, and $t_i^{rp}$ is the volume of gross exports of good $i$ from country $p$ to country $r$.

A few words should be said about the vector of factor contents of goods. Given the assumption that intermediate inputs are freely traded, a country is able to purchase intermediates both domestically and from all of its trade partners. The production of each intermediate input in each country may differ in terms of their factor requirements because of technology differences and geographic sourcing patterns. Furthermore, unit costs then depend on all factor prices in the world rather than only the domestic ones. This makes it necessary to extend the framework as outlined in Lai and Zhu (2007) to include intermediates.[2]

Lai and Zhu (2007) assume that the per unit cost of intermediates to produce one unit of good $i$ are the same across countries and equal to $p_i^I$. They further mention (footnote 4, p. 392) that if this assumption is relaxed (e.g. because of trade costs) their main inequalities may be violated; (see also Staiger, 1986). For our work, it is important to note that without FPE and with countries sourcing intermediates from different countries we may expect there to be differences in the per unit cost of intermediates needed to produce one unit of a particular good. Assume for now, that the cost of intermediates to produce one unit of good $i$ is the same across countries. With CRTS the per unit cost of producing $i$ in country $r$ is given by $w^r d_i^r + p_i^{I,r} I_i^r$. Perfect competition implies zero profits on exports of $i$ from $p$ to $r$. Hence,

$$p_i = w^p d_i^p + p_i^{I,p} I_i^p$$

where $p_i$ is the world price of good $i$.[3] For importing country $r$, unit profits on good $i$ must be

[2] The approach by Lai and Zhu (2007) is based on direct factor inputs only. At this stage we leave this for future research and concentrate on the effects of different intermediate inputs requirements.

[3] Again, the issue of aggregation of goods to the industry-level may lead to a different set of goods being

non-positive,

$$p_i \leq w^r d_i^r + p_i^{I,r} I_i^r$$

Combining these two equations yields

$$w^p d_i^p + p_i^{I,p} I_i^p \leq w^r d_i^r + p_i^{I,r} I_i^r$$

Assuming Hicks-neutral differences in factor efficiency, if country $r$ and $p$ had the same factor prices, country $r$ would need $\frac{\lambda_i^p}{\lambda_i^r} d_i^p$ direct inputs to produce one unit of good $i$. If countries $r$ and $p$ face different factor prices, while $\frac{\lambda_i^p}{\lambda_i^r} d_i^p$ is a feasible way for country $r$ to produce one unit of good $i$, it need not be optimal. Cost minimization therefore implies

$$w^p d_i^p + p_i^{I,p} I_i^p \leq w^r \frac{\lambda_i^p}{\lambda_i^r} d_i^p + p_g^{I,r} I_i^r$$

Combining gives

$$\begin{aligned} w^p d_i^p + p_i^{I,p} I_i^p &\leq w^r \frac{\lambda_i^p}{\lambda_i^r} d_i^p + p_g^{I,r} I_i^r \\ (w^p - w^r \frac{\lambda_i^p}{\lambda_i^r}) d_i^p + (p_i^{I,p} I_i^p - p_g^{I,r} I_i^r) &\leq 0 \end{aligned}$$

To derive the national-level restrictions we aggregate over $i$ using $t_i^{rp}$ as weights. Defining $t_{V,i}^{rp} = d_i^r t_i^{rp}$ and aggregating yields:

$$\sum_i (\frac{w^p}{\lambda_i^p} - \frac{w^r}{\lambda_i^r}) \lambda_i^p t_{V,i}^{rp} + (p_i^{I,p} I_i^p - p_i^{I,r} I_i^r) t_i^{rp} \leq 0$$

or

$$\sum_i (\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p}) \lambda_i^p t_{V,i}^{rp} + (p_g^{I,r} I_i^r - p_i^{I,p} I_i^p) t_i^{rp} \geq 0$$

By symmetry we also have

$$\sum_i (\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p}) \lambda_i^r t_{V,i}^{pr} + (p_i^{I,r} I_i^r - p_i^{I,p} I_i^p) t_i^{pr} \leq 0$$

produced within an industry and a different set of prices.

Combining gives testable restriction

$$\sum_i (\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p})\lambda_i^p t_{V,i}^{rp} + (p_i^{I,r} I_i^r - p_i^{I,p} I_i^p) t_i^{rp} \geq \sum_i (\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p})\lambda_i^r t_{V,i}^{pr} + (p_i^{I,r} I_i^r - p_i^{I,p} I_i^p) t_i^{pr}$$

$$\sum_i (\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p})(\lambda_i^p t_{V,i}^{rp} - \lambda_i^r t_{V,i}^{pr}) + (p_i^{I,r} I_i^r - p_i^{I,p} I_i^p)(t_i^{rp} - t_i^{pr}) \geq 0$$

A few remarks are necessary. First, the first term on the rhs is exactly the one derived by Lai and Zhu (2007). It should be noted that this is based on direct input coefficients only. A next step therefore is to derive this restriction by using direct plus domestic indirect input coefficients. This should however be done relatively easy when using $\mathbf{B}^r = \mathbf{D}^r(\mathbf{I} - \mathbf{A}^{rr})^{-1}$ where $\mathbf{A}^{rr}$ denotes the domestic matrix of input coefficients (compare also to Choi and Krishna, 2004, Appendix B, where however productivity levels are benchmarked to a third country).[4]

[ ... include results ...]

Second, the second term is in line with the result as derived in Staiger (1986) and also mentioned in Lai and Zhu (2007), footnote 4, that the restriction can be violated. Thus a first step is to provide empirical analysis how important this term might be and also to assess the potential bias it might have on the results. Furthermore, it should be noted that trade in intermediates also carries trade in factors which is not yet properly accounted for.[5] In the next section we try to take this into account more properly.

