Does Factor Endowment Differences Predict Bilateral Factor Trade?

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Abstract

It does.

Longer Abstract

I propose a trade-in-task framework that relates bilateral factor trade with relative factor endowments and the sizes of countries. Using the newly available World Input-Output Database, I derive bilateral factor trade data for four factors: capital and low-, medium- and high-skilled labour. Empirical tests show that the direction of net factor export in a pair of countries is highly related with the differences in their relative factor abundance and trade balance. I also show that consumption similarity condition holds quite well for traded factors. Further analysis on the share of factor export and comparative advantage shows that cost saving should not be a major motive behind factor trade.

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1. Introduction

The Heckscher-Ohlin-Vanek (HOV) model has an important position in the trade literature. This model links a country's factor content of trade with its structure of relative factor abundance, providing a simple testable framework for the Heckscher-Ohlin (HO) theorem. HOV compares a country's relative abundance with world-average level: when a country has a higher-than-average relative abundance of factor f it will be the net exporter of that factor. Since the 1980s, a large number of empirical tests of HO theorem focused on the HOV model. The results are, however, mixed: some studies show that HOV's predicting power is no better than "tossing a coin" (e.g. Bowen et al. 1987, Trefler 1995), while other more recent works show better performance of the model but only after complex adjustments, for example allowing for non-tradables and relaxing strong assumptions like homogeneous technology and preferences across countries (Davis and Weinstein 2001). Most HO research focuses on the "original form" of HOV by investigating the net factor exports from each country. Yet there is little research on a "bilateral" story to explore the relationship between relative factor abundances, and the bilateral factor content of trade between pair of countries.

The target of this paper is therefore to test HO theorem by investigating factor trade flows bilaterally between different countries. This paper is in particular related with Debaere (2003), Choi and Krishna (2004), and Lai and Zhu (2007). I derive a HOV-like theoretical framework by introducing trade-in-task and monopolistic competition in the HO model of Bergstrand (1989) and Deardorff (1998). This gives a testable hypothesis that net factor trade between a pair of countries is determined by their differences in relative factor endowment. In the empirical analysis I follow the criteria in Trefler and Zhu (2010) and derive a consistent measure of bilateral factor trade that controls for factor contents in domestic and traded intermediate inputs, using the recently available World Input Output Database (WIOD, Timmer et al 2015). I show that the differences in relative factor endowment has high explanatory power for the direction of net factor export between two countries, and the predicting power remains high even for the country pairs within Europe whose endowment structures are relatively similar. Using bilateral factor trade data, I find the existence of a large degree of home bias in factor use. While for traded factors, the so-called "consumption similarity" condition (Trefler and Zhu 2010) holds quite well, indicating that monopolistic competition and "love-for-variety" are more relevant than the Ricardian cost-saving motive in factor trade.

As I will discuss in details, a bilateral framework has at least two distinct advantages over standard HOV. First, HOV compares factor structure of all countries to a single benchmark (i.e. world average) while in the bilateral framework a country is compared with all its trade partners. So, the bilateral framework is more robust to observational errors and trade fluctuations. Second, multiple assumptions (like Ricardian trade and monopolistic competition model) would lead to a same HOV prediction (Deardorff 1993). The analysis of bilateral factor trade data provides an examination on the relevance of these alternative assumptions regarding consumption and technology.

There are already several researches on bilateral factor trade, notably Debaere (2003), Choi and Krishna (2004), and Lai and Zhu (2007). My research provides an extension to current literature by using new and more detailed data on workers and traded intermediates inputs, such that bilateral factor trade can be measured much more precisely. Factor trade in this paper is defined as factor services created by a factor in a country *i* that finally ends up in the final consumption of country *j*. This definition is in accordance with the criteria of Trefler and Zhu (2010) to be both "economically meaningful" and "HOV-relevant". The measure of factor trade frequently used in the literature is derived on the assumption of identical technology; it was frequently assumed that technology in every country is the same as U.S. (e.g. Leontief 1953, Bowen et al. 1987, Trefler 1995); this not true. Recent works control for technical differences; Davis and Weinstein (2001) and Choi and Krishna (2004) used domestic IO tables for each country, and Lai and Zhu (2007) allows different factor efficiency across countries/industries. However, their methodologies lack the ability to capture traded intermediate inputs which nowadays play an increasing important role in global production fragmentation. Lai and Zhu consider only the final stage of production. The method using domestic IO tables captures factors embedded in domestic intermediate input, but not in traded intermediate input, in addition we cannot tell whether exported goods are final consumption goods or intermediate inputs for the importer.

To see this, consider a situation in which Japan exports microprocessors and lenses to China to be assembled into digital cameras, which are subsequently exported to the U.S. When using only domestic IO tables, the Chinese IO table correctly tells that China exports low-skilled content to the U.S. (i.e. assembly). However, we do not observe the indirect exports of high-skilled content by Japan to the US: in the Chinese IO table, the Japanese contents are registered as "imported material" and cannot be further traced. On the Japanese side, Japanese domestic IO table and trade data tell that Japan is exporting high-skilled contents to China, however China is actually not the place where these Japanese contents are consumed. More generally, this problem will arise for all countries that specialise in upstream stages of production. To solve this problem, I use multi-regional IO tables that allow for technical differences across countries, and in which exports can be explicitly traced until final consumption. Therefore, bilateral trade of factors can be measured such that they are consistent with the criteria of Trefler and Zhu (2010).

The second important extension from current literature is that I will test explicitly whether the so-called consumption similarity relationship holds for factor content trade. When consumption similarity holds, factor export can be predicted by a gravity-like equation, i.e. the export of a factor f from country i to j should equals the product of (a) the source country i's f-factor abundance and (b) the importer j's consumption as a percentage of world total consumption. The purpose of this analysis is two-fold. First, Trefler and Zhu (2010) shows that a HOV prediction holds robustly to perturbations in production technology if and only if the consumption similarity holds for industrial consumption. In this paper, consumption similarity focuses on the consumption of factor instead of industrial output, but my analysis should help in evaluating the robustness of the HOV. Second, this test compares the effectiveness of alternative theories behind the HOV prediction. Both Ricardian cost-driven motive of trade and the monopolistic competition "love-for-variety" model give the same HOV prediction, but consumption similarity is quite unlikely to hold under the former motive.

The rest of the paper is organized as follows. Section 2 introduces a theoretical framework and compares it with standard HOV model. Section 3 discusses data source and empirical methodology in deriving the bilateral trade data. Section 4 reports the results for the bilateral HOV test, section 5 tests the consumption similarity conditions, and section 6 provides further tests concerning the motive of factor content trade.

2. A Simple Framework of Bilateral Factor Trade

This section introduces a model that predict bilateral trade in factor content between a pair of countries. The model setup follows Bergstrand (1989) and Deardorff (1998) with monopolistic competition and Armington assumptions. My framework is related but different from Krugman (1979) and Ethier (1982)'s famous love-for-variety model, because I allow factors to be exported directly via trade-in-task. Krugman assumes similar but different products are produced using different factors within each country, and trade taken place in products, while Ethier interpret these goods as semi-finished intermediates which later being costlessly assembled into final consumption goods by the importing country. Trade-in-task is a more appropriate way of modelling for the recent wave of production fragmentation. Think about a country with a large abundance of labour but extreme scarcity in capital. Since the production of products (semi-finished intermediates) requires both capital and labour, if the trade happens at goods level then the abundance of low-skilled labour cannot be fully utilized, because its expensive capital goods pushes up the price of components (or goods). While under production fragmentation, this country may import (capital-intensive) intermediate inputs and perform labour-intensive tasks such that labour itself is exported.

I assume each country i consumes a "general final good" U_i (this good can be viewed as the composition of the country's consumption basket). The production of the general final goods has a Armington structure with two stages. On the upper stage, the general final good is produced by the aggregated factors services of different kinds, in a Cobb-Douglas form:

$$U_i = \prod_f \left(Q_i^f\right)^{\alpha^f}, \qquad \sum_f \alpha^f = 1 \tag{1}$$

Q_i^f denotes the (aggregated) factor service of factor f that is used by country i. Alpha parameters represent the preferences of for different factors; in equilibrium α_f equals the share of spending on factor f. Now I assume identical preference across countries, later I will discuss the situation where preferences differ across countries.

On the lower stage, the factor service is a CES aggregation of different varieties of tasks, given by:

$$Q_i^f = \left(\sum_a \left(q_{a,i}^f\right)^{\rho^f}\right)^{\frac{1}{\rho^f}}, \qquad 0 < \rho^f < 1 \tag{2}$$

$q_{a,i}^f$ stands for the quantity of task using factor f that is produced by a firm a and purchased by country i. The firm a can be either a domestic of foreign firm. Each firm produces its unique variety of task and is protected by a patent, so the tasks from different firms are imperfect substitutes. Countries can import tasks indirectly via a third nation: for instance in the example in the introduction, U.S. purchases Japanese contents that are embedded in Chinese products. Note that the production function (1) and (2) features constant return to scale, the production structure can be viewed as the follows: a country purchases different type of tasks $q_{a,i}^f$ directly and indirectly from the world, and then the tasks are costlessly "assembled" into the general final good via first (2) and then (1).

