MULTIPLE CONES, FACTOR PRICE DIFFERENCES AND THE FACTOR CONTENT OF EXPORTS[1]

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(Incomplete draft)

Abstract

This paper examines pattern of trade predictions in the multi-cone Heckscher-Ohlin model. I revisit Helpman (1984) and show that his bilateral restrictions provide an incomplete characterization of a multi-cone free trade equilibrium. I identify additional restrictions and illustrate that these restriction form the building block of a multi-cone factor content specification which is the factor dual to Alan Deardorff's (1979) well-known chain of comparative advantage goods prediction. Applying Choi and Krishna's (2004) OECD data set to the complete set of restrictions, I find limited support for the empirical validity of these restrictions..

JEL classification: F11
Key words: Heckscher-Ohlin theorem, factor content restrictions, cones of diversification.

1. Introduction

"Every 'good' scientific theory is a prohibition; it forbids certain things to happen. The more a theory forbids, the better it is" (Karl Popper, 1963, p. 36).

This paper investigates pattern of trade predictions in the multi-cone Heckscher-Ohlin model. It builds on the seminal work by Helpman (1984) who has identified factor price restrictions (or prohibitions) on the factor content of bilateral

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trade.[3] From an empirical perspective, Helpman's bilateral restrictions are highly attractive for three reasons. First, they are based on free trade rather than autarky factor prices.[4] Second, they do not rely on any specific assumptions about consumer preferences. And third, since the restrictions pertain to bilateral rather than multilateral trade flows, an empirical test can restrict itself to a subset of countries with high quality data. By taking Helpman's restrictions to the data, Choi and Krishna (2004) have claimed to provide a more general approach of testing Heckscher-Ohlin than the Heckscher-Ohlin-Vanek model, which has dominated the empirical trade literature for the past two decades.[5]

This paper revisits Helpman's (1984) multi-cone Heckscher-Ohlin specification and the empirical evidence for it. It makes two contributions. On the theoretical inside, I show that Helpman's (1984) equilibrium characterization where the factor content of exports from country *i* to country *j* is restricted by the factor price difference between these two countries is *incomplet*e. In particular, I show that the factor content of exports from country *i* to country *j* is not only restricted by the factor price difference between countries *i* and *j*, but also by the factor price difference between country *i* and *any* other third country *k*. The intuition for this is that in a Heckscher-Ohlin model, where all countries are assumed to be in different cones of diversification, free trade factor prices embody information about a country's relative factor scarcities. As a result, a complete characterization of a trading

3 Helpman and Krugman (1985, pp. 24-27) and Feenstra (2004, pp.58-60) provide detailed discussions of Helpman (1984).
4 Helpman's paper has been inspired by Deardorff's general formulations of comparative advantage (Deardorff, 1980) and Heckscher-Ohlin (Deardorff, 1984). The empirical challenge of Deardorff's formulations is that the predictions are based on autarky prices, which are usually not observed. However, Bernhofen and Brown (2004) have recently overcome this challenge by identifying a natural experiment, Japan's 19th century opening up to international trade, to test comparative advantage using high quality autarky prices.
5 Building on Choi and Krishna (2004), Lai and Zhu (2006) provide further empirical support for a bilateral prediction that incorporates technological differences.

equilibrium mandates that all measures of factor scarcities are involved in imposing restrictions on trade flows.

The identification of additional restrictions is good news as the theory “forbids more”, and as a result there is more at stake in testing it. In addition, the new restrictions on gross exports imply a multitude of joint restrictions on *net exports*, which are difficult to interpret. I argue that, in contrast to Choi and Krishna (2004) and Lai and Zhu (2007) who test the (incomplete) set of joint restrictions on net exports, a direct test of the theory should investigate the empirical validity of the (complete) set of restrictions on gross exports.

In the empirical part of the paper I apply the full set of equilibrium restrictions to Choi and Krishna’s (2004) data set of 8 OCED countries. I find substantial deviations from the theoretical predictions and little overall support for the theoretical specification. After taking a closer look at the data, I identify systematic country-specific deviations from the predictions which suggests a systematic cost ranking of the sample countries. In particular, the data analysis suggest that factor prices might reflect country-specific differences in factor efficiencies rather than countries’ differences in factor endowments. Then I identify ranges for Hicks-neutral technological differences which make the model work.

The paper is organized as follows. Section 2 revisits Helpman (1984) and derives the full set of equilibrium restrictions. Section 3 provides a simple example which illustrates that the full set of restrictions is compatible with the logic of the multi-cone diagram. Section 4 provides a brief summary of Choi and Krishna’s (2004) data set. Section 5 gives the empirical results and section 6 contains the conclusion.

2. Restricting the factor content of exports: revisiting the theory

Helpman's specification aims to extend Deardorff's (1979) and Brecher and Choudhri's (1982) two-country, two-factor "chain formulation" to multiple countries and factors. The central theme in these papers is to provide Heckscher-Ohlin predictions in the absence of factor price equalization. All three papers investigate the property of a competitive free trade equilibrium with two key characteristics. First, all countries possess identical production functions. Second, countries' factor endowments are assumed to be sufficiently dissimilar so that countries' factor prices are different in a free trade equilibrium.

Formally, consider a competitive equilibrium with *m* countries, *n* goods, *l* factors and a common technology matrix, $A(.)=\langle a_{v\tau}(.)\rangle$, where $a_{v\tau}$ are the units of factor *v* necessary to produce 1 unit of good *τ*. Although identical technologies imply the same functional forms for $a_{v\tau}$, the equilibrium least-cost input coefficients will depend on country specific factor prices. Since there are no trade costs, goods prices are equalized. The free trade equilibrium is characterized by *l*-vectors of factor prices $w^1,\ldots,w^m$, where w^i is the factor price in country i.