### 2.2 Approach 2

We start with only one direct input factor. The world price vector is given by

$$\mathbf{p}' = \mathbf{p}'\mathbf{A} + \mathbf{w}'\hat{\mathbf{d}} = \mathbf{w}'\hat{\mathbf{d}}\big(\mathbf{I} - \mathbf{A}\big)^{-1} = \mathbf{w}'\mathbf{B}$$

where $\mathbf{B}$ is a matrix of dimension $NG \times NG$. We denote a particular column of this matrix with $\mathbf{b}_{*i}^{*r}$. Perfect competition implies zero profits of exports of product $g$ from country $p$ to $r$.

$$p_i^p = \mathbf{w}'\mathbf{b}_{*i}^{*p}$$

[4] Note that the derivation of the restriction is based on a single factor.

[5] One also has to think whether the aggregation by total trade flows is appropriate.

For importing country $r$, unit costs of production of $i$ must be larger

$$p_i^p \leq \mathbf{w}'\mathbf{b}_{*i}^{*r}$$

Combining these two equations yields

$$\mathbf{w}'\mathbf{b}_{*i}^{*p} \leq \mathbf{w}'\mathbf{b}_{*i}^{*r}$$

Let $t_i^{rp}$ be gross imports of $r$ from $p$. We aggregate across sectors using

$$\sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{rp} \leq \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{rp}$$

or

$$\sum_i \mathbf{w}'\left(\mathbf{b}_{*i}^{*p} - \mathbf{b}_{*i}^{*r}\right) t_i^{rp} \leq 0 \qquad \text{or} \qquad \sum_i \mathbf{w}'\left(\mathbf{b}_{*i}^{*r} - \mathbf{b}_{*i}^{*p}\right) t_i^{rp} \geq 0$$

By a symmetric argument we achieve

$$\sum_i \mathbf{w}'\left(\mathbf{b}_{*i}^{*r} - \mathbf{b}_{*i}^{*p}\right) t_i^{pr} \leq 0$$

Combining these two inequalities result in

$$\sum_i \mathbf{w}'\left(\mathbf{b}_{*i}^{*r} - \mathbf{b}_{*i}^{*p}\right) t_i^{rp} \geq \sum_i \mathbf{w}'\left(\mathbf{b}_{*i}^{*r} - \mathbf{b}_{*i}^{*p}\right) t_i^{pr}$$

This can be rewritten as

$$\sum_i \mathbf{w}'\left(\mathbf{b}_{*i}^{*r} - \mathbf{b}_{*i}^{*p}\right)(t_i^{rp} - t_i^{pr}) \geq 0$$

or

$$\begin{aligned}
\sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{rp} - \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{rp} - \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{pr} + \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{pr} &\geq 0 \\
\sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{rp} + \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{pr} &\geq \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{rp} + \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{pr} \\
\frac{\sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{rp} + \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{pr}}{\sum_i \mathbf{w}'\mathbf{b}_{*i}^{*p} t_i^{rp} + \sum_i \mathbf{w}'\mathbf{b}_{*i}^{*r} t_i^{pr}} &\geq 1
\end{aligned}$$

In matrix notation this can be written as

$$\frac{\mathbf{w}'\mathbf{B}^r\mathbf{t}^{rp} + \mathbf{w}'\mathbf{B}^p\mathbf{t}^{pr}}{\mathbf{w}'\mathbf{B}^p\mathbf{t}^{rp} + \mathbf{w}'\mathbf{B}^r\mathbf{t}^{pr}} \equiv \theta \geq 1$$

This can be rewritten as (following Choi and Krishna, 2004)

$$\frac{\mathbf{w}'\mathbf{B}^r\mathbf{t}^{rp} + \mathbf{w}'\mathbf{B}^p\mathbf{t}^{pr}}{\mathbf{w}'\mathbf{B}^p\mathbf{t}^{rp} + \mathbf{w}'\mathbf{B}^r\mathbf{t}^{pr}} \equiv \theta \geq 1$$

For more than one factor the equation would look like

$$\frac{\sum_k \mathbf{w}'_k\mathbf{B}^r\mathbf{t}^{rp} + \mathbf{w}'_k\mathbf{B}^p\mathbf{t}^{pr}}{\sum \mathbf{w}'_k\mathbf{B}^p\mathbf{t}^{rp} + \mathbf{w}'_k\mathbf{B}^r\mathbf{t}^{pr}} \equiv \theta \geq 1 \tag{1}$$

## 3 Data

The data used for the analysis is taken from 'The World Input-Output Database' (WIOD) as available in January 2011.[6] In this section we provide a short description of the data to be used and how these have been constructed; more detailed information can be obtained from papers mentioned below. The WIOD data are the outcome of an effort undertaken to bring together information from national accounts statistics, supply and use tables, trade in goods and services data and corresponding data on factors of production (ICT and Non-ICT capital, labor by educational attainment categories) for 40 countries over the period 1995-2006. A detailed description of datasources can be found in Erumban et al. (2010) on national accounts data and the supply and use tables, Francois and Pindyuk (2010) on services trade and Pöschl and Stehrer (2010) on goods trade.

National accounts data have been collected for all countries over the period 1995-2006 which served as benchmark values. Existing supply and use tables have then been adjusted to these national accounts data with some of the tables being estimated for years for which these were not available. Some countries only provide input-output tables which has been transformed back into supply and use tables. In this process all tables have been standardized over years and across countries with respect to product and industry codings. These tables contain information on supply and use of 59 products in 35 industries together with the information on final use and value added. Accompanying this information corresponding trade data were collected at the

[6] See www.wiod.org.