Different types and varieties of tasks are produced by firms. A type-f task uses factor f. I assume that the production function for a same type of task is same across countries after adjusting for factor productivity differences; the production featuring a constant marginal cost with a fixed setup cost. The fixed cost is payable in terms of the factor the firm uses. The total cost for a type-*f* firm in country *i* to produce *q* units of task is therefore:

$$C^f(q,i) = w_i^f \phi_i^f \left(FC^f + MC^f q\right) \tag{3}$$

w_i^f is the price of factor *f* in country *i*, and ϕ_i^f adjusts for factor productivity. Given the CES aggregation of (2), the elasticity of substitution between two varieties is $\varepsilon^f = (1/\rho^f) > 1$. Follows Krugman (1979) and Ethier (1982), the optimal pricing rule of firms is to charge a constant mark-up over its marginal cost. The price is determined by $p_i^f = \frac{\varepsilon^f}{\varepsilon^f - 1} w_i^f \phi_i^f MC^f$; it is the same for all type-*f* firms in country *i*. Under a competitive factor market, the equilibrium profit for each firm is zero, so total cost equals total revenue, i.e. $p_i^f q = C^f(q,i)$, which gives the equilibrium output per firm:

$$q_i^f = \frac{FC^f}{MC^f}\left(\frac{\rho^f}{1-\rho^f}\right) = q_*^f \tag{4}$$

It is same across countries. So, the size of employment (or capital usage) in each firm in *i* is $\phi_i^f \left(FC^f + MC^f q_*^f\right) = \phi_i^f FC^f \varepsilon^f$. Use M_i^f to denote the abundance of factor *f*, so country *i*'s number of type-*f* firm, or in another word the number of varieties of task-*f* produced by *i*, is:

$$N_i^f = \left(\frac{M_i^f}{\phi_i^f}\right) / FC^f \varepsilon^f = \frac{M_i^{*f}}{FC^f \varepsilon^f} \tag{5}$$

$M_i^{*f} = M_i^f / \phi_i^f$ is country *i*'s effective abundance of *f*, adjusted for factor productivity.

I am interested in the export of factor *f* from country *i* to *j*. For this moment I assume balanced trade, so country *j*'s expenditure equals its GDP, Y_j. Under equilibrium, the total expenditure spent on factor *f* is $\alpha^f Y_j$. I also assume no trade cost; in the appendix provide a model with trade cost which gives a very similar prediction for bilateral factor trade for the set of countries that are closely located. Under free trade, all countries are as if in a same market; factor price equalisation holds after adjusting for productivity difference, i.e. $w_i^f \phi_i^f = w^{*f}$ for all *i* and *f*. The price of tasks p_i^f is also the same for all varieties in all countries, so *j* would spread its budget evenly on all available varieties. Its expenditure on country i's type-*f* task, or in another word the value of factor content exported from *i* to *j*, is:

$$E_{ij}^f = \frac{N_i^f}{N_W^f} \alpha^f Y_j \tag{6.a}$$

$N_W^f = \Sigma_i N_i^f$, i.e. the total number of varieties of type-*f* tasks in the world. We can rewrite (6.a) by multiplying both nominator and denominator by the total cost of each firm ($w^{*f} FC^f \varepsilon^f$):

$$E_{ij}^f = \frac{w^{*f} N_i^f FC^f \varepsilon^f}{w^{*f} N_W^f FC^f \varepsilon^f} \alpha^f Y_j = \frac{w^{*f} M_i^{*f}}{w^{*f} M_W^{*f}} \alpha^f Y_j$$
$$= \frac{s_i^f Y_i}{\alpha^f Y_W} \alpha^f Y_j = s_i^f \frac{Y_i Y_j}{Y_W} \tag{6.b}$$

$s_i^f = w^{*f} M_i^{*f} / Y_i$ is the share of GDP in *i* that is contributed by factor *f*, which represents its relative endowment of *f*. From the first line to the second, I used the fact that the world income earned by factor *f* equals world expenditure on *f* tasks, which is α^f times world GDP. (6.b) shows that the factor export between a pair of country depends on the size of two economies, and the relative abundance of the factor in the exporting country. By symmetry the factor export from j to i is $E_{ij}^f = s_j^f Y_i Y_j / Y_W$, so the net factor trade from i to j is given by:

$$NE_{ij}^f = \left(s_i^f - s_j^f\right) \frac{Y_i Y_j}{Y_W} \tag{7}$$

So, the differences in relative factor endowment determines the direction of net factor trade.

Imbalanced trade and heterogeneous preference can be easily adapted in the model. I denote the consumption to GDP ratio of a country i as τ_i. The ratio's deviation from unity captures trade imbalance, since when a country runs a trade deficit (surplus), its consumption is larger (smaller) than its GDP. The total expenditure of country *j* is $C_j = \tau_j Y_j$. To account for hetergeneous perference, each country now has its own α_i^f with $\sum_f \alpha_i^f = 1$. Take both adjustments into consideration, the consumption of country *j* on type-*f* tasks now becomes $\alpha_j^f \tau_j Y_j$. Note that there is no change in the equilibrium size of factor employment per firm ($\phi_i^f FC^f \varepsilon^f$); this is independent of trade balance or preference so the number of varieties in each country, i.e. equation (5), remains unchanged. Now equation (6.a) and (6.b) becomes:

$$E_{ij}^f = \frac{w^{*f} M_i^{*f}}{w^{*f} M_W^{*f}} \alpha_j^f \tau_j Y_j = \frac{s_i^f Y_i}{s_W^f Y_W} \alpha_j^f \tau_j Y_j = \tilde{s}_i^f \alpha_j^f \tau_j \frac{Y_i Y_j}{Y_W} \tag{6'}$$

$s_W^f = \left(\sum_i s_i^f Y_i\right) / Y_W$, representing the average share of income earned by factor *f* in the whole world, so $\tilde{s}_i^f = s_i^f / s_W^f$ measures country *i*'s relative endowment of factor *f* in comparison to the world average. Equation (6') predicts that factor trade is positively related with exporter's relative abundance, importer's trade deficit, and importer's preference for that factor. After these adjustments, the predicted net export becomes:

$$NE_{ij}^f = E_{ij}^f - E_{ji}^f = \left(\tilde{s}_i^f \alpha_j^f \tau_j - \tilde{s}_j^f \alpha_i^f \tau_i\right) \frac{Y_i Y_j}{Y_W} \tag{7'}$$

The bilateral factor export prediction in this model is consistent with standard HOV prediction. The net factor export from country i is the summation of NE_{ij}^f over all *j*. Under balanced trade and homogeneous preference for factors, HOV prediction is restored:

$$NE_i^f = \sum_j NE_{ij}^f = \sum_j (s_i^f - s_j^f)\frac{Y_iY_j}{Y_W} = \frac{s_i^f Y_i(\sum_j Y_j)}{Y_W} - \frac{Y_i(\sum_j s_j^f Y_j)}{Y_W}$$
$$= s_i^f Y_i - \frac{Y_i(\sum_j s_j^f Y_j)}{Y_W} = w^{*f}M_i^{*f} - (Y_i/Y_W)w^{*f}M_W^{*f} = V_i^f - (Y_i/Y_W)V_W^f \quad (8)$$

Here $V_i^f = w^{*f}M_i^{*f}$, which is the total value of the factor abundance in a country. And for the specification adjusted for unbalanced trade and heterogeneous preference:

$$NE_i^f = \sum_j (\tilde{s}_i^f \alpha_j^f \tau_j - \tilde{s}_j^f \alpha_i^f \tau_i)\frac{Y_iY_j}{Y_W} = \frac{(s_i^f/s_W^f)Y_i(\sum_j Y_j \alpha_j^f \tau_j)}{Y_W} - \frac{(Y_i\alpha_i^f\tau_i)(\sum_j (s_i^f/s_W^f)Y_j)}{Y_W} \quad (8')$$

$$= s_i^f Y_i - \alpha_i^f \tau_i Y_i = s_i^f Y_i - \frac{\alpha_i^f}{s_W^f}\tau_i \frac{Y_i}{Y_W}(s_W^f Y_W) = V_i^f - \tilde{\alpha}_i^f \tau_i (Y_i/Y_W)V_W^f$$

It is similar as the original HOV, with adjustment for trade balance (τ_i) and preference ($\tilde{\alpha}_i^f$). $\tilde{\alpha}_i^f = \alpha_i^f/\alpha_W^f = \alpha_i^f/s_W^f$ which captures the preference of country *i* relative to the world average preference ($\alpha_W^f = s_W^f$ since α_W^f equals the world share of income spent on *f*).

I will test both standard HOV and bilateral factor trade predictions. Bilateral factor trade analysis has considerable value-add on top of standard HOV due to at least the following two reasons. First, bilateral analysis utilizes more available information in international trade, and the results are expected to be more robust to trade fluctuations or observational errors. Standard HOV compares a country's endowment vector V_i with a single benchmark: the world endowment V_w. Problem arises when the structure of domestic abundance is close to the world average. In such case the sign-test prediction is very sensitive to observational errors in the factor abundance of the country and fluctuations in trade balance. A fluctuation/error of one or two percentage points can be sufficient to reverse the sign prediction of a country from net factor exporter to importer. While in the bilateral analysis, the factor abundance structure is bilateral compared such that all trade partners of a country act as benchmarks. So, the conclusion concerning whether a country fits the Heckscher-Ohlin prediction is less likely being affected by disturbance terms.

Second and more important, bilateral trade data helps in evaluating the underlying assumptions behind the standard HOV prediction. As pointed out by Trefler and Zhu (2010), multiple alternative assumptions concerning technology and consumption would lead to the same HOV prediction. Mainly there are two categories of models: cost-saving driven motives of trade, and love-for-variety motive. With bilateral trade data, it is feasible to distinguish which motive plays a more important role in determine the pattern of international trade.