If T^{ij} denotes the vector of gross exports from country *i* to country *j*, F^{ij} denotes the factor content of T^{ij} evaluated at the exporter's input techniques, i.e. $F^{ij}=A(w^i)T^{ij}$. For two countries, *i* and *j*, who are engaged in bilateral trade, Helpman (1984) derives the following restriction on the bilateral factor content of trade F^{ij}:

$$(w^j-w^i)'F^{ij} \geq 0. \qquad (1)$$

By symmetry, one obtains an equivalent restriciton on the gross trade flow from country j to country i:

$$(w^i-w^j)'F^{ji} \geq 0. \qquad (2)$$

Adding (1) and (2) results in a bilateral restriction on the net trade flow between countries i and j:

$$(w^j - w^i)'(F^{ij} - F^{ji}) \geq 0. \quad (3)$$

The intuition for the bilateral restrictions (1) and (2) can be illustrated with the familiar Lerner-Pearce diagram. Figure 1 depicts the case of 6 goods, 2 factors (labour and capital) and 3 countries. The goods' isoquants, numbered from 1 to 6, depict the input combinations that can produce $1 worth of output at the free trade goods prices. Goods are ordered in their degree of relative capital-intensity, where good 1 is most capital-intensive and good 6 is least capital-intensive. The rays connecting the origin to the tangencies between the isoquants and the isocost lines define three cones of diversification: C^1, C^2 and C^3 . The implicit assumption behind this specification is that there is a one-to-one correspondence between the countries' factor endowment ranking and the ranking of countries' equilibrium factor price ratios: $K^1/L^1 > K^2/L^2 > K^3/L^3 \iff w^1/r^1 > w^2/r^2 > w^3/r^3$. In any pair-wise comparison, the more capital-abundant country is expected to have a higher equilibrium wage-rental ratio.

Since countries' factor endowments are assumed to be in different cones of diversification, the three countries will specialize in the production of different goods.[6] Country 1, which is most capital abundant, produces and exports the most capital-intensive goods 1 and 2; country 2 produces and exports goods 3 and 4 and country 3, which is most the most labour abundant, produces and exports the most labour-intensive goods 5 and 6.[7] This chain prediction on the commodity pattern of trade goes back to Deardorff (1979).

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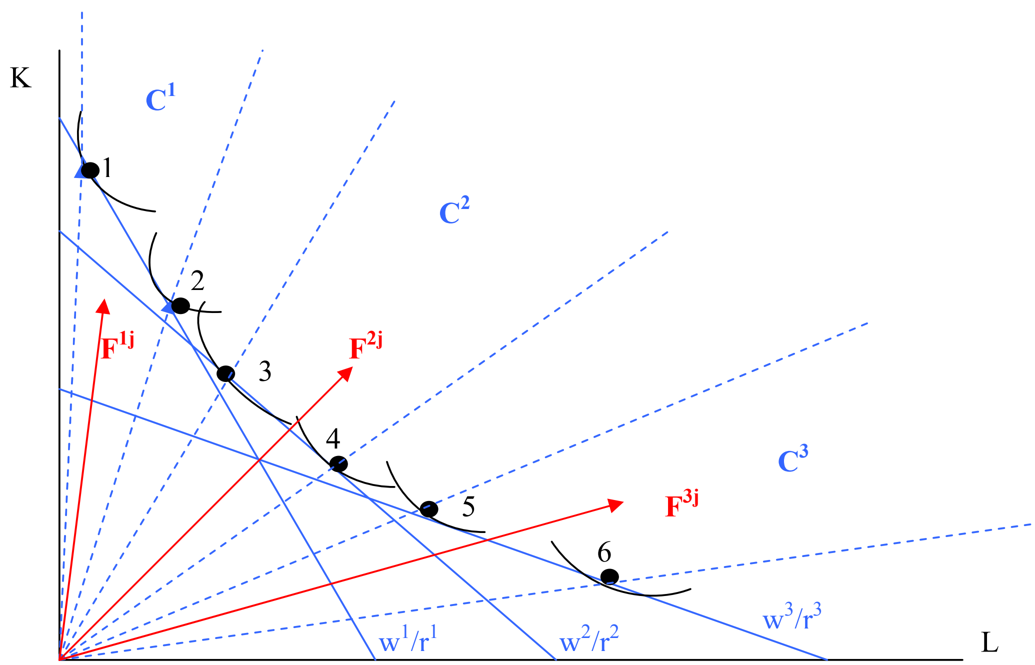
[6] For clarity of exposition, I didn't depict the countries' factor endowments in the diagram.
[7] Although this framework doesn't make any explicit assumption about preferences, it implicitly assumes that preferences are such that the free trade equilibrium actually exists. In particular, to ensure that there is some trade, one needs to assume that consumers care about foreign-produced goods.

The commodity chain prediction has implications for the equilibrium factor content of exports. For example, take an equilibrium factor content of export vector, F^{2j}, from country 2 to any country j (where j=1 or 3). Since country 2 is producing only goods 3 and 4, the capital-labour ratio of F^{2j} must lie between the capital-labour ratios of goods 3 and 4. Generally, any equilibrium factor content export vector of country *i* is restricted to lie in country *i*'s cone of diversification: i.e. $F^{ij} \in C^{i}$.