same level of disaggregation at the product level. With respect to goods trade which are taken from UN COMTRADE data at the HS 6-digit level this is rather straightforward as there exists a correspondence from HS-6 to the product level in the supply and use tables (CPA). However services trade is only available from balance-of-payment statistics providing information on a detailed basis only in BoP categories. Using a rough correspondence these were merged to the product level data provided in the supply and use tables. Additionally, the trade data are split up into use categories fitting the needs of supply and use tables, i.e. intermediates, consumption and gross fixed capital formation. Goods trade has been split up by applying a categorization of products into intermediates, final consumer goods and gross fixed capital goods. The correspondence used for this was made up starting from the usually used BEC classification (provided by UN) but have been adapted to the specific needs (see Pöschl and Stehrer, 2010). In particular, the correspondence between HS6-digit and BEC categories has been revised and in a number of cases we use weights for particular products to distinguish between intermediates and the other categories. For services trade, however, there is no such information available. Therefore, we used data from existing input-output and supply and use data and applied average shares across countries. Relying on these underlying data we started from the import vector provided in the supply tables. Import values for each country and product are split up first into the three use categories. Second, within each use category a proportionality assumption is applied to split up the imports for each use category across the relevant dimensions. For example, imports of intermediates are split across using industries according to the shares resulting from the original use table. Similarly, imports for final consumption is split up into final demand categories. Investment are allocated only to gross fixed capital formation (i.e. not considering changes in inventories and valuables). This resulted in an import use table for each country. Finally each cell of the import use table was again split up by country of origin resulting in 39+1 (for rest of world) import use tables for each country. Merging these tables together provides a full set of inter-country supply and use tables. Finally, an international input-output table was constructed by applying the transformations of model D as described in the Eurostat manual (Eurostat, 2008). This results in a world input-output database for 40 countries and 35 industries, i.e. the intermediates demand block is of dimension $1400 \times 1400$, plus the additional rows on value added and columns on final demand categories. Rest of the world is not explicitly modeled in this case but appears only in the import columns (imports from rest of the world by product) and export column (exports to rest of the world). In the application below only an assumption on the structure of input coefficients is necessary which will be outlined below.

Corresponding data at the industry level allow splitting up value added into capital and labor income. Furthermore, capital income can be split up into ICT and Non-ICT income, and labor income into income of low, medium and high educated workers. These additional data for the factor incomes corresponds in construction the method applied in the EU KLEMS database Timmer et al. (2007) and efforts undertaken in the World KLEMS project. [7] Finally, the database also includes imports from rest of the world and exports to rest of the world.[8] To take account of trade with these countries one would have to construct such an entity. For the purpose of this paper we can do this by adding additional blocks (rows and columns) in the coefficient matrix. In this paper we present results when assuming that this rest of the world has the same structure as Brazil. Qualitatively the results do not depend on this assumption.

# 4 Results

## 4.1 Cost differences in intermediate inputs

[TO BE INCLUDED ...: Evidence and literature that that different countries use different combinations of intermediates to produce a good and/or show that aggregation (from the product to the industry level) leads to different combinations of intermediates; differences in intermediates costs shares across countries, etc.]

## 4.2 Testing restrictions

We provide some very preliminary evidence of a test of equation (1).[9] For this we calculated two versions one when including the full information of traded intermediates and a second one when only using direct input coefficients for years 1995, 2000, and 2006. Table 1 presents the percentage shares where the restriction is satisfied which is also summarized in Figure 1. Generally, the test performs not too well when using the direct and indirect input measure and

[7] Some of these data are still preliminary and will be replaced later by improved information. Furthermore, for a number of countries and factors we had to impute values from other countries which again is a source of a potential imprecision.

[8] In the construction process of the WIOD intercountry tables exports to rest of the world also serve as balancing item.

[9] These results are very preliminary and based on the September 2010 version of the WIOD data.

**Table 1** Testing of restrictions, in %

| | Direct inputs | | | Direct and indirect inputs | | |
|---|---|---|---|---|---|---|
| Reporter | 1995 | 2000 | 2006 | 1995 | 2000 | 2006 |
| AUS | 49.3 | 55.3 | 54.7 | 59.8 | 64.1 | 68.6 |
| AUT | 41.0 | 49.5 | 54.5 | 49.0 | 65.4 | 71.9 |
| BEL | 43.6 | 43.6 | 56.0 | 47.5 | 54.6 | 73.1 |
| BGR | 69.2 | 90.9 | 100.0 | 66.7 | 100.0 | 100.0 |
| BRA | 53.5 | 63.3 | 61.9 | 60.6 | 69.0 | 74.9 |
| CAN | 55.1 | 57.8 | 57.9 | 56.9 | 65.2 | 70.8 |
| CHN | 37.9 | 50.3 | 52.4 | 37.7 | 50.0 | 57.5 |
| CYP | 58.5 | 55.1 | 52.0 | 59.0 | 66.1 | 68.6 |
| CZE | 71.4 | 70.3 | 71.9 | 75.2 | 74.4 | 80.1 |
| DEU | 53.4 | 56.5 | 53.9 | 51.2 | 65.9 | 72.8 |
| DNK | 60.7 | 63.5 | 62.9 | 69.5 | 78.2 | 80.2 |
| ESP | 43.5 | 47.5 | 50.1 | 51.6 | 53.8 | 67.4 |
| EST | 68.1 | 61.9 | 62.6 | 71.8 | 70.6 | 76.8 |
| FIN | 54.6 | 61.6 | 58.7 | 57.9 | 66.6 | 70.5 |
| FRA | 50.9 | 57.8 | 57.1 | 57.0 | 65.4 | 68.2 |
| GBR | 66.4 | 73.0 | 57.9 | 62.8 | 79.2 | 71.2 |
| GRC | 53.8 | 58.0 | 48.8 | 55.0 | 57.6 | 60.5 |
| HUN | 80.6 | 79.5 | 76.0 | 82.8 | 85.7 | 87.4 |
| IDN | 36.9 | 41.5 | 48.5 | 38.1 | 39.7 | 51.2 |
| IND | 50.8 | 50.4 | 56.7 | 47.1 | 48.3 | 58.5 |
| IRL | 57.1 | 62.7 | 59.9 | 59.6 | 68.4 | 67.4 |
| ITA | 49.3 | 52.9 | 55.6 | 51.2 | 64.7 | 67.3 |
| JPN | 65.6 | 62.5 | 61.7 | 64.1 | 65.2 | 69.0 |
| KOR | 43.8 | 41.2 | 39.8 | 50.9 | 55.7 | 54.6 |
| LTU | 58.5 | 62.9 | 64.8 | 67.1 | 70.8 | 75.5 |
| LUX | 43.1 | 32.3 | 37.5 | 49.0 | 49.7 | 53.1 |
| LVA | 56.9 | 63.6 | 62.2 | 65.7 | 73.1 | 74.1 |
| MEX | 56.8 | 59.1 | 67.1 | 64.2 | 63.8 | 73.4 |
| MLT | 57.7 | 60.3 | 59.7 | 60.9 | 69.9 | 77.9 |
| NLD | 51.5 | 54.3 | 50.6 | 55.0 | 61.8 | 59.9 |
| POL | 73.6 | 65.8 | 66.3 | 80.3 | 76.0 | 77.7 |
| PRT | 50.9 | 62.0 | 60.4 | 56.1 | 69.5 | 72.5 |
| ROM | 30.5 | 38.4 | 47.0 | 26.7 | 39.7 | 49.7 |
| RUS | 38.7 | 46.6 | 62.1 | 43.2 | 47.7 | 72.6 |
| SVK | 75.2 | 71.2 | 77.1 | 81.9 | 75.8 | 83.0 |
| SVN | 26.8 | 27.5 | 33.2 | 65.5 | 75.4 | 80.7 |
| SWE | 52.7 | 62.4 | 61.4 | 68.8 | 78.0 | 80.2 |
| TUR | 55.0 | 63.7 | 67.1 | 59.4 | 67.7 | 74.0 |
| TWN | 61.5 | 61.8 | 54.0 | 66.3 | 68.5 | 67.0 |
| USA | 58.3 | 56.1 | 52.9 | 67.4 | 62.3 | 67.3 |