To see that, assume a 2x2x2 world. Country *i* has 4 workers and 5 capital, while *j* has 5 workers and 4 capital; both countries have the same preference. Table 1 illustrates the trade outcome of different scenarios. Column 1 and 2 represent the cost-saving motive of trade where the products from two countries are assumed to be identical. Column 1 shows the situation where trade is only feasible on product level. The production functions of capital and labour intensive goods are assumed to be $G_1=K^{2/3}L^{1/3}$ and $G_2=K^{1/3}L^{2/3}$ respectively, and the utility $U=G_1^{1/2}G_2^{1/2}$. It can be verified that country *i* produces $2^{(2/3)}$ units of G_1 using 1 worker and 2 capital, and $2*2^{(2/3)}$ units of G_2 using 4 workers and 2 capital, while a similar but reverse picture holds for country 2. Under trade, country 1 would export $0.5*2^{(2/3)}$ units of G_2 (which implies 1 worker and 0.5 capital) in exchange for $0.5*2^{(2/3)}$ units of G_1, such that both country ends up in $1.5*2^{(2/3)}$ units of both G_1 and G_2. Column 2 represents the situation where trade taken place at task level but the tasks are assumed to be identical: in the end both countries need half of all available factors in the world, so *i* exports 0.5 labour in exchange for 0.5 capital.

Column 3 represents the situation in which the trade perfectly follows the love-for-variety motive. No matter whether the monopolistic competition takes place in task-level or goods-level, both country exports half of its factors to the trade partner.

[INSERT TABLE 1 ABOUT HERE]

It can be seen from the table that the net-factor exports in all three specifications are the same. Under cost-saving motive, bilateral trade is much less than trade under love-for-variety. In addition, testable hypothesis can be build to test the existence of cost-saving motive of trade: in such situation, the percentage of exported factor as a share of total factor endowment is larger for the factor that the country has a comparative advantage, while this share is the same under the love-for-variety motive.

3. Data Source and the Derivation of Bilateral Factor Trade

I use the newly available World Input Output Database (WIOD, Timmer et al 2015, freely accessible via `www.wiod.org`) as the primary data source. WIOD provides multi-regional input output tables annually for 1995 to 2009 for 40 countries and regions, covering most of the developed countries and major developing economies like the BRIC. It provides detailed information on factor usage, international trade, and the organization of global value chain. I am aware the existence of a comparable dataset, i.e. the GTAP project. But GTAP is not free. While GTAP covers larger number of countries, its multi-regional IO tables are based on national IO tables of a single benchmark year. The multi-regional IO tables in WIOD project are constructed by matching national IO tables of multiple years from official statistic bureaus, with annual WTO trade data. Therefore WIOD is better capable to trace the dynamics in domestic and international IO structure.

Follows the HOV-relevance criteria as in Trefler and Zhu (2010), factor export from country i to j is here defined as the values created by a particular factor in i that end up in the final use of country j (for $i = j$, this measure captures the domestic factor usage). To derive this measure for bilateral factor export, I follow Johnson and Noguera (2012) and Timmer et al (2014) which use Input-Output analysis to properly control traded intermediate inputs. The derivation of factor export follows a "backward looking" strategy: to get the factor export from country i to j, I first pick the vector of all final goods consumed by j, and then decompose these final goods into ultimate factors from different countries that are used in production. Those factors originate from country i are therefore the factor export from i to j.

Formally, the export of factor f from i to j is calculated as follows:

$$E_{ij}^{f} = \boldsymbol{\iota}_i' \left[\text{diag}\left(\boldsymbol{v}^f\right) (\boldsymbol{I} - \boldsymbol{A})^{-1} \boldsymbol{d}_j \right]$$

Assume there are N countries and each country has G industries. In the equation, $\boldsymbol{d}_j$ is a column vector with NG elements, representing the final demand of country j from each country/industry. $\boldsymbol{A}$ is the multi-regional input-output technical matrix with the size NG*NG; each element $A_{(i,a),(j,b)}$ represents the value of intermediate goods from country i industry a that is directly used in the production of \$1 goods in country j industry b. The term $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ is the famous "Leontief Inverse" which equals $\boldsymbol{I} + \boldsymbol{A} + \boldsymbol{A}^2 + \cdots + \boldsymbol{A}^\infty$, and $(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{d}_j = \boldsymbol{d}_j + \boldsymbol{A}\boldsymbol{d}_j + \boldsymbol{A}^2\boldsymbol{d}_j + \boldsymbol{A}^3\boldsymbol{d}_j + \cdots \boldsymbol{A}^\infty\boldsymbol{d}_j$. $\boldsymbol{A}\boldsymbol{d}_j$ is the direct intermediate inputs used in the production of $\boldsymbol{d}_j$, while in order to produce $\boldsymbol{A}\boldsymbol{d}_j$ amount of intermediate inputs, a further amount of intermediate input $\boldsymbol{A}^2\boldsymbol{d}_j$ is required, etc, therefore $(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{d}_j$ captures the total production required in order to make $\boldsymbol{d}_j$ final goods. $\boldsymbol{v}^f$ is an NG column vector representing the value of factor f that is directly used in producing \$1 of output in each country/industry. So the term in the square bracket represent the worldwide usage of factor f in order to make the final products for j. Finally $\boldsymbol{\iota}_i' = [0, 0, \dots, 1, 1, \dots 1, 0, 0, \dots, 0]$, with element 1 for industries in country i and zero otherwise; $\boldsymbol{\iota}_i'$ is used to sum up all factor f that belongs to country i.

I perform the same calculation for low-, medium- and high-skilled labour, and capital to obtain the bilateral trade in these four factors between each pair of countries.

In table 2, I compare the ratio between two measures of factor export: (a) the measure used in this paper, with (b) the measure derived from bilateral gross export data and domestic IO tables, as in for example Trefler (1995) and Davis and Weinstein (2001). The table investigate the differences in these two measurements for the factor export from different countries into the U.S. Measure (b) has two problems. First, by counting the factors in gross export, one may wrongly include the intermediate inputs that are processed by the importer and later on export to a third nation; this effect will over-estimate the factor export. Second, by using domestic IO tables, we cannot trace the factors that are indirectly exported into the destination country via a third country, which will underestimate factor export. From this comparison we find significant mismatches between two measures. For Canada and Mexico, measure (b) reports higher factor export into the U.S. than (a), indicating that the first effect dominants; these two countries might export considerable intermediate inputs into the U.S. for further processing and then exported to other countries. For all other countries, especially East European countries, the measure using domestic IO table under-estimate factor export by a large margin, showing that quite big part of factor export goes indirectly. In addition, the ratio between two measure varies a lot across country groups, so the currently frequently used measure (b) is not a good proxy for actual factor export, and according to Trefler and Zhu (2010)'s criteria, it is unsuitable to use (b) for HO analysis.

[INSERT TABLE 2 ABOUT HERE]

By taking the summation of all exported (imported) factors, I obtain a measure for total exported (imported) factor E_i^f(or I_i^f), and net exported factor of each country (NE_i^f):

$$E_i^f = \sum\nolimits_{\forall j,\, j\neq i} E_{ij}^f, \qquad I_i^f = \sum\nolimits_{\forall j,\, j\neq i} E_{ji}^f, \qquad NE_i^f = E_i^f - I_i^f$$

It should be noted that Trefler and Zhu (2010) use a different strategy to derive net factor export, by investigating factor content inflow/outflow embedded in goods that ships into (out from) each country. According to Johnson and Noguera (2012), the measure of net factor export used here is equivalent as Trefler and Zhu. But their method does not distinguish the destination country of factor export, therefore lacks the ability in tracing factor trade bilaterally between countries.

4. Sign Tests on Standard HOV and Bilateral Factor Export Predictions

I first use the above derived factor export data to perform a standard HOV sign test, i.e. whether the left and right side of $NE_i^f = V_i^f - cs_i V_W^f$ has the same sign, cs_i is the share of country i's consumption in world GDP. I perform the test for all years from 1995 to 2009; the results are reported in table 3. The left part reports unweighted sign test; in many cases the standard HOV correctly predicts the direction of net factor trade, and the overall fitness is around 85~90%. The right part reports the sign test weighted by each country's size of factor abundance. Unlike most researches that find weighted sign test has a higher, I find that the weighted test shows much higher *variations*.

It is interesting why the volatility in the weighted test is so high, especially for medium-skilled labour whose sign-test fitness dances between 0.5 and 0.99 in the 15-year period. A closer examination reveals that big economies like U.S. and U.K. are occasionally among the countries who fail the HOV in medium-skilled labour since 2000. I calculated above-defined relative abundance indicator $\tilde{s}_i^f$ for each factors of each country, and it shows that U.S. and U.K.'s abundance in medium-skilled labour is quite close to the world average: for the U.S., $\tilde{s}_{USA}^{MED}$ gradually decreases from 1.25 to 1.05 in the 15 year period, and for UK it is around 0.95. The HOV prediction for them are frequently "close to the mark" [1], such that predicted sign of net export is sensitive to observational errors in factor endowment and actual direction of net factor trade is sensitive fluctuations in trade. This confirms my arguments concerning the robustness of the traditional HOV test.