Figure 1: Multi-cone diagram



It is important to recall that the free trade production allocation is Pareto optimal, or globally cost efficient. For example, it is globally inefficient for country 2 to export factor services with relatively high capital-labour ratios (i.e. which lie in C^1) since it is cheaper to producer these factor services in country 1 where the relative price of capital is lower. Alternatively, it is also globally inefficient for country 2 to export factor services with relatively low capital-labour ratios (i.e. which lie in C^3) since it is cheaper to produce these factor services in country 3 where the relative price of labour is lower. Global cost minimization can be thought of prohibiting F^{ij} to fall outside of C^{i}.

Helpman's (1984) restrictions (1) and (2) are based on this bilateral cost comparison. To illustrate, take the two equilibrium factor content of exports between countries 1 and 2, F^{12} and F^{21}. We know that F^{12} is a combination of the factor services of the most capital-intensive goods 1 and 2, whereas F^{21} is a combination of the factor services of the more labour-intensive goods 3 and 4. Since the relative cost of capital is higher in country 2 it is more costly to produce goods 1 and 2, or in fact a combination of them, in country 2 than in country 1. This implies that if F^{12} is valued at w^2, then this hypothetical production cost must be as least as high as the actual equilibrium production cost w^1F^{12}, i.e. $w^2F^{12} \geq w^1F^{12}$. Applying the same argument to F^{21}, we obtain the restrictions $(w^2-w^1)'F^{12} \geq 0$ and $(w^1-w^2)'F^{21} \geq 0$.

However, since Helpman focuses only on a single bilateral cost comparison between the source and the destination country, his characterization of equilibrium trading patterns is incomplete. In particular, since the relative cost of capital in country 3 is also higher than in country 1, it must also be more costly to produce F^{12} in country 3 than in country 1. This implies that if F^{12} is evaluated at the factor price vector w^3, then this hypothetical production cost must also be at least as high as the equilibrium production cost w^1F^{12}, which yields the additional restriction $(w^3-w^1)'F^{12} \geq 0$. The key point here is that the cost comparisons are invariant to where country 1 is exporting its goods, i.e. $w^2F^{1j} \geq w^1F^{1j}$ and $w^3F^{1j} \geq w^1F^{1j}$ (j=2,3). In the 3-country case, global cost efficiency implies 2 sets of restrictions on each country's factor content of exports $(w^k-w^i)'F^{ij} \geq 0$ (i=1,2,3; k≠i) .

Going back to the general case of m countries, we can now formally derive all the restrictions on F^{ij} by applying the global cost minimization logic discussed above[8]. This is accomplished by the following two inequalities:

$$w^{i}F^{ij}= w^{i}A(w^{i})X^{ij} \leq w^{k}A(w^{k})X^{ij}, \qquad (4)$$

$$w^{k}A(w^{k})X^{ij} \leq w^{k}A(w^{j})X^{ij}=w^{k}F^{ij}. \qquad (5)$$

Inequality (4) says that the (hypothetical) cost of producing the export vector X^{ij} in country k must be at least as high as the actual cost of producing it in country i. Although countries i and k have the same technologies, the differences in factor prices imply that it is more costly to produce X^{ij} in country k than in country i. Since all countries are assumed to be in different cones of diversification, this comparison holds for any destination index j. Country i is more efficient in producing X^{ij} not only in comparison to the country to which the exports are shipped ($k=j$), but also in comparison to all of its other trading partners ($k \neq j$). Inequality (5) says that if X^{ij} were produced in country k, then it would be cheaper to produce it with the input coefficients based on its own factor price vector w^{k}. Combining (4) and (5), we obtain the key result of this paper:

$$(w^{k}-w^{i})'F^{ij} \geq 0, \qquad \text{for all } k \neq i. \qquad (6)$$

Applying the same logic to F^{ji}, we obtain:

$$(w^{l}-w^{j})'F^{ji} \geq 0, \qquad \text{for all } l \neq j. \qquad (7)$$

Several things should be noticed. First, (6)-(7) involve many more restrictions than derived by Helpman (1984) in (1)-(2). For m countries, (6) and (7) yield a total of $m(m-1)^2$ restrictions whereas (1) and (2) yield only a total of $m(m-1)$. For Choi and Krishna's (2004) data set of 8 countries, this amounts to a total of 392 restrictions

[8] The derivation builds on the cost minimization approach of Helpman and Krugman (1985, p. 27). Alternatively, the Theory Appendix derives the restrictions by using the property of the GDP function, building on Helpman (1984) and Feenstra (2004, p.58).

instead of just 56.[9] From an empirical perspective, there is more at stake in testing the theory as the theory forbids more.

Second, while adding (1) and (2) leads to a single joint restriction (3) on the net factor content of exports F^{ij}-F^{ji}, adding (6) and (7) leads to a multitude of joint restrictions on F^{ij} and F^{ji}:

$$(w^k-w^i)'F^{ij} + (w^l-w^j)'F^{ji} \geq 0 \quad \text{for all } k\neq i \text{ and } l\neq j. \tag{8}$$

For m countries, (8) yields $(m\text{-}1)^2$ joint restrictions for each country pair. Although (8) coincides with (3) for the special case of k=j and l=i, it is not clear how interpret this multitude of restrictions. Given their data set of 8 countries, Choi and Krishna tested just the 28 joint restrictions from (3), one for each country pair. However, (8) suggests that this number needs to be multiplied by a factor of 49, which amounts to a total of 1372 restrictions. Given that (6) and (7) are sufficient conditions for (8) and the lack of interpretation of (8), our empirical analysis will primarily focus on (6) and (7). However, we will also investigate (8) to allow for a comparison with Choi and Krishna (2004).