*Source:* WIOD database, Version September 2010; author's calculations

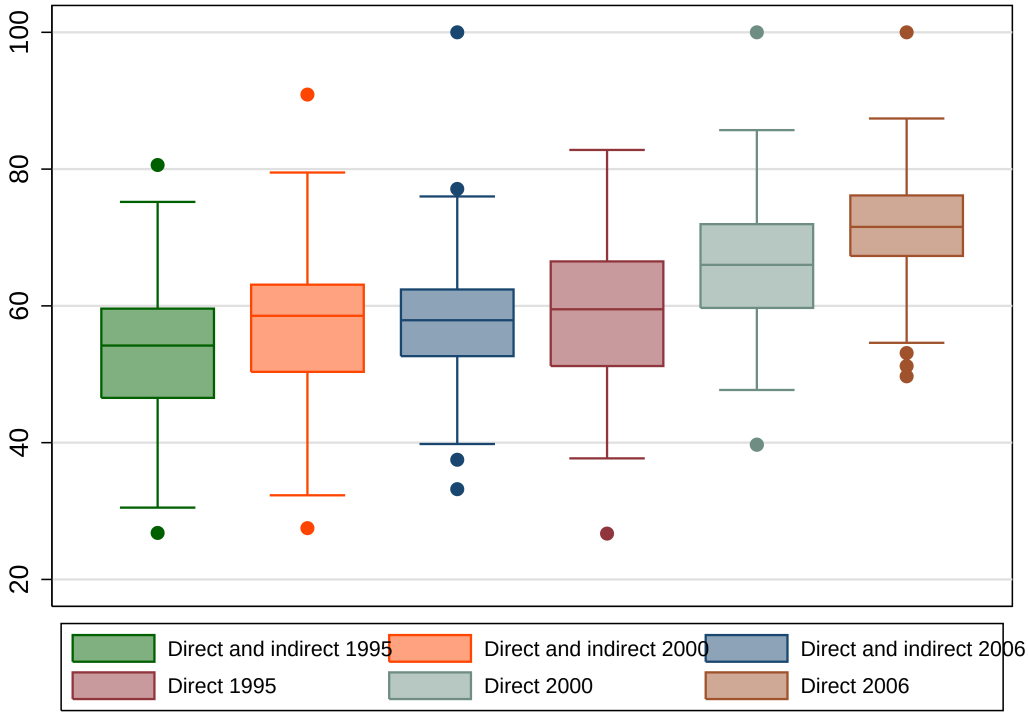


Figure 1: Boxplot

the mean (or median) is only slightly larger than 50%. When using direct coefficients only the results improves and the share increases to 70% in 2006. Futhermore, the fit seems to become better over time in both cases.

However, this results hide some variation across countries. Therefore, in Figures 2 we present the shares for individual countries again for both measures of inputs.

One can see that the shares vary quite a bit from less than 40% to even 100% in case of Bulgaria though for most of the countries the shares are in between 50 to 70% in case of using direct and indirect coefficients and 60 to 80% in case of using direct input coefficients only. The fact, that the test performs better in the latter case maybe hints towards an upward bias of the 'successes' due to not considering intermediate inputs as a source of comparative advantages properly. Further note, that the ranking of countries in these two graphs is similar (the rank correlation coefficient as 0.76 and highly significant). Countries with higher success rates are mostly Eastern European and less developed countries and tend to be smaller countries (though there are also exceptions to this).