Now I move to the test on bilateral factor trade. I build tests on the equation (7'), i.e. $NE_{ij}^f = \left(\tilde{s}_i^f \alpha_j^f \tau_j - \tilde{s}_j^f \alpha_i^f \tau_i\right)\left(Y_i Y_j / Y_w\right)$. The sign of net export of factor *f* from *i* to *j* depends on the term in the bracket. So equivalently, one may test the sign of $\ln\left(\tilde{s}_i^f \alpha_j^f \tau_j / \tilde{s}_j^f \alpha_i^f \tau_i\right)$, which can be re-written as:

$$\ln\left(\frac{\tilde{s}_i^f \alpha_j^f \tau_j}{\tilde{s}_j^f \alpha_i^f \tau_i}\right) = \ln\left(\frac{\tilde{s}_i^f \tilde{\alpha}_j^f \tau_j}{\tilde{s}_j^f \tilde{\alpha}_i^f \tau_i}\right) = \left[\ln \tilde{s}_i^f - \left(\ln \tilde{\alpha}_i^f + \ln \tau_i\right)\right] - \left[\ln \tilde{s}_j^f - \left(\ln \tilde{\alpha}_j^f + \ln \tau_j\right)\right]$$

This expression is easier for test as well as for interpretation. Note that the term in the square bracket

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[1] HOV prediction is based on V_i-sV_w, here the $\tilde{s}_i^f$ compares whether composition of medium-skilled labour is close to world average (i.e. V_i and V_w). Since we use consumption share in world GDP as the "s" parameter in HOV, we should also taken into consideration of the trade balance. U.S. usually runs around 4% trade deficit, while trade is more or less balanced in and UK. So taken both the value of $\tilde{s}_{USA}^{MED}$ and trade balance into consideration, the "room for error" for measurement error and trade fluctuations is around 0~15 percentage points for the U.S. and 5 pts for U.K. Many other factors or other countries' $\tilde{s}_i^f$ deviates much more from 1; for example for low-skilled labour, $\tilde{s}_{USA}^{LOW}$ is only around 0.35, implying a quite low relative abundance for low-skilled labour in the U.S., and $\tilde{s}_{China}^{LOW}$ is around 3.

contains only the information from one country. It can be interpret as factor export propensity of a country $\theta_i^f = \ln \tilde{s}_i^f - (\ln \tilde{\alpha}_i^f + \ln \tau_i)$, which depends positively on its relative abundance of a factor ($\tilde{s}_i^f$), negatively on its preference for the that factor compared with world average ($\tilde{\alpha}_i^f = \alpha_i^f / \alpha_W^f$), and negatively on the trade deficit (τ_i). A trade-balanced country with the same factor abundance structure and preference as world average, all three components $\ln \tilde{s}_i^f$, $\ln \tilde{\alpha}_i^f$ and $\ln \tau_i$ would be zeros. In a pair of countries, the one with a higher θ_i^f is predicted to be the net exporter. We can also trace the explanatory power of these three components in predicting factor trade.

Figure 1 provides a rough overview that compares a country's factor export propensity θ_i^f with its actual position in net factor trade for 2007 (the results on bilateral version tests are similar across all years, so I choose 2007 since it is the latest year before the financial crisis. All bilateral tests in the paper are based on year 2007 unless specified. The results are quite similar for all years from 1995 to 2009, which are available upon request). The horizontal axis ranks each country according to their export propensity of a factor, from small to large; the country with the largest θ_i^f gets the value of 41 and the smallest gets 1. The vertical axis is the number of trade pairs in which a country is an net exporter; for example when a country is a net factor exporter to all its trade partners, it gets a value of 40 (there are 41 countries in the model, so each country belong to 40 pairs). This graph corresponds to a rank-order test: If the equation above perfectly predicts the trade behaviour, a country ranked Nth in its factor export propensity would be net exporter to N-1 countries that has a smaller export propensity. Therefore ideally the plot should be on the line y=x-1. Figure 1 shows that the dots do have a clear upwards trend. There are some variances on the graph for capital, but for three kinds of labour the observations are pretty close to a straight line, indicating a high prediction power for the export propensity index.

This figure reveals the importance of adjusting for trade balance in predicting net factor export. Many HOV literature in the past assumes balanced trade, while in reality trade balance is the exception rather than the rule. When a country runs trade surplus, it might be the net exporter of everything even if it has a disadvantage in some factors. For example, highly developed countries like the Netherlands and Luxembourg are supposed to have comparative advantage in skillness, but they show a high export propensity for almost all factors including low-skilled labour, and indeed they are net-exporters in the bilateral trade for most of factors. This is due to the their large and consistent positive trade balance: Netherlands' consumption to GDP ratio is around 0.9 which implies a strong trade surplus; for Luxembourg the trade surplus is even larger.

[INSERT FIGURE 1 ABOUT HERE]

More formally, I use a sign test to investigate the predicting power of factor endowment, preference and trade balance in explaining net factor trade between countries. It is similar as the sign test for HOV, but in a bilateral setup: I check the success rate of the export propensity in predicting the direction of actual net factor export bilaterally between countries. Table 4 reports the performance of this bilateral sign test.

[INSERT TABEL 4 ABOUT HERE]

The first column report the baseline sign test for 2007 where I compare the value of θ_i^f for two countries, to see whether the country with a larger θ_i^f is indeed the net exporter of *f* in the pair. The test shows considerable high fitness: It correctly predicts around 85% of the direction of net factor trade for three kinds of labour; for capital the fitness is a bit lower, but is still around 80%. Column (2) is the weighted sign test. Since each observation in bilateral test involves two countries, I use the geometric mean of their factor endowments as weight. The results of (1) and (2) are very similar. Column (3) pools all observations in 1995-2009, and shows no significant difference from the sign test of 2007. In Appendix table A.1, I also performed the weighted and unweighted bilateral test for all years from 1995 to 2009. In contrast with the standard HOV test, the predicting power for bilateral tests is stable for the whole period.

In column (4) to (6), I split the countries into two groups based on their income level. The motivation is that Heckscher-Ohlin motive of trade might be stronger for countries with very different factor abundance structure, as shown in Lai and Zhu (2007). Since I have four factors here, I choose to divide countries into two sets according to their per-capita income; an economy is "rich" if it has a real GDP per capita above $25,000 in 2007. Under this cut-off value, 22 economies are classified as "rich" and 19 as "poor". Column (6) shows that the fitness of three kinds of labour is the highest for Rich-Poor pairs, which confirms Lai and Zhu. But the fitness for pairs between two rich (or two poor) countries also remains as high as 80~85%. In column (7) I do the sign test for the subset of European countries (i.e. EU-EU pairs) which are geographically closely located and have relatively similar abundance structure, which gives also a similar high fitness.

Apart from the relative factor abundance, the factor export propensity θ_i^f also contains two "adjustment" terms: preference for factors and trade balance. It is interesting to see the relative importance of these two adjustments in improving the sign test. In column (8) to (10) I uses alternative measures for the export propensity. Column (8) corresponds to the sign test which predicts the direction of net factor trade using only the relative abundance (i.e. $\ln \tilde{s}_i^f$). The fitness for this "abundance only" specification reaches around 80% for low- and medium-skilled labour, which is already quite good. However, for high-skilled labour and capital, the differences in relative factor abundance only correctly predict 71% and 62% of the signs, which is not much better than tossing a coin. Column (9) adjust for preference differences but not trade balance (i.e. comparing $[\ln \tilde{s}_i^f - \ln \tilde{\alpha}_i^f]$ between two countries), and column (10) adjusts for trade balance but not preference (i.e. $[\ln \tilde{s}_i^f - \ln \tau_j]$). Result in (9) is even a bit worse than (8), while (10) has largely improved compared (9) or (8), but is still 3~5 percentage points lower than the baseline where both non-balanced trade and heterogeneous preference are controlled. This suggests that while the adjustments in both preference and unbalanced trade have influences in the predicting power of HOV, unbalanced trade plays a more important role.

Since the adjustment for trade balance generates a major improvement for the sign test, I perform a robustness check using alternative data for trade balance. Column (11) uses the total final use to GDP ratio from UN statistics instead of WIOD. The result shows that the fitness on high-skilled labour decreases by 4 percentage points compared with the baseline model, but there is no major change for the fitness on three other factors.

To sum up, in general the bilateral sign test on net factor shows quite high and consistent predicting power. The model did not reach that high predicting power as Davis and Weinstein (2001), but I did not make that complex adjustments as in those HOV analysis.

5. Testing Consumption Similarity in Factor Trade

Using the factor export data derived in section 3, it is possible to test the so-called "consumption similarity" directly. Trefler and Zhu (2010) show that consumption similarity in industrial output is equivalent as a locally-robust HOV prediction. While my test focuses on consumption similarity of factors, it is still interesting to see how good does the similarity holds; this test helps in evaluating the robustness of HOV predictions under alternative assumptions regarding consumption and technology.

Trefler and Zhu define consumption similarity as follows: C_{gji} represents a country *j*'s consumption of goods g produced by country i, and C_{gwi} is world total consumption of goods g by i. If a country j

consumes a share of cs_j in the world GDP, its consumption on good g by country i is given by $C_{gij} = cs_j C_{gwi}$; this equality holds for any i, j and g. Intuitively, it means that a country j consumes a share of cs_j of any kind of products that are available in the world. In this paper I am going to test whether consumption similarity holds for factors, i.e. whether we have $E_{ij}^f = cs_j V_i^f$. This condition corresponds to the factor export prediction in equation (6') where preference is assumed to be identical across countries. (i.e. $\alpha_j^f = \alpha^f = s_W^f$ for all j, so $E_{ij}^f = \tilde{s}_i^f \alpha_j^f \tau_j \frac{Y_i Y_j}{Y_W} = \frac{s_i^f}{s_W^f} \alpha^f \frac{Y_i Y_j}{Y_W} = \left(s_i^f Y_i\right)\left(\frac{Y_j}{Y_W}\right) = V_i^f cs_j$). Since the previous section already shows that the adjustment for heterogeneous preference does not raise much of the HOV sign predicting power, the homogeneous preference assumption in consumption similarity should be reasonable. If consumption similarity holds, a country j would use a fixed share of cs_j for any kinds of factors from any country. Say, if U.S. consumption is 20% of world total, and a country X has a abundance of high-skilled labour worths \$100, then the H-labour export from X to U.S. should be 100×20%=\$20.