3. A simple illustration

We use an example to illustrate that the factor price restrictions in (6) and (7) do indeed replicate the factor content predictions from Figure 1. Consider the case of 3 countries and 2 factors and assume a multi-cone equilibrium where countries free trade factor prices are given as follows: w^1=7, w^2=5, w^3=3, r^1=1, r^2=2, and r^3=4. The ranking of factor price ratios $w^1/r^1 > w^2/r^2 > w^3/r^3$ implies a factor endowment ranking

[9] For Lai and Zhu's data set of 41 countries, the number of restrictions increases from 1,640 to 65,600.

that is compatible with Figure 1. Country 1 is most capital abundant, country 3 is least capital abundant and country 2 is in between.

Figure 2a: single restriction on F^{21} : $(w^1-w^2)F^{21}\geq 0$

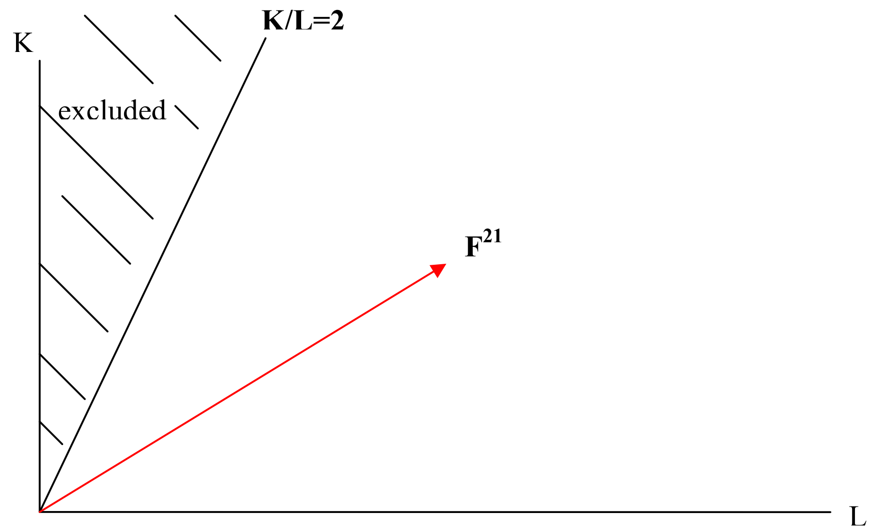
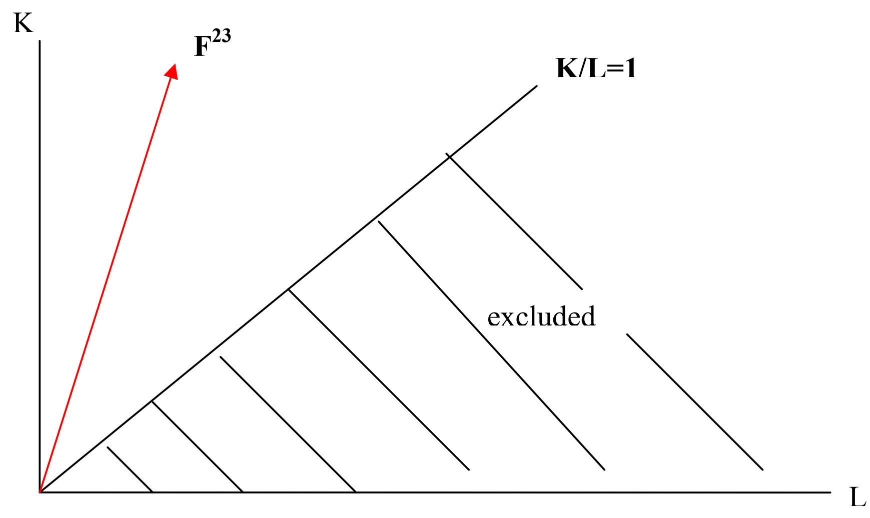


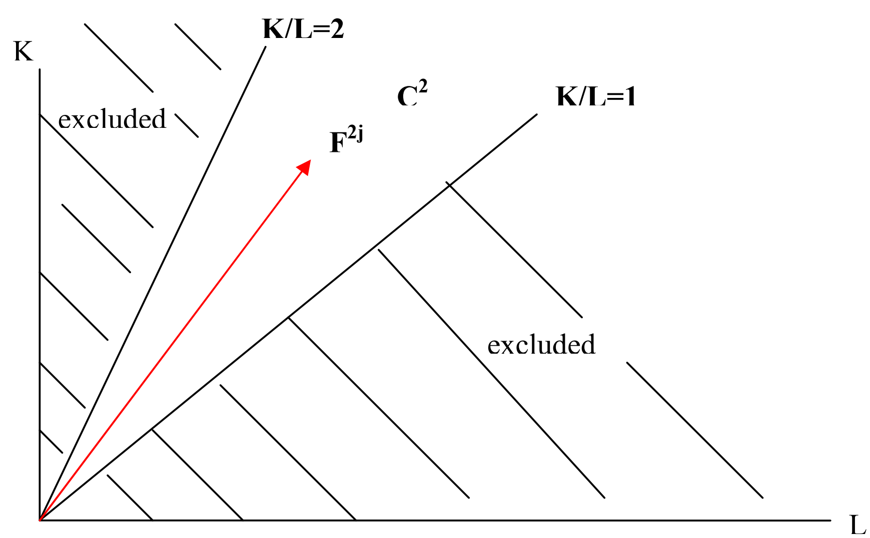
Figure 2b: single restriction on F^{23}: $(w^3-w^2)F^{23}\geq 0$



To illustrate the main point, we just consider the factor content of exports from country 2 to countries 1 and 3, i.e. $F^{21}=(L^{21},K^{21})$ and $F^{23}=(L,^{23}K^{23})$. Figures 2a and 2b depict the case of Helpman's single bilateral restrictions, whereas Figure 2c depicts the complete set of restrictions. For example, in Figure 2a the restriction $(w^1-w^2)F^{21}\geq 0$ implies an upper bound of 2 for the capital labour ratio of F^{21}, i.e. $K^{21}/L^{21}\leq 2$. Since this restriction involves only a cost comparison with the more capital-abundant country 1, it excludes only relatively high capital-labour ratios.