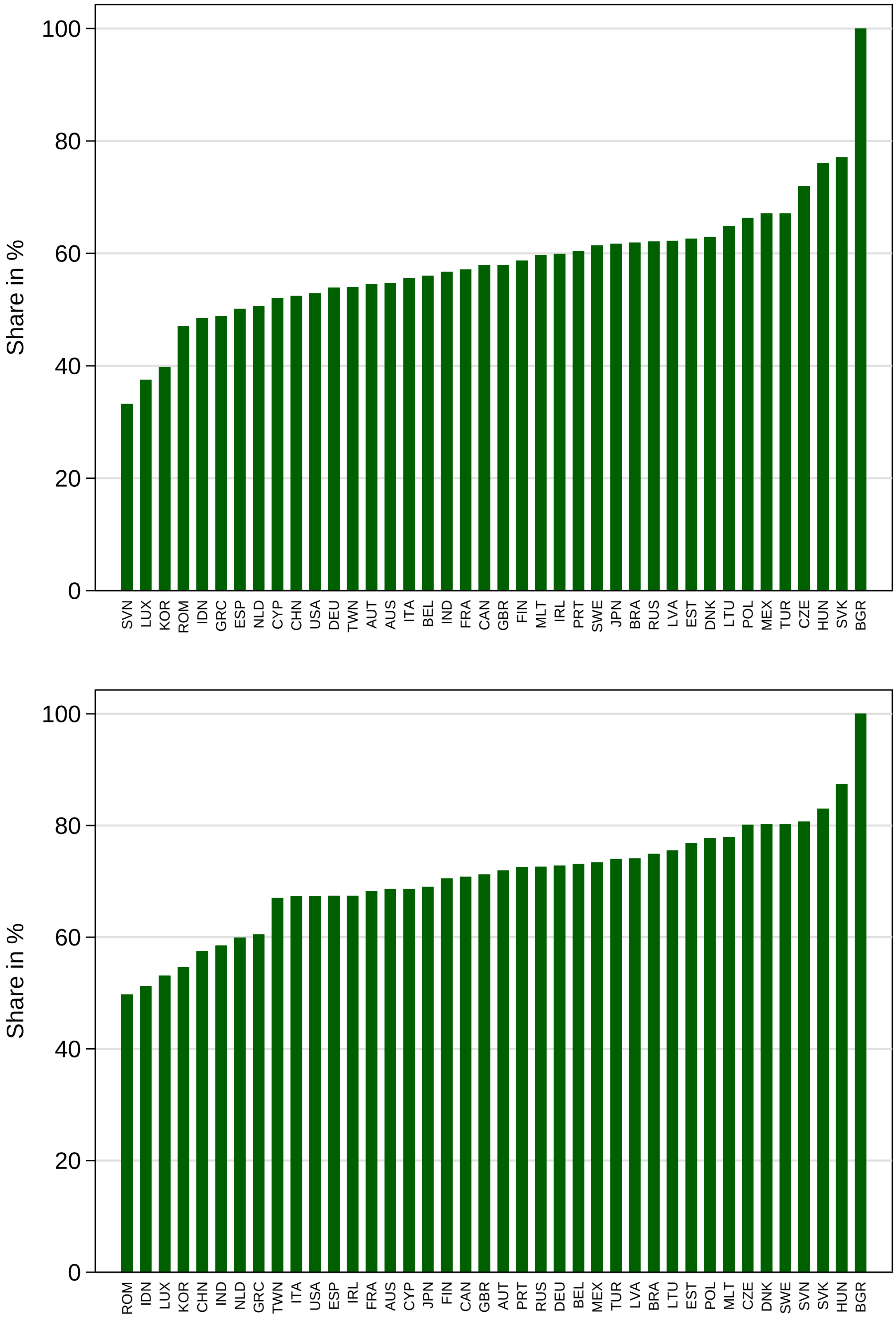


Figure 2: Direct and indirect inputs (upper graph) and direct inputs (lower graph), 2006

## 5 Conclusions

[ ... to be included ...]

# A Technical appendix

## A.1 Helpman, 1984

Helpman (1984) argues that in absence of FPE and no restrictions on preference the following relationship for a country's net import vector and - even more importantly - bilateral trade data testable restriction can be derived. It is further assumed that technologies across countries are identical, though techniques can be different, i.e. $\mathbf{D}^r = \mathbf{D}(\mathbf{w}^r)$, and that there are no intermediates (though it is mentioned that this can be generalized) and therefore no traded intermediates. We start with the inequalities given by

$$\begin{aligned}
\mathbf{p}'\big(\mathbf{q}^r + \mathbf{t}^{rp}\big) &\leq \Pi(\mathbf{p}, \mathbf{V}^r + \mathbf{t}_V^{rp}) \\
&\leq \Pi(\mathbf{p}, \mathbf{V}^r) + \Pi(\mathbf{p}, \mathbf{t}_V^r) \\
&\leq \Pi(\mathbf{p}, \mathbf{V}^r) + \Pi_V(\mathbf{p}, \mathbf{V}^r)\mathbf{t}_V^{rp} \\
&= \mathbf{p}'\mathbf{q}^r + \mathbf{w}'^r\mathbf{t}_V^{rp}
\end{aligned}$$

where $\mathbf{p}$ is the $G \times 1$ free-trade price vector, $\mathbf{q}^r$ is the $G \times 1$ free trade production vector, $\mathbf{t}^{rp}$ is the $G \times 1$ gross import vector by country $r$ from $p$, $\mathbf{V}^r$ is the $K \times 1$ endowment vector, and $\mathbf{t}_V^{rp} = \mathbf{D}^p\mathbf{t}^{rp}$ (which is of dimension $K \times 1$) where $\mathbf{D}^p$ denotes the $K \times G$ direct factor input matrix used in exporter country $p$; $\mathbf{w}$ is the $K \times 1$ vector of factor prices. Further, $\Pi$ denotes a GDP function (concave) and $\Pi_V$ the associated gradient.