Trefler and Zhu investigate different industries and find consumption similarity is mostly violated in four industries: agriculture, food, construction, and government services. They create a hypothetical dataset, in which they impose consumption similarity on these four sectors. Using Trefler (1995)'s "Missing Trade" measure, they show that HOV prediction of factor net export holds very well; missing trade is almost eliminated after controlling these industries. However, their test only provides indirect support for consumption similarity. They didn't make sensitivity analysis on technology or show the test result for multiple years, so the robustness of their HOV result is not granted. Moreover, the fitness of HOV does not necessarily imply consumption similarity. To see this, look at a perfect neo-classical world with two countries where HOV holds by definition. Since the capital abundant country will neither export any labour intensive product, nor import any capital-intensive good from its labour abundant trade partner, consumption similarity fails.

Using bilateral factor export data, I am going to perform direct tests on consumption similarity of factors, to see how well does it hold before and after the "problematic" industries being controlled. In case of perfect consumption similarity, $E_{ij}^f = cs_j V_i^f$ holds for any i, j, including the cases *i*=*j*. All three variables in the equality are observable: E_{ij}^f and V_i^f are actual data for factor export and endowment derived above (for *i*=*j*: E_{ii}^f is *i*'s consumption of its domestic factor f), and cs_j equals $c_j/\sum Y_i$, i.e. country *j*'s total final use divided by world GDP. Taking logarithm of factor trade prediction from consumption similarity gives $\ln E_{ij}^{f} = \ln cs_j + \ln A_i^{f}$, therefore I estimate the following equation:

$$\ln E_{ij}^{f} = \beta_0 + \beta_1 \ln A_i^{f} + \beta_2 \ln cs_j + \varepsilon_{ij}^{f}$$

Under strict consumption similarity, $\widehat{\beta_1}$ and $\widehat{\beta_2}$ should be close to unity, and $\widehat{\beta_0}$ close to zero.

If $\widehat{\beta_1}$ and $\widehat{\beta_2}$ are close to one while β_0 significantly negative, it indicates the existence of home bias and a weaker consumption similarity for traded factors. More specifically, if we perform a regression that excludes the cases when *i=j*, the magnitude of $\widehat{\beta_0}$ proxies the size of home bias. To see that, for simplicity I assume each country uses a share $(1-\xi)$ in their expenditure for non-tradable tasks[2] produced by domestic factor. The factor supply in country i for producing tradable tasks is ξA_i^{f} $(\xi < 1)$; tradable tasks can also be consumed domestically. If a country's consumption of tradable tasks is a share cs_j^{tr} of world total tradables, under consumption similarity we would have $E_{ij}^{f} = cs_j^{tr}(\xi A_i^{f})$ for $i \neq j$ and $E_{ii}^{f} = NonTradables + cs_i^{tr}(\xi A_i^{f})$ for the consumption of domestic goods. Since cs_j^{tr} and cs_j should approximitely equal, if we use the same the regression above for the subsample where $i \neq j$, a more negative $\widehat{\beta_0}$ implies smaller ξ, hence a larger home bias.

The equations of the export of four different factors (*f*=L, M, H, and K) are estimated simultaneously using a seemingly unrelated regression, to control for the correlations of trade in different factors within each pair of countries. The results for 2007[3] are reported in Table 5-I. The specifications in this table include also domestic factor usage (i.e. the cases *i=j*); (1) is a unrestricted seemingly unrelated regression, while (2) assumes the degree of home bias is the same for different factors, so β_0 is restricted to be identical across equations. Comparing (1) and (2), there are no major differences. The results support for a weaker consumption similarity in traded factors. $\hat{\beta}_2$ is estimated to be around 0.75, and more importantly, $\hat{\beta}_1$ is very close to one, which means country *j*'s the final use of factors from country i is indeed proportionally linked with *i*'s total factor abundance. However, strict consumption similarity does not hold and there is a large home bias: $\hat{\beta}_0$ is around -2, which is far from zero. Also it seems that the home bias is a bit higher for high-skilled labour as represented by its most negative $\hat{\beta}_0$, while the difference between other factors is small.

[INSERT TABLE 5-I AND 5-II ABOUT HERE]

[2] Including some tasks that are in principle tradable, but exclusively for domestic consumption. For example, tasks like advertisement design is easily transferable via internet. However, if it involves domestic language and/or some legal/custom related expressions, in many cases the task can only be done by domestic specialists and the output is only useful for the domestic country.

[3] The results for all other years from 95 to 09 are available on request. $\widehat{\beta_1}$ and $\widehat{\beta_1}$ are similar across years, while the dynamics of $\widehat{\beta_0}$ will be discussed later.

Given the existence for a considerable home bias, I exclude the cases of *i=j* in Table 5-II and focus on traded factors. Column (3) replicates column (1) but exclude the observations where *i=j*. interestingly, the estimates in (3) show no major changes from (1), but the model fitness improves significantly as indicated by the increase of R^2 from around 0.68 to 0.8. It shows that a considerable part of the predicting error in (1) originates from the error terms where *i=j*, which further confirmed the existence of large home bias. In specification (4) I bring in the logarithm distance between the importer and exporter to control for trade costs. Similar as many previous researches on goods trade, distance shows significantly negative effects on factor trade. The inclusion of distance further improves the model fitness; the adjusted R^2 now reaches around 0.9. In addition, $\hat{\beta}_2$ now becomes much closer to unity. And as stated in the model part and the appendix, with trade cost the exact consumption similarity may not hold for all countries, but for countries that closely located with each other the consumption similarity remains. Therefore in column (5) I replicate the regression in (4) using the country pairs within Europe. Comparing the coefficients in (5) with (4) the impact of distance on factor trade becomes larger, and $\hat{\beta}_2$ coefficient becomes somewhat lower; consumption similarity still seems to hold quite well.

These regression results confirm the weaker version of consumption similarity for traded factors. To illustrate this more intuitively, Figure 2 plots the imported/domestic factor final usage by Netherlands and China. The marks indicate the country of origin of the factors. The horizontal axis represents the abundance of factors of each country, and the vertical axis represents the factors that originate from a country and finally being used by China or Netherlands (i.e. the factor export from that country to China or Netherlands), both in logarithms.

[INSERT FIGURE 2 ABOUT HERE]

If consumption similarity holds, the marks should locate linearly; this is indeed the case. The straight lines represent the predicted values from regression (3) in Table 5-II, which fit the traded factor usages very well. There are some derivations from the fitted line, for example China uses more-than-predicted factors from Taiwan Area and South Korea, and the Netherlands “import too much” from Belgium. These fluctuations are clearly due to the geographical proximity, and the derivations are not that large. Therefore, consumption similarity of traded factors is supported. And when we look at the usage of domestic factors, it is significantly above the trend line by a large margin, showing a considerable home bias.

Trefler and Zhu (2010) shows that four industries has the largest home bias, namely agriculture, food, construction, and government services. It is nature to investigate whether strict consumption similarity is restored after controlling for these sectors. Trefler and Zhu impose consumption similarity on these sectors and generate a hypothetical data for the check. Here I use a slightly different method; I exclude the these sectors and replicate the regression in Table 5-I and II, the results are reported in Table 6-I and II. . I only exclude the factors being directly used by these sectors but not the factors embedded in their intermediate inputs, since the inputs should be, in principle, tradable. For example, government uses a lot of computers in their administration, but computer is a good example of highly traded goods. The results are presented in Tables 5-I and 5-II. Strikingly, I do not find much difference between Table 4 and 5. If home bias is largely due to these four industries, the $\hat{\beta}_0$ coefficients in table 5 should become much closer to zero. However, the magnitude of $\hat{\beta}_0$ decreases a bit, but there is only little change compared with Table 4. As a further robustness check, in the appendix Table A.2 I also present the results where all factors in the final products of these four industries are also dropped, i.e. I exclude factors embedded in all upper-stream inputs of these sectors; I still get a similar result as Table 5.

[INSERT TABLE 6-I AND 6-II ABOUT HERE]

Table 6 therefore shows home bias is also large for the rest of industries, which is different from Trefler and Zhu (2010): There are two potential reasons for the difference. First, Trefler (1995)'s missing trade indicator is more about HOV prediction itself, instead of consumption similarity. Second, imposing consumption similarity on these sectors may systemically bias the result in favour of the existence of consumption similarity: these four sectors have considerable weight in countries' consumption basket. For example in 2007 in the U.S., the total value of factors used in these sectors consists of about 22% of national consumption; this ratio is higher in developing countries like China, which amounts to around 27%. So by construction, ¼ of the fitness is granted when one generates the hypothetical data. Excluding the factors used by these industries should therefore give a sharper result.

I also investigate whether the size of home bias changes from 1995 to 2009. I replicate regression (2) in Table 5-I for different years, and plot the estimates of $\hat{\beta}_0$ in Figure 3; two dashed lines stands for 95% confidence interval. It shows a gradual upward trend in $\hat{\beta}_0$, which implies a decreasing home bias. By comparing the $\hat{\beta}_0$ beginning and end periods, we see that the decrease in home bias is statistically significant. This is inline with the increasing progress of globalisation. In appendix Table A.2, I replicate the analysis but exclude the four "problematic" sectors, which shows a similar trend.