Figure 2b depicts the restriction $(w^3-w^2)F^{23}\geq 0$, which involves a cost comparison between country 2 and the more labour abundant country 3. This restriction implies a lower bound of 1 for the capital-labour ratio of F^{23}, i.e. $K^{23}/L^{23}\geq 1$, excluding only relatively low capital-labour ratios. However, neither diagram corresponds to the prediction in Figure 1, since they suggest a destination specific upper or lower bound for the factor content of exports by country 2.

Figure 2c: complete set of restrictions on F^{2j}: $(w^k-w^2)F^{2j}\geq 0$ (j,k=1,3)



In contrast, Figure 2c depicts the complete set of restrictions on F^{2j}, $(w^j - w^2)F^{2j} \geq 0$ (j=1,3). In particular, since it involves a cost comparison with both trading partners, it implies a common upper bound of 2 and a common lower bound of 1 for the capital labour ratios of $F^{21}$and F^{23}. This is compatible with the prediction from Figure 1, where F^{2j} must lie in some "intermediate" cone C^2.

4. Data

I test the restrictions using the data from Choi and Krishna (2004). Since their paper provides a detailed discussion of the data, I will be briefly highlight just the main features of the data. The data set consists of internationally comparable data on factor prices and the factor content of exports for 8 countries: the United States, Canada, Denmark, France, Germany, the United Kingdom, the Netherlands and Korea. All data pertain to 1980.

A. Factor prices

The production technology is assumed to consist of five factors of production: four types of labour and capital. The factor prices of labour pertain to the wages of the following four labour groups: (i) production workers, (ii) managerial workers, (iii) clerical workers and (iv) others.[10] The factor prices were collected from various national and international sources.

The data set consists of two measures of the returns to capital at the economy level, denoted by Capital I and Capital II. Capital I is found by dividing the annual

[10] In addition to the 4-group labour classification, Choi and Krishna (2004) consider also a 2-group labour classification where managerial, clerical and others are aggregated into a single "non-production" category. However since Table 1 reveals considerable wage variation between these 3 categories (see Table 1), I use just the 4-group classification.

operating surplus of the economy by the economy's net capital stock.[11] Capital II is determined by the ratio of the total return to capital to the net capital stock, where the total return to capital is calculated as the difference between GDP and the total employee compensation. Since Capital I is net of taxes on production, while capital II is gross of indirect taxes, the latter will provide a higher estimate than the former.

Table 1 reports the factor prices for each factor category and country in US dollars. The figures suggest quite a bit of factor price variation in the labour categories across countries. Not surprisingly, Korean wages are the lowest in all labour categories by a substantial margin. Comparing the Korean wage with the sample median (which excludes Korea), the Korean wage ranges from 12% ("others") to 27% ("managerials") of this median. Since Korea has also the highest rental price of capital (for both capital measures) Korea occupies the 'lower boundary cone' in the labour-capital space, i.e. it is the least capital-abundant country.

The contenders for the most capital abundant country are capital-measure specific: Denmark for Capital I and the US for Capital II. Both take a middle position in their nominal labour costs (i.e. their labour costs are, on average, below the median of the sample excluding Korea). Denmark has the lowest rental rate of capital using Capital I and the US has the lowest rental rate of capital for Capital II. However, the relative capital abundance is a bit more pronounced for Denmark than for the US: Capital I for Denmark is 58% of the sample median whereas Capital II for the US is only 87% of the sample median.[12]

Table 1: Factor Prices

Category	US	Canada	Denmark	France	Germany	UK	Netherlands	Korea
A. Labour (in U.S. Dollars)								
Production	13,059	12,592	13,333	14,715	18,789	12,595	18,177	1,638

[11] The operating surplus is part of the cost component decomposition of an economy's GDP, where GDP is decomposed into (i) employees' compensation, (ii) operating surplus and (iii) other cost components like indirect taxes and subsidies.
[12] These sample medians are again exclusive of Korea.

Managerial	26,589	21,165	24,985	40,855	34,011	21,011	36,670	7,189
Clerical	14,869	11,460	17,313	16,221	16,389	9,323	18,363	2,910
Others	21,578	16,960	15,788	22,859	24,544	14,529	25,083	2,495
B. Capital								
Capital I	0.08	0.103	0.053	0.078	0.091	0.075	0.097	0.155
Capital II	0.165	0.19	0.174	0.18	0.203	0.203	0.185	0.234

Source: Choi and Krishna (2004)

B. Factor content of trade

The factor content of trade vectors are constructed by combining data from a 17 sector ISIC classification with the corresponding country-specific technology matrices. From the 17 sectors, nine are two-digit manufacturing industries and eight are one-digit non-manufacturing sectors. The industries and their classification numbers are listed in Table A1 of the Appendix.