This equation implies that the value of imports is smaller or equal than the value of factors imported from country $p$ (derived with country $p$ technology evaluated with the importer country's ($r$) factor prices.

$$\mathbf{p}'\mathbf{t}^{rp} \leq \mathbf{w}'^r\mathbf{t}_V^{rp} = \mathbf{w}'^r\mathbf{D}^p\mathbf{t}^{rp}$$

Constant returns to scale technology and perfect competition in the export market $r$ of country $p$ assures that the value of exports equals the value of factors exported from country $p$ to country $r$ (evaluated with the exporters country factor prices):

$$\mathbf{p}'\mathbf{t}^{rp} = \mathbf{w}'^p\mathbf{t}_V^{rp} = \mathbf{w}'^p\mathbf{D}^p\mathbf{t}^{rp}$$

Combining the latter two equations yields

$$(\mathbf{w}'^r - \mathbf{w}'^p)\mathbf{t}_V^{rp} \geq 0$$

Using analogous arguments for country $p$ imports from country $r$ one arrives at

$$(\mathbf{w}'^r - \mathbf{w}'^p)\mathbf{t}_V^{pr} \leq 0$$

Combining these two equations results in the fundamental testable restriction of the HOV model:

$$(\mathbf{w}'^r - \mathbf{w}'^p)(\mathbf{t}_V^{rp} - \mathbf{t}_V^{pr}) \geq 0$$

On average, country $r$ is a net importer from country $p$ of the content of those factors of production that are cheaper in $p$ than in $r$ (Helpman, 1984, p. 91).

For later use we can rewrite this equation in the following way (as suggested by Choi and Krishna, 2004):

$$\begin{aligned}
(\mathbf{w}'^r - \mathbf{w}'^p)(\mathbf{t}_V^{rp} - \mathbf{t}_V^{pr}) &\geq 0 \\
\mathbf{w}'^r\mathbf{t}_V^{rp} - \mathbf{w}'^r\mathbf{t}_V^{pr} - \mathbf{w}'^p\mathbf{t}_V^{pr} + \mathbf{w}'^p\mathbf{t}_V^{rp} &\geq 0 \\
\mathbf{w}'^r\mathbf{t}_V^{rp} + \mathbf{w}'^p\mathbf{t}_V^{pr} &\geq \mathbf{w}'^r\mathbf{t}_V^{pr} + \mathbf{w}'^p\mathbf{t}_V^{rp} \\
\frac{\mathbf{w}'^r\mathbf{t}_V^{rp} + \mathbf{w}'^p\mathbf{t}_V^{pr}}{\mathbf{w}'^p\mathbf{t}_V^{rp} + \mathbf{w}'^r\mathbf{t}_V^{pr}} &\geq 1
\end{aligned}$$

or

$$\frac{\mathbf{w}'^r\mathbf{D}^p\mathbf{t}^{rp} + \mathbf{w}'^p\mathbf{D}^r\mathbf{t}^{pr}}{\mathbf{w}'^p\mathbf{D}^p\mathbf{t}^{rp} + \mathbf{w}'^r\mathbf{D}^r\mathbf{t}^{pr}} \geq 1$$

### A.2 Staiger, 1986

As just mentioned above, Helpman (1984) does not account for traded intermediates. Based on this approach and the literature favoring the ”gross concept” (i.e. using direct plus indirect calculations) like (Deardorff, 1982) and (**?**), Staiger (1986) extends Helpman (1984) allowing for traded intermediates. However, Staiger (1986) shows that ”... in the context of a relationship involving post-trade factor prices [...] the appropriate calculations in a world with traded intermediate goods are based on the *direct* rather than the *gross* measurement of factor content." (Staiger, 1986, p. 362) Under standard assumptions he arrives at

$$(\mathbf{w}'^{r} - \mathbf{w}'^{p})\mathbf{t}_D^{rp} \geq 0 \qquad \forall k, h$$

where $\mathbf{t}_D^{rp}$ is $N \times 1$ vector of direct factor content of gross exports from country $p$ to $r$ (i.e. factor content of gross imports of country $r$ from $p$). It is noted that this inequality holds without regard to the source of intermediate inputs (as only direct inputs are used) and that no generally valid restriction can be placed on the sign of $(\mathbf{w}'^{r} - \mathbf{w}'^{p})\mathbf{T}_I^{rp}$, where $\mathbf{T}_I^{rp}$ is factor content of indirect imports of country $r$ from $p$ which is shown by a numerical example. "Consequently, a restriction analogous to [...] but employing *gross* factor content calculations cannot be supported by the model." (Staiger, 1986, p. ???). It is however important to note that this results relies on the assumptions of free trade in intermediates and that these are available at the same costs: "Since intermediate goods that are freely traded and available to all countries at the same cost can have no effect on the international pattern of production in the post-trade equilibrium, these relationships concern only direct factor content calculations. " (Staiger, 1986, p. 367). Implicitly, this also implies that intermediate inputs per unit of output must be the same across countries.

However, it is further noted that "... the key element [...] is that intermediate goods are available to all countries at the same price." (Staiger, 1986, p. ???). Violations of these requirements (tariffs, transport costs) can cause differences in the price at which different countries can use of intermediates, the restriction above could be violated. However, the paper does not provide a solution for such a case (and, particularly, does not say that in these cases a *gross* calculation would be preferable). It is also noted that non-traded intermediates are consistent with this restriction. The factor content in such a case must be calculated at a 'direct plus non-traded indirect' basis though it remains unclear whether 'non-traded' means 'domestic use' or intermediates which cannot or are not traded.

### A.3 Choi and Krishna, 2004

Choi and Krishna (2004) extend the framework by Helpman (1984) by including the presence of intermediate inputs in production. The vector of factor content then becomes

$$\mathbf{t}_V^{rp} = \mathbf{D}^p(\mathbf{I} - \mathbf{A}^p)\mathbf{t}^{rp}$$

Using the same arguments as (Helpman, 1984) they arrive at

$$(\mathbf{w}'^r - \mathbf{w}'^p)(\mathbf{t}_V^{rp} - \mathbf{t}_V^{pr}) \geq 0$$

Perform tests including IO matrices that include domestically produced intermediates only, i.e. using domestic IO matrices rather than total IO matrices (following the arguments by Staiger, 1986); (but see App. A as mentioned in footnote 8, p. 894).

Discussion if technologies are not identical across countries. Country $r$ is more productive in the production of every good by a factor $\lambda_i^r$ (i.e. Hicks-neutral difference in all sectors); only derived in Appendix B (but not implemented in tests).