[INSERT FIGURE 3 ABOUT HERE]

6. Investigate the Motives behind Factor Trade

Bilateral factor trade data also helps in evaluating the motives behind international trade. In the recent literature, there are mainly two streams of motives in modelling trade. One stream follows monopolistic competition and imperfect substitution (i.e. love-for-variety), as in Krugman (1979) and Ethier (1982); the model part of this paper also assumes this motive. Another stream assumes factor price non-equalization and emphases on cost-saving, as in Helpman (1984). The cost saving motive follows the thoughts in Adam Smith and Ricardian Trade, but trade is allowed at factor level instead of goods. Helpman (1984) argues that while factor prices tend to converge under international trade, price does not necessarily equalize. So the direction of trade is determined by the factor price differences between domestic and foreign countries; a country exports the factors that are relatively expensive abroad, and import the factors that are cheaper in the international market than domestic market.

It is interesting to explore which motive is more relevant in trade. Based on the fitness in the consumption similarity test above, the love-for-variety effect should be more important. If cost saving is the major motive for trade, then the import of a country should concentrate on several countries where the effective factor cost is lowest (factor price adjust for productivity, plus transport cost into the importing country), and similarly the export should be concentrated on the market where the country can get highest effective return. However, this is not observed; consumption similarity holds quite well for the traded factors: the factor import seems to be evenly spread across different countries in proportion to the factor endowment of the exporter, and similar for factor export. It is quite unlikely to be the outcome of cost-minimizing trade.

The empirical strategy frequently used in testing the cost-saving motive is introduced by Helpman (1984) and extended by Choi and Krishna (2004) and Lai and Zhu (2007). They compare the actual cost of the bundle of imported factors embedded in imported tasks/products, with the hypothetical cost if these tasks/products are produced by domestic factors. When the cost-saving motive holds, the actual cost should be cheaper than the hypothetical one. Due to the limitation in data, this paper is unable to test the cost saving motive in the same: for the model when effective factor price equalization is assumed *not* to hold, as emphasized in Lai and Zhu (2007) we need to adjust for efficiency differences for different factors across countries. For my analysis, it requires the efficiency scores for capital and three kinds of different skilled labour respectively for each country; the data are not available. Therefore, I build a test based on the implication of cost-saving factor trade, to investigate whether the share of exported factor as a percentage of total endowment is higher for the factors with comparative advantage.

Intuitively, in the extreme case that factors and tasks are perfectly homogeneous, a country will not export the factor for which it has a comparative disadvantage; if factor price does not equalize, the domestic price of the disadvantageous factor is higher than the international level. When the love-for-variety and cost-saving motives co-exist, there will be factor export for comparative disadvantageous factors, but the share of exported factor in total factor abundance should be higher for the factors with comparative advantage. An illustrative case is already presented in the last part of section 2. Since I have factor export data for multiple factors, I can test the hypothesis concerning cost-saving motive of factor trade, controlling for country fixed effect and factor fixed effect. I estimate namely the following regression:

$$es_i^f = \beta_1 \tilde{s}_i^f + \beta_i + \beta^f + \varepsilon_{i,f}$$

Here $es_i^f = \left(\sum_{j \neq i} E_{ij}\right)/V_i^f$, i.e. the value of factor export divided by the total worth of the endowment in factor *f*. $\tilde{s}_i^f$ is the above defined relative factor endowment indicator which captures the country's comparative advantage. If the hypothesis concerning cost-saving factor trade holds, β_1 should be significantly positive. β_i controls for the country-fixed effect in factor export; when a country is more open to trade it would export a larger proportion of all factors. β^f controls for factor fixed effect. As discussed in offshoring literature, routine tasks are the most offshorable and are usually done by medium-skilled labour (e.g. Autor et al 2006), so I expect that on average each country export a higher share of its medium-skilled labour.

I do the test for 2007 and the result is in Table 7. In the first column, I do a simple OLS which excludes all fixed effects, while in (2) I introduce country fixed effect and further in (3) the factor fixed effect. The results indicate that factor fixed effect and country fixed effect explains the majority of the variances in factor content trade differences, while the comparative advantage indicator is insignificant in all three cases. For the factor fixed effect, I use low-skilled labour as benchmark. Column (3) shows that medium-skilled labour has on average the highest export share among all factors, which confirms the highest offshorability of medium-skilled tasks. High-skilled labour has the lowest export share, while low-skilled labour and capital goods are in the middle and their difference in export share is insignificant.

For robustness check, in column (4) I replace the dependent variable and the comparative advantage index by their logarithms, i.e. $\ln es_i^f$ and $\ln \tilde{s}_i^f$. And in column (5) I replace the comparative advantage indicator by a dummy variable representing whether the country has a comparative advantage in a factor (i.e. whether $\tilde{s}_i^f$ is larger than one). The coefficient on comparative advantage stays highly insignificant. Therefore, factor export share seems to be independent of a country's comparative advantage, and cost saving should not be the major motive behind factor trade.

7. Concluding Remarks

In this paper I derive a simple and tractable trade-in-task model which uses factor endowment to predict factor trade bilaterally between different countries. I derive a measure for bilateral factor trade for 1995 to 2009 that properly controls for traded intermediate inputs, based on multi-regional input-output database in the WIOD. The new measure of factor trade covers four factors, and is in line with the criteria of Trefler and Zhu (2010) to be both HOV-relevant and economic meaningful. This measure differs significantly from "traditional" measure of factor export based on domestic IO tables and gross export of each country, and is expect to provide a more accurate and comprehensive picture of trade in factor content.

Using the factor trade data, I first make a standard HOV sign test and find it is not robust over time. In contrast, the bilateral sign test shows consistent and robust results that the differences in factor endowment and trade surplus/deficit have strong power in predicting the direction of net factor export in each pair of countries. I test the so-called consumption similarity conditions for factors, and find a strong home bias that countries consumes much more domestic factors than predicted; but for traded factors, consumption similarity holds quite well. Lastly, I also test whether the share of factor being exported is related with a country's comparative advantage but find no evidence, suggesting that cost saving should not be the driven motive for international trade in factor content.

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Tables and Figures

Table 1. Illustration of Bilateral Factor Export under Different Assumptions

Type of Trade		(1) Perfect Neo-classical Trade	(2) Free Trade of Homogeneous Tasks	(3) Love-For-Variety Type of Models
L Export	*i->j*	1	0.5	2.5
	j->i	0.5	-	2
K Export	*i->j*	0.5	-	2
	j->i	1	0.5	2.5
Net Export from *i* to *j*	*L*	1 - 0.5 = +0.5	+0.5	2.5 - 2 = +0.5
	K	0.5 – 1 = -0.5	-0.5	2 – 2.5 = -0.5
HOV prediction for *i*		V_i - (1/2)V_W = (5,4) - (1/2)*(9,9) = (5,4) - (4.5,4.5) = (+0.5, -0.5)		

Initial abundance: Country i: 5L, 4K. Country j: 4L, 5K. The reported numbers are derived from the production and utility function as described in the main text.

Table 2. Comparison between Different Measures of Factor Export

The numbers represent the ratio of two measures: (a) Implied factor export embedded in final goods exported from different countries into the U.S., using Domestic IO tables, divided by (b) the more proper measure of factor export described in this paper, based on multi-regional IO tables.

Country	Factor L	M	H	K	Country	Factor L	M	H	K
Luxembourg	0.320	0.256	0.174	0.176	Portugal	0.675	0.647	0.632	0.649
Latvia	0.298	0.297	0.325	0.293	Turkey	0.700	0.649	0.638	0.651
Lithuania	0.403	0.387	0.360	0.378	Netherlands	0.674	0.689	0.733	0.586
Estonia	0.414	0.389	0.366	0.380	Cyprus	0.621	0.669	0.677	0.718
Russia	0.422	0.405	0.408	0.417	Korea	0.710	0.696	0.667	0.646
Slovenia	0.424	0.410	0.410	0.427	Denmark	0.708	0.713	0.767	0.561
Bulgaria	0.463	0.412	0.428	0.388	Taiwan	0.706	0.707	0.745	0.669
Malta	0.504	0.429	0.360	0.541	Germany	0.711	0.716	0.732	0.719
Czech	0.446	0.454	0.537	0.430	Sweden	0.716	0.726	0.763	0.718
Poland	0.459	0.444	0.515	0.488	France	0.738	0.736	0.764	0.744
Romania	0.522	0.511	0.494	0.425	Italy	0.750	0.754	0.784	0.738
Slovakia	0.480	0.493	0.571	0.488	Japan	0.775	0.756	0.741	0.765
Spain	0.548	0.525	0.504	0.546	U.K.	0.778	0.771	0.773	0.768
Hungary	0.549	0.571	0.675	0.594	Brazil	0.808	0.818	0.814	0.816
Belgium	0.580	0.596	0.647	0.569	India	0.883	0.887	0.890	0.853
Finland	0.618	0.623	0.629	0.616	Ireland	0.835	0.866	0.894	0.919
Austria	0.629	0.624	0.641	0.637	China	0.900	0.890	0.898	0.889
Greece	0.706	0.650	0.716	0.487	RestOfWorld	0.906	0.919	0.948	0.903
Indonesia	0.685	0.656	0.633	0.591	Mexico	1.057	1.064	1.070	1.080
Australia	0.682	0.676	0.759	0.461	Canada	1.065	1.071	1.072	1.073