The country-specific technology matrices give the total (direct and indirect) factor inputs required to produce one dollar of net output in each industry. Each technology matrix $\boldsymbol{A^c}$ is constructed by multiplying a country's direct input matrix $\mathbf{B^C}$ (factor by industry categorization) with its input-output matrix $\boldsymbol{\check{T}^c}$ (industry by industry categorization) such that $\boldsymbol{A^c} = \mathbf{B^C}(\mathbf{I} - \boldsymbol{\check{T}^c})^{-1}$.[13] This specification of the technology matrix guarantees that the factor content takes into account only domestically produced intermediate goods.

5. Empirical analysis

I apply the above data set to predictions on the factor content of gross and net exports. Section 5.1 contains the empirical results on the factor content of gross exports and section 5.2 examines net trade flows. Although the underlying theory makes predictions on the pattern of gross exports, we also investigate the implications

[13] The direct input matrix $\mathbf{B^C}$ measures how much direct input of each factor is required to produce one dollar of gross output in each industry. The input-output matrix $\boldsymbol{\check{T}^c}$ measures how much output an industry must buy from another industry to produce one dollar of its gross output.

for bilateral export flows to allow for a direct comparison with Choi and Krishna (2004).

5.1 Predicting the factor content of gross exports

First, I examine whether the factor content of a countries' gross exports fulfil all the 7 restrictions in (6). Following the reasoning in (3), we can think of the factor price differences defining a country-specific cone and a factor content vector will be in that cone if it satisfies all 7 restrictions.[14] Given that there are 8 countries, we have a sample of 56 bilateral and 8 multi-lateral exports, where the latter is defined as the factor content of a country's exports to all 7 trading partners. Table 2 summarizes the results from testing the multi-lateral specification. The findings are quite stark. Table 2 reveals that either all or none of a country's exports fall in its country-specific cone with no systematic difference between shipments to a single country or to the whole group.[15]

Table 2

Exports satisfying all the restrictions

	Capital I		**Capital II**	
	Correct	**share of total**	**Correct**	**share of total**
United States	0	0.00	0	0.00
Canada	0	0.00	0	0.00
Denmark	8	1.00	0	0.00
France	0	0.00	0	0.00
Germany	0	0.00	0	0.00
United Kingdom	0	0.00	0	0.00
Netherlands	0	0.00	0	0.00
Korea	8	1.00	8	1.00
all countries	**16**	**0.25**	**8**	**0.125**

Total of 64 exports (7 bilateral and 1 multi-lateral flow per country)

[14] It is important to notice that the multi-cone specification requires factor price information of all trading partners. Focusing only on a subset of trading partners creates a bias towards a confirmative finding. Consequently, increasing the sample size can only lead to a weakening of the results as it will be accompanied by an increase in the number of restrictions that need to be fulfilled.

[15] Since I didn't find any different results when considering trade flows to a subset of trading partners (e.g. US exports to France and Germany only), I report only the findings for the multi-lateral exports to all sample trading partners.

Overall, the results suggest poor support for the multi-lateral specification: the success rate is 25% for the capital I measure and 12.5% for the capital II measure. While all Korean exports are compatible with the predictions, Danish exports fall in this country's cone for the capital I measure, but not for the capital II measure. None of the exports of the other 6 countries fall in the respective cones.

One might argue that the lack of empirical support for the multilateral specification might be the result of the relative strictness of the multi-cone Heckscher-Ohlin prediction since it predicts that an export flow must fulfil all seven restrictions. However, small measurement errors might prevent this from happening. For example, if a country's export vector fulfills only six of the seven restrictions, it would not qualify to fall into this country's cone, although one would consider this to be only a minor violation of the prediction. To investigate this, we now deviate from grouping the restrictions into cones and investigate the sign of the restrictions (6) and (7) separately.

For 8 countries, (6) and (7) implies a total of 49 restrictions for each country: 7 bilateral exports are each restricted by 7 different factor price differences. The results are given in Table 3.

Table 3

Exports satisfying the individual restrictions

	Capital I		Capital II	
	correct	share of total	Correct	share of total
United States	26	0.53	42	0.86
Canada	28	0.57	41	0.84
Denmark	49	1.00	35	0.71
France	14	0.29	14	0.29
Germany	7	0.14	0	0.00
United Kingdom	42	0.86	25	0.51
Netherlands	0	0.00	7	0.14
Korea	49	1.00	49	1.00
all countries	**215**	**0.55**	**213**	**0.54**
Excluding Korea	**166**	**0.48**	**164**	**0.48**

392 restrictions (49 per country); 343 restrictions excluding Korea

Table 3 reveals considerable country variation in the success rate of the restrictions, ranging from 0% to 100%. Overall, the restrictions perform very poorly for Germany and the Netherlands (14% and 0%), perform fairly well for Denmark (100% and 71%) and fit perfectly for Korea. For the US, Canada and the UK the success rate is fairly sensitive to the capital measure, varying between 51% and 86%. For France, the success rate is slightly below 29% range for both capital measures. Despite the variation across countries, the average success rate over the whole sample is roughly the same across the capital measures, 55% for capital I and 54% for capital II. If we exclude Korea from the sample, the overall success rate drops to 48%.

The results reported in Tables 2 through 3 beg an explanation for the high success rate of the restrictions on Korean exports. The factor price data from Table 1 provide a possible clue to the answer. In particular, the large factor price differences between Korea and the other 7 OECD countries are more likely to reflect differences in factor productivity rather than differences in factor endowments. While the identical technology assumption seems to be justifiable for the 7 OECD countries, it appears to be suspect if one includes Korea.