Rewrite equation above as

$$\frac{\mathbf{w}'^r\mathbf{t}_V^{rp} + \mathbf{w}'^p\mathbf{t}_V^{pr}}{\mathbf{w}'^p\mathbf{t}_V^{rp} + \mathbf{w}'^r\mathbf{t}_V^{pr}} \equiv \theta \geq 1$$

$$\frac{\mathbf{w}'^r\mathbf{B}^p\mathbf{t}^{rp} + \mathbf{w}'^p\mathbf{B}^r\mathbf{t}^{pr}}{\mathbf{w}'^p\mathbf{B}^p\mathbf{t}^{rp} + \mathbf{w}'^r\mathbf{B}^r\mathbf{t}^{pr}} \equiv \theta \geq 1$$

gives "the ratio of the sum of the importer's (hypothetical) cost of production (using importer's factor prices and exporter's factor usage) to the total ('actual') cost of production in the exporting countries (i.e. using the actual producer's factor prices and factor usage)" (Choi and Krishna, 2004, p. 900).

Each term in this equation has an interpretation (Choi and Krishna, 2004, p. 900):

- $\mathbf{w}'^r\mathbf{B}^p\mathbf{t}^{rp}$: hypothetical cost of production of the gross import vector of $r$ from $p$ using the factor content of (exporter) country $p$ and factor prices of importer country $r$
- $\mathbf{w}'^p\mathbf{B}^r\mathbf{t}^{pr}$: hypothetical cost of production of the gross import vector of $p$ from $r$ using the factor content of (exporter) country $r$ and factor prices of importer country $p$
- $\mathbf{w}'^p\mathbf{B}^p\mathbf{t}^{rp}$: actual costs of producing gross import vector of $r$ from $p$ using the factor content of (exporter) country $p$ and factor prices of (exporter) country $p$
- $\mathbf{w}'^r\mathbf{B}^r\mathbf{t}^{pr}$: actual costs of producing gross import vector of $p$ from $r$ using the factor content

of (exporter) country $r$ and factor prices of (exporter) country $r$

$\theta$ will also give an intuitive sense of the extent of data's conformance to or departure from the theory for those countries (Choi and Krishna, 2004, p. 900).

The approach also allows for Hicks-neutral technology differences:

$$\begin{aligned}
\mathbf{p}'(\mathbf{q}+\mathbf{t}^{rp}) &\leq \Pi(\mathbf{p},\mathbf{V}^r+\frac{1}{\lambda^r}\mathbf{t}_V^{rp}) \\
&\leq \Pi(\mathbf{p},\mathbf{V}^r)+\Pi_V(\mathbf{p},\mathbf{V}^r)\frac{1}{\lambda^r}\mathbf{t}_V^{rp} \\
&= \mathbf{p}'\mathbf{q}+\frac{\mathbf{w}'^r}{\lambda^r}\mathbf{t}_V^{rp}
\end{aligned}$$

where with $\lambda^r > 1$. It is assumed that all factors of production in country $r$ are more productive than those in country $p$. The zero profit condition in country $r$ implies $\mathbf{p'}\mathbf{t}^{rp} = \mathbf{w}'^p\mathbf{t}_V^{rp}$ which results in

$$\left(\frac{\mathbf{w}'^r}{\lambda^r}-\mathbf{w}'^p\right)\mathbf{t}_V^{rp} \geq 0$$

A symmetric argument leads to

$$\left(\frac{\mathbf{w}'^r}{\lambda^r}-\frac{\mathbf{w}'^p}{\lambda^p}\right)\mathbf{t}_V^{rp} \geq 0 \qquad \text{or} \qquad \left(\frac{\mathbf{w}'^p}{\lambda^p}-\frac{\mathbf{w}'^r}{\lambda^r}\right)\mathbf{t}_V^{rp} \leq 0$$

where now the Hicksian parameter is benchmarked to a third country. Therefore

$$\left(\frac{\mathbf{w}'^r}{\lambda^r}-\frac{\mathbf{w}'^p}{\lambda^p}\right)(\mathbf{t}_V^{rp}-\mathbf{t}_V^{pr}) \geq 0$$

With industry-specific (Ricardian) technology differences (but still Hicks-neutral)

$$\sum_i \left(\frac{\mathbf{w}'^r}{\lambda_i^r}-\mathbf{w}^p\right)\mathbf{t}_{Vi}^{rp} \geq 0$$

from which

$$\sum_i \left(\frac{\mathbf{w}'^r}{\lambda_i^r}-\frac{\mathbf{w}'^p}{\lambda^p}\right)(\mathbf{t}_{Vi}^{rp}-\mathbf{t}_{Vi}^{pr}) \geq 0$$

would result. This is however not applied in the paper nor is it discussed which input matrix should exactly be used; theoretically it is assumed that $\mathbf{D}^p = \hat{\boldsymbol{\lambda}}^p\mathbf{D}(\mathbf{w}^p)$ where $\hat{\boldsymbol{\lambda}}^p$ denotes a $K \times K$ matrix with Ricardian technology differences at the diagonal. Note that direct factor input matrix $\mathbf{D}^r$ already accounts for Ricardian technology differences (or even also factor and sector-biased differences) which we will discuss later on.

### A.4 Lai and Zhu, 2007

Again we apply the common assumptions. Intermediate inputs are considered as traded freely (as argued in Staiger, 1986) (or non-traded) and requirements are identical across countries (as argued in **?**). By these assumptions intermediate inputs are not a source of comparative advantages. Let $\lambda_i^c$ denote productivity of industry $i$ in country $c$ (factor-augmenting and Hicks-neutral) and $d_i^p = \phi_i(\lambda_i^p d_i^p)$ with $\phi_i$ being a internationally common production function. A larger $\lambda_i^p$ indicates greater productivity. $t_i^{rp}$ is the volume of gross exports of good $i$ from country $p$ to country $r$ (i.e. gross imports of country $r$ from $p$),

Per unit cost of production of exporter country $p$ and zero-profit condition implies that costs equals the world price $p_i$.

$$p_i = w^p d_i^p + p_i^I$$

Costs in the importing country have to be higher than the world price imposing a restriction on importing country

$$p_i \leq w^r d_i^r + p_i^I$$

Combining these two equations lead to the inequality

$$w^p d_i^p \leq w^r d_i^r$$

Note that costs of intermediates cancel as these are assumed to be freely traded and requirements are identical across countries.