Table 3. HOV Sign Test

	Unweighted					Weighted				
Year	L	M	H	K	ALL	L	M	H	K	All
95	87.8	87.8	90.2	90.2	89.0	96.0	95.0	94.7	95.4	95.3
96	95.1	90.2	87.8	87.8	90.2	98.9	92.0	95.4	94.9	94.7
97	92.7	82.9	87.8	87.8	87.8	75.6	86.0	96.3	96.0	90.6
98	90.2	87.8	85.4	85.4	87.2	98.0	89.6	96.8	96.3	94.7
99	90.2	92.7	80.5	80.5	86.0	93.4	92.7	94.8	95.2	94.2
00	90.2	85.4	87.8	87.8	87.8	93.5	56.3	82.6	81.8	76.0
01	90.2	87.8	85.4	85.4	87.2	93.3	53.6	85.3	83.3	76.4
02	90.2	87.8	92.7	92.7	90.9	93.1	53.3	98.3	97.3	84.8
03	90.2	82.9	87.8	87.8	87.2	93.4	50.2	94.2	93.3	81.7
04	90.2	85.4	82.9	82.9	85.4	93.1	55.4	92.8	92.0	82.4
05	87.8	85.4	85.4	85.4	86.0	89.8	55.4	92.8	92.0	82.3
06	82.9	95.1	85.4	85.4	87.2	89.0	65.7	93.7	93.1	85.8
07	85.4	80.5	90.2	90.2	86.6	87.1	55.3	94.7	95.1	84.2
08	85.4	87.8	87.8	87.8	87.2	85.1	64.7	97.2	96.9	87.8
09	87.8	92.7	92.7	92.7	91.5	86.2	99.4	97.7	97.6	96.9

L, M, H, K correspond to low-, medium-, high-skilled labour and capital. There are quite large fluctuations in the weighted HOV test, because sometimes big economies, like U.S. and U.K are among the countries who failed in HOV sign test.

Table 4: The Sign Test on the Direction of Bilateral Net Factor Export (2007)

(% Fit)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	baseline	Weighted	95-09	R-R	P-P	R-P	EU	A	A+P	A+TB	UNdata
L	87.2	87.6	85.4	87.4	86.5	87.6	87.7	82.1	80.9	84.0	86.7
M	85.0	84.5	84.4	84.8	84.8	85.4	88.3	78.5	77.7	83.8	84.9
H	84.4	85.8	83.7	80.9	81.3	87.8	84.6	71.2	68.3	78.8	80.3
K	79.5	80.1	77.6	81.7	82.5	77.3	80.3	62.2	63.2	74.3	78.7

Table 5. Analysing Consumption Similarity in Factor Content:

Table 5 – I Regression for Bilateral Factor Export, Include Domestic Factor Use

	(1) Whole Sample Unrestricted				(2) Whole Sample with Constraint			
	L	M	H	K	L	M	H	K
β_1	0.977	0.98	0.994	0.983	0.978	0.979	0.963	0.987
	0.002	0.002	0.004	0.004	0.002	0.002	0.003	0.002
β_2	0.763	0.764	0.761	0.768	0.771	0.774	0.785	0.776
	0.019	0.019	0.02	0.019	0.019	0.019	0.02	0.019
ln(dist)								
Cons. (β_0)	-2.02	-2.06	-2.47	-1.99		-1.98		
	0.105	0.105	0.113	0.108		0.104		
Obs.	1681	1681	1681	1681	1681	1681	1681	1681
Adj-R^2	0.694	0.693	0.668	0.684	0.694	0.693	0.672	0.684

Table 5 – II Regression for Bilateral Factor Export, Exclude Domestic Factor Use

	(3) Exclude the Use of Domestic Factor				(4) Control For Distance				(5) Europe only			
	L	M	H	K	L	M	H	K	L	M	H	K
β_1	0.976	0.977	0.987	0.979	0.979	0.98	0.993	0.977	0.985	0.984	1.004	0.968
	0.002	0.002	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.006	0.006
β_2	0.78	0.781	0.779	0.785	0.921	0.918	0.916	0.91	0.816	0.813	0.811	0.817
	0.015	0.015	0.015	0.014	0.01	0.01	0.01	0.01	0.014	0.014	0.014	0.014
ln(dist)					-0.799	-0.777	-0.78	-0.705	-1.099	-1.076	-1.053	-1.026
					0.016	0.016	0.016	0.017	0.038	0.037	0.038	0.038
Cons. (β_0)	-2.06	-2.08	-2.46	-1.99	5.09	4.88	4.5	4.38	6.541	6.334	5.717	6.197
	0.082	0.081	0.088	0.086	0.152	0.151	0.154	0.159	0.276	0.278	0.287	0.288
Obs.	1640	1640	1640	1640	1640	1640	1640	1640	702	702	702	702
Adj-R^2	0.802	0.806	0.796	0.802	0.922	0.921	0.917	0.907	0.935	0.936	0.929	0.922

Table 6. Analysing Consumption Similarity in Factor Content (Exclude Value-added in Agriculture, Food, Construction and Government Services Sectors)

Table 6 – I Regression for Bilateral Factor Export, Include Domestic Factor Use

	(1) Whole Sample Unrestricted				(2) Whole Sample with Constraint			
	L	M	H	K	L	M	H	K
β_1	0.987	0.998	1.023	1.002	0.991	0.987	0.97	0.985
	0.002	0.002	0.004	0.004	0.002	0.002	0.002	0.002
β_2	0.776	0.773	0.77	0.77	0.784	0.79	0.806	0.792
	0.018	0.019	0.019	0.019	0.018	0.019	0.019	0.018
ln(dist)		.						
Cons. (β_0)	-1.81	-2.01	-2.57	-2.11	-1.797			
	0.099	0.1	0.109	0.108	0.099			
Obs.	1681	1681	1681	1681	1681	1681	1681	1681
Adj-R^2	0.725	0.713	0.686	0.689	0.724	0.714	0.692	0.692

Table 6 – II Regression for Bilateral Factor Export, Exclude Domestic Factor Use

	(3) Exclude the Use of Domestic Factor				(4) Control For Distance				(5) Europe Only			
	L	M	H	K	L	M	H	K	L	M	H	K
β_1	0.986	0.996	1.015	0.996	0.988	0.997	1.017	0.994	0.988	0.998	1.018	0.980
	0.002	0.002	0.004	0.004	0.002	0.002	0.004	0.004	0.003	0.004	0.005	0.006
β_2	0.792	0.791	0.788	0.79	0.924	0.921	0.918	0.91	0.823	0.816	0.812	0.814
	0.014	0.014	0.014	0.014	0.009	0.009	0.01	0.01	0.014	0.014	0.014	0.014
ln(dist)					-0.764	-0.756	-0.75	-0.697	-1.031	-1.014	-1.018	-1.003
					0.015	0.015	0.016	0.017	0.037	0.038	0.038	0.038
Cons. (β_0)	-1.84	-2.03	-2.54	-2.08	4.99	4.74	4.17	4.2	6.28	5.93	5.45	5.95
	0.077	0.078	0.083	0.086	0.145	0.147	0.151	0.158	0.275	0.280	0.288	0.288
Obs.	1640	1640	1640	1640	1640	1640	1640	1640	702	702	702	702
Adj-R^2	0.821	0.817	0.807	0.804	0.929	0.926	0.920	0.907	0.938	0.935	0.928	0.921

Table 7. Regression on the Share of Factor Export

	(1)	(2)	(3)	(4)	(5)
Comparative	-0.0050	0.0044	-0.0005	0.0006	0.0075
advantage	0.0169	0.0078	0.0058	0.0203	0.0065
M			0.0145	0.0508	0.0163
			0.0086*	0.0300*	0.0086*
H			-0.0694	-0.2914	-0.0687
			0.0086***	0.0300***	0.0085***
K			-0.0105	-0.0306	-0.0100
			0.0086	0.03	0.0084
R^2	0.0006	0.7975	0.8930	0.9159	0.8942
Obs.	164	164	164	164	164

Notes: Significance level: *: 0.1, **: 0.01, ***: 0.001. Dependent Variable: (1) (2) (3) and (5): Factor export as share of total factor abundance; (4) is logarithm of this variable. M, H, K stand for the fixed effects of medium-, high-skilled labour and capital; low-skilled labour acts as benchmark. Regressions (2) to (5) include country fixed effect. Coefficients for constant term and the country fixed effects are omitted.

Figure 1. Rank Order Plot:
Factor Export Propensity and the Position as a Net Factor Export in Bilateral Trade