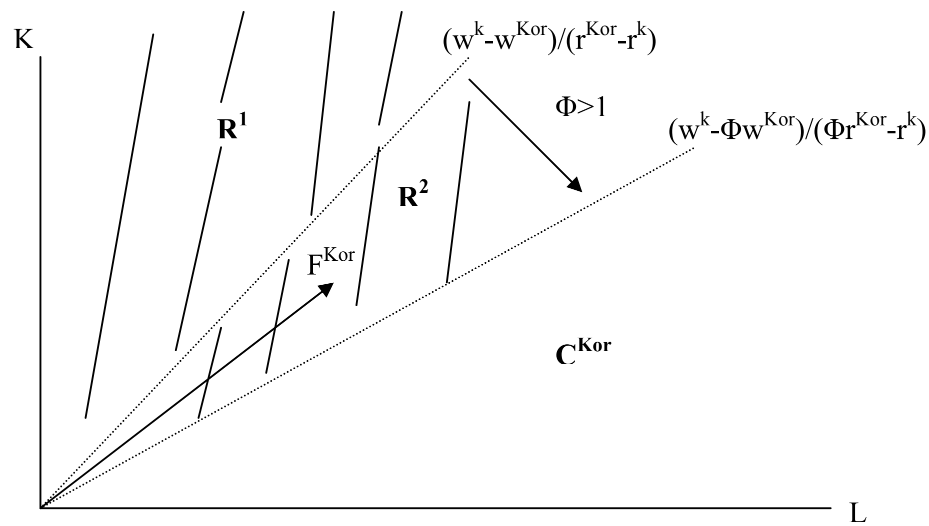
To illustrate the potential misspecification that arises from the inclusion of Korea, we relax the identical technology assumption and assume Hicks-neutral factor efficiency differences. In particular, assume that all input factors in any of the OECD countries is more productive than those in Korea by a fixed factor of Φ, where $\Phi>1$. Using the logic from section 3, one can derive a productivity adjusted restriction on the gross exports of Korea,

$$(w^{k}-\Phi w^{Kor})'\mathrm{F}^{\mathrm{Kor}} \geq 0, \qquad (9)$$

where the factor content of any of Korea's export vector F^{Kor} is restricted by the factor difference between the factor price vector w^j in country *j* and the productivity adjusted Korean factor price vector Φw^{Kor}.

Figure 3 illustrates the effects of technological differences in the two-factor case. Ignoring the productivity difference in the restriction results in a rejection region R^1 which is smaller than the true, productivity adjusted rejection $R^1 \cup R^2$.[16] The magnitude of the specification error is reflected in the size of the shaded area. As a result, if Korea's export vector F^{Kor} falls the area R^2 it will satisfy (6), but not (9).

Figure 3: Effect of technological differences



5.2 Revisiting Choi and Krishna (2004)

In this section we test the multi-lateral restrictions on the two-way trade flows between countries i and j, which allows for a direct comparison with the findings in Choi and Krishna (2004). Instead of testing the predictions (1) and (2) on gross

[16] Formally, $(w^i-w^{Kor})F^{Kor} \geq (w^i-\Phi w^{Kor})F^{Kor}$.

exports F^{ij} and F^{ji} separately, Choi and Krishna test the restrictions on net exports F^{ij}-F^{ji} given in (3)[17] These restrictions can be rewritten as follows:

$$\frac{w^j F^{ij} + w^i F^{ji}}{w^i F^{ij} + w^j F^{ji}} \geq 1 \qquad (10)$$

The left-hand side of inequality (10) has the following interpretation. For a given country pair, the denominator is the sum of the production costs of the bilateral exports. The numerator can be interpreted as the counterfactual production costs that results from valuing the factor content of exports by the importers factor prices. Since the counterfactual production costs can't be smaller, the ratio must be greater than or equal to 1.

Table A2 in the Appendix replicates Choi and Krishna's test of the 28 restrictions suggested by (10).[18] The tests perform remarkably well; the success rate is 86% using Capital I and 71% using Capital II. Remarkably, the ratios that are below 1 violate (10) by only very small margins.

However, from section 2 we know that there are many more restrictions to be considered. In particular, inequality (8) can rewritten to obtain :

$$\frac{w^k F^{ij} + w^l F^{ji}}{w^i F^{ij} + w^j F^{ji}} = \theta \geq 1 \qquad \text{for all } k \text{ and } l. \qquad (11)$$

It is immediately clear that (10) is a special case of (11) and that the latter implies many more counterfactual cost comparisons. In particular, the numerator in (11) is the sum of the counterfactual costs that results from valuing the factor content

[17] In a previous working paper version of their 2004 article, the authors test (1) and (2) separately.
[18] Despite using the same data set, the magnitudes in Table A2 deviate a bit from the corresponding entries in Tables 3 and 4 in Choi and Krishna (2004, p. 901-902). A possible explanation is the use of different rounding strategies; we chose not to round up until the final results.

of bilateral exports using the factor prices of *any* other country in the sample. The theory predicts that the ratio must be greater than or equal to 1 for all factor price configurations. While (10) implies only a single restriction for a given country pair, (11) yields 49 different restrictions per country pair, resulting in a total of 1372 restrictions.