Assume for the moment that factor prices are the same and that the importer country $r$ needs $\frac{\lambda_i^p}{\lambda_i^r} d_i^p$ units of input compared to the exporter country (e.g. if workers in country $p$ are twice as productive as workers in country $p$, country $r$ would need $\frac{\lambda_i^r}{\lambda_i^p} = 2$ workers to produce same amount of output). If factor prices are different, $\frac{\lambda_i^p}{\lambda_i^r} d_i^p$ would be a feasible bundle of inputs for country $r$ though not optimal as it could reduce production costs via (factor) substitution and optimal bundle would be given by $d_i^r$. This implies that (hypothetical) production costs - with country $p$ choice-of-technique adjusted for Hicks-neutral technology differences times country $r$

factor prices - are larger than "actual" production costs would be, i.e.

$$w^p d_i^p \leq w^r \frac{\lambda_i^p}{\lambda_i^r} d_i^p$$

Combining this and the previous inequality yields

$$\begin{aligned} w^p d_i^p &\leq w^r \frac{\lambda_i^p}{\lambda_i^r} d_i^p \\ \frac{w^p}{\lambda_i^p} d_i^p &\leq \frac{w^r}{\lambda_i^r} d_i^p \Rightarrow \frac{w^p}{\lambda_i^p} \leq \frac{w^r}{\lambda_i^r} \end{aligned}$$

which can be rewritten as

$$\Big(\frac{w^p}{\lambda_i^p} - \frac{w^r}{\lambda_i^r}\Big) d_i^p \leq 0$$

For aggregation we use country $r$ gross imports from $p$, $t_i^{rp}$, as weights and use $t_{V,i}^{rp} = d_i^p t_i^{rp}$, i.e. the amount of factors imported from country $p$,

$$\sum_i \Big(\frac{w^p}{\lambda_i^p} - \frac{w^r}{\lambda_i^r}\Big) \lambda_i^p t_{V,i}^{rp} \leq 0 \qquad \text{or} \qquad \sum_i \Big(\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p}\Big) \lambda_i^p t_{V,i}^{rp} \geq 0$$

A symmetric argument leads to

$$\sum_i \Big(\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p}\Big) \lambda_i^r t_{V,i}^{pr} \leq 0$$

Combining the latter two equations gives

$$\sum_i \Big(\frac{w^r}{\lambda_i^r} - \frac{w^p}{\lambda_i^p}\Big) \big(\lambda_i^p t_{V,i}^{rp} - \lambda_i^r t_{V,i}^{pr}\big) \geq 0$$

which is the productivity adjusted version of Helpman (1984), equation (16).

This allows to test the following hypothesis with the most general being Ricardian differences in technology:

$$\begin{aligned}
\sum_i \frac{w^r}{\lambda_i^r}\lambda_i^p t_{V,i}^{rp} - \sum_i \frac{w^r}{\lambda_i^r}\lambda_i^r t_{V,i}^{pr} - \sum_i \frac{w^p}{\lambda_i^p}\lambda_i^p t_{V,i}^{rp} + \sum_i \frac{w^p}{\lambda_i^p}\lambda_i^r t_{V,i}^{pr} &\geq 0 \\
\Big(\sum_i \frac{w^r}{\lambda_i^r}\lambda_i^p t_{V,i}^{rp} + \sum_i \frac{w^p}{\lambda_i^p}\lambda_i^r t_{V,i}^{pr}\Big) - \Big(\sum_i \frac{w^r}{\lambda_i^r}\lambda_i^r t_{V,i}^{pr} + \sum_i \frac{w^p}{\lambda_i^p}\lambda_i^p t_{V,i}^{rp}\Big) &\geq 0 \\
\Big(\sum_i \frac{w^r}{\lambda_i^r}\lambda_i^p t_{V,i}^{rp} + \sum_i \frac{w^p}{\lambda_i^p}\lambda_i^r t_{V,i}^{pr}\Big) &\geq \Big(\sum_i w^r t_{V,i}^{pr} + \sum_i w^p t_{V,i}^{rp}\Big) \\
\frac{\big(\sum_i \frac{w^r}{\lambda_i^r}\lambda_i^p t_{V,i}^{rp} + \sum_i \frac{w^p}{\lambda_i^p}\lambda_i^r t_{V,i}^{pr}\big)}{w^r \sum_i t_{V,i}^{pr} + w^p \sum_i t_{V,i}^{rp}} &\geq 1
\end{aligned}$$

If technology differences are uniform across sectors this inequality reduces to

$$\frac{\frac{w^r}{\lambda^r}\lambda^p \sum_i t_{V,i}^{rp} + \frac{w^p}{\lambda^p}\lambda^r \sum_i t_{V,i}^{pr}}{w^r \sum_i t_{V,i}^{pr} + w^p \sum_i t_{V,i}^{rp}} \geq 1$$

and for identical technologies across countries

$$\frac{w^r \sum_i t_{V,i}^{rp} + w^p \sum_i t_{V,i}^{pr}}{w^r \sum_i t_{V,i}^{pr} + w^p \sum_i t_{V,i}^{rp}} \geq 1$$

A second hypothesis is tested on the relationship between the factor content of bilateral trade and relative factor abundance following Debaere (2003).

One should further note that the approach relies on direct factor requirements only; further this approach builds on single factors rather than taking the whole bundle of factors into account.

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