Table 4

Testing inequality (11) (each entry contains the share of restrictions that satisfy $\theta \geq 1$)

Capital I

	Canada	Denmark	France	Germany	UK	Netherlands	Korea
US	0.55	0.84	0.49	0.20	0.67	0.49	1.00
Canada		0.88	0.51	0.18	0.76	0.45	1.00
Denmark			0.92	0.37	0.96	0.47	1.00
France				0.06	0.63	0.12	1.00
Germany					0.31	0.02	1.00
UK						0.51	1.00
Netherlands							1.00
All	**0.62**	(% of correct signs of 1372 restrictions (28 country pairs))					
excl. Korea	**0.49**	(% of correct signs of 1029 restrictions (21 country pairs))					

Capital II

	Canada	Denmark	France	Germany	UK	Netherlands	Korea
US	0.78	0.78	0.59	0.16	0.73	0.57	1.00
Canada		0.82	0.53	0.10	0.67	0.51	1.00
Denmark			0.92	0.12	0.71	0.39	1.00
France				0.04	0.41	0.20	1.00
Germany					0.12	0.00	1.00
UK						0.49	1.00
Netherlands							1.00
All	**0.59**	(% of correct signs of 1372 restrictions (28 country pairs))					
excl. Korea	**0.46**	(% of correct signs of 1029 restrictions (21 country pairs))					

Table 4 contains the results from testing the restrictions in (11). Since there are 49 restrictions for each country pair, each entry gives the share of restrictions which satisfy (11). Overall, the results are consistent with our findings in the previous section. The success rate is perfect for the bilateral trade flows that involve Korea and fairly high for bilateral trade flows that involve Denmark. The restrictions perform rather poorly for trade flows involving the Netherlands and Germany and are mixed for Canada, the US, the UK and France. Taking the average over all country pairs, the success rate is 62% for Capital I and 59% for Capital II; excluding Korea the success rate drops to under 50%.

Overall, the results reported in Tables 3 and 4 suggest that observed factor price differences are, on average, poor predictors for the direction of the factor content trade between the sample of 7 OECD countries (i.e. excluding Korea). A possible explanation for this finding is that the observed factor price differences do not reflect factor endowments differences that are large enough for justifying the assumption that countries all occupy different cones.[19] If countries occupy a single cone then the left-hand side will be equal to 1. Hence, testing whether θ=1 provides evidence for factor price equalization. Table A3 in the Appendix reports the average magnitudes of θ for each country pair. Although there is substantial variation in the average values among the country pairs, the overall average of the 1029 restrictions (excluding Korea) is remarkably close to 1: 1.01 using for Capital I and 1.00 for Capital II. This confirms the conjecture that this set of OECD countries does not fulfil the assumption of the underlying theoretical specification.

5.3 Investigating pattern in the data and modifications in the assumptions of the model

…see Presentation.

6. Conclusion

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[19] This is consistent with the empirical findings of Debaere and Demiroglu (2003).

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Appendix

Table A1: Industry classification

Industry Description	ISIC Code
Agriculture, hunting, forestry and fishing	1
Mining and quarrying	2
Food, beverages, and tobacco	31
Textiles, apparel, and leather	32
Wood products	33
Paper, paper products and printing	34
Chemical products	35
Nonmetallic mineral products	36
Basic metal industries	37
Fabricated metal products and machinery	38
Other manufacturing	39
Electricity, gas and water	4
Construction	5
Wholesale and retail trade, retaurants and hotels	6
Transport, storage and communication	7
Finance, insurance, real estate and business services	8
Community, social and personal services	9

Table A2: Replication of Choi and Krishna (2004) (left-hand side of (10))

Left-hand side of (14)

Capital I

	CA	DE	FR	GER	UK	NE	KO
US	1.00	1.03	1.05	1.00	0.98	1.18	1.72
CA		1.14	1.06	1.01	1.01	1.17	1.62
DE			1.08	0.99	1.04	1.03	2.45
FR				0.99	1.04	1.01	2.73
GER					0.97	1.00	2.35
UK						1.10	1.88
NE							3.62
Average		**1.37**		28 restrictions with Korea			
w.out KO		**1.04**		21 restrictions without Korea			
≥1	24	28	**0.86**	% of correct sign			
w.out KO	17	21	**0.81**	% of correct sign			

Capital II

	CA	DE	FR	GER	UK	NE	KO
US	1	0.9976	1.06	0.99998	1.01	1.14	1.53
CA		1.03	1.04	0.99	0.9953	1.14	1.48
DE			1.08	0.99	1.03	1.02	1.99
FR				0.99	1.03	1.01	2.29
GER					0.99	0.99	2
UK						1.07	1.65
NE							3.01
Average		**1.27**		28 restrictions with Korea			
w.out KO		**1.03**		21 restrictions without Korea			
≥1	20	28	**0.71**	**% of correct sign**			
w.out KO	13	21	**0.62**	**% of correct sign**			

Table A3: Average Magnitude of θ (left-hand side of (15))

Each entry is the average of 49 ratios for each country pair

Capital I

	CA	**DE**	**FR**	**GER**	**UK**	**NE**	**KO**
US	1.02	1.14	1.00	0.89	1.08	0.99	1.99
CA		1.18	1.00	0.88	1.10	0.96	2.04
DE			1.15	0.97	1.23	0.99	2.80
FR				0.86	1.05	0.87	2.74
GER					0.94	0.79	2.08
UK						1.04	1.76
NE							3.34
Total average		**1.35**		1372 restrictions (28x49)			
w.out KO		**1.01**		1029 restriction (21x49)			

Capital II

	CA	**DE**	**FR**	**GER**	**UK**	**NE**	**KO**
US	1.06	1.07	1.04	0.92	1.05	1.03	1.78
CA		1.07	1.01	0.90	1.05	1.00	1.85
DE			1.15	0.93	1.06	0.98	1.91
FR				0.87	0.99	0.93	2.33
GER					0.91	0.84	1.81
UK						1.05	2.06
NE							2.89
Total average		**1.27**		1372 restrictions (28x49)			
w.out KO		**1.00**		1029 restriction (21x49)			