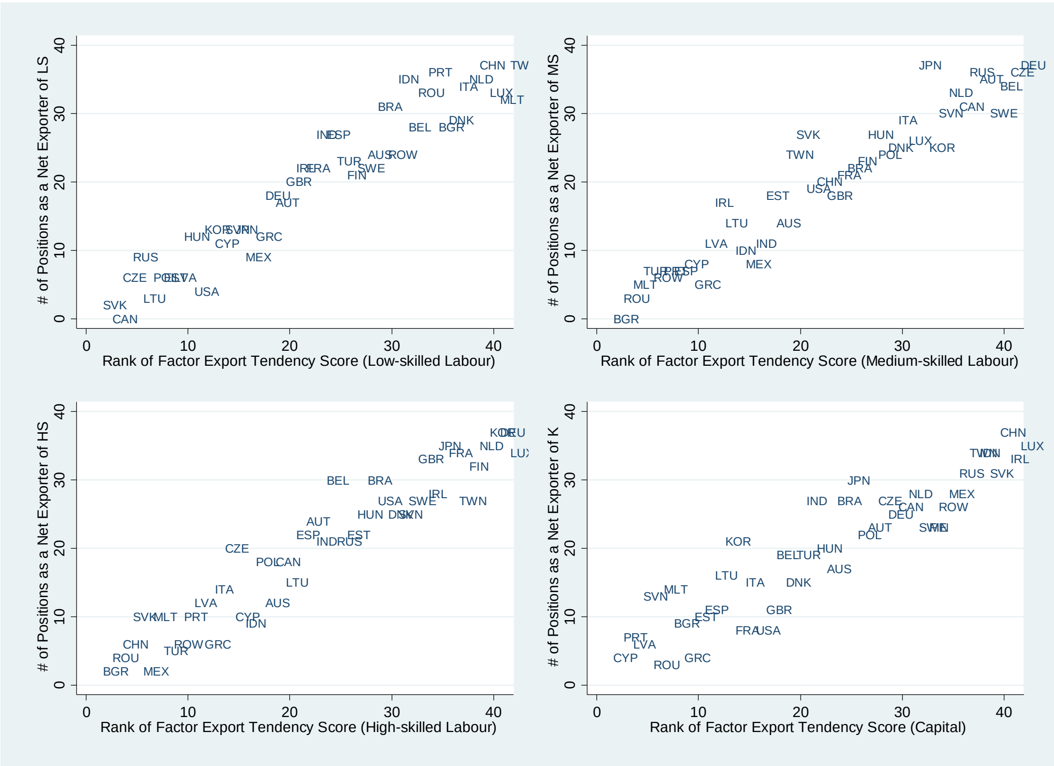


Figure 2: Domestic and Imported Factor Usage By China and the Netherlands

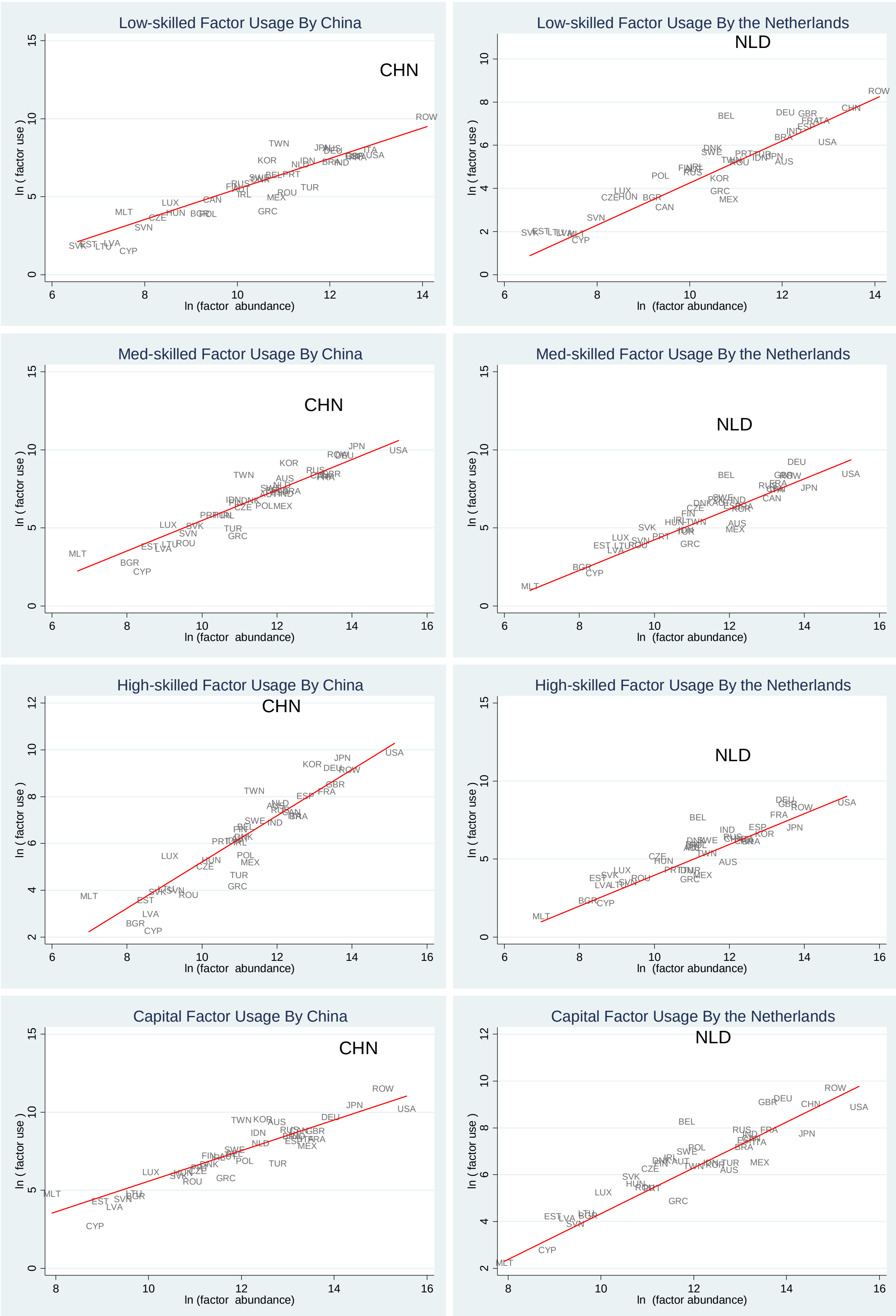
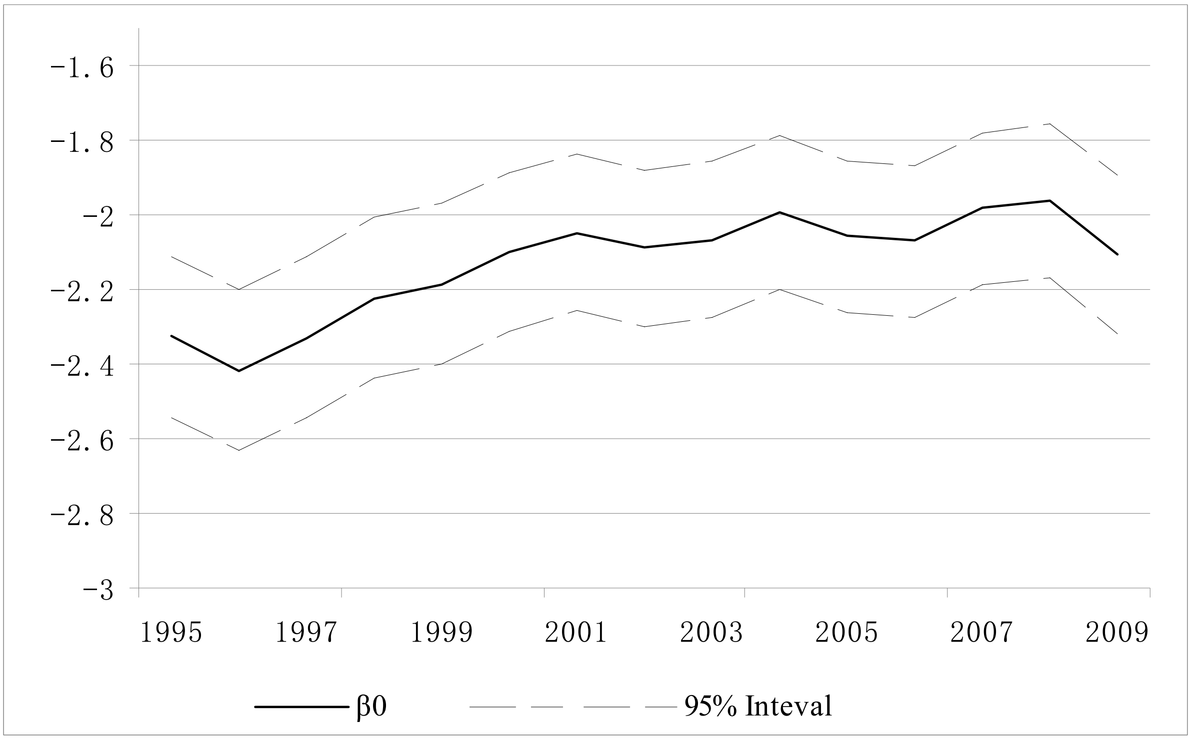


Figure 3. Changes of Home Bias (β_0) from 1995 to 2009



Appendix

Table A. 1: Fitness (%) of Bilateral Factor Content Trade Sign Test, 1995 to 2009

	Unweighted				Weighted			
year	L	M	H	K	L	M	H	K
1995	88.5	83.2	83.3	78.8	88.6	82.8	86.0	77.2
1996	86.6	83.9	83.0	77.3	86.3	83.6	83.8	75.6
1997	86.6	81.5	81.6	74.3	85.2	81.2	85.0	75.3
1998	84.8	85.1	83.4	77.7	84.5	84.8	87.3	74.3
1999	84.4	83.4	84.0	76.8	83.4	82.4	89.7	80.1
2000	84.4	85.6	82.9	76.7	83.5	86.4	85.9	83.7
2001	83.8	84.1	83.7	77.6	83.7	83.1	87.1	81.2
2002	84.9	86.1	84.5	76.8	83.5	86.4	90.8	81.5
2003	84.0	85.2	84.3	77.0	82.2	84.8	89.2	80.3
2004	84.4	84.8	83.9	78.3	81.9	84.6	89.5	82.7
2005	84.9	84.1	85.2	79.4	83.4	85.0	91.3	82.7
2006	86.2	85.1	84.5	78.3	85.6	85.5	90.2	80.9
2007	87.2	85.0	84.4	79.5	87.6	84.5	85.8	80.1
2008	85.1	85.4	83.7	78.3	85.7	85.4	87.0	79.1
2009	85.6	84.0	82.9	77.6	86.9	84.5	85.8	80.3

(Replication of Specification (1) and (2) in Table 4, for multiple years.)

Table A.2. Analysing Consumption Similarity in Factor Content (Exclude Value-added and all upper-stream intermediate input in Agriculture, Food, Construction and Government Services Sectors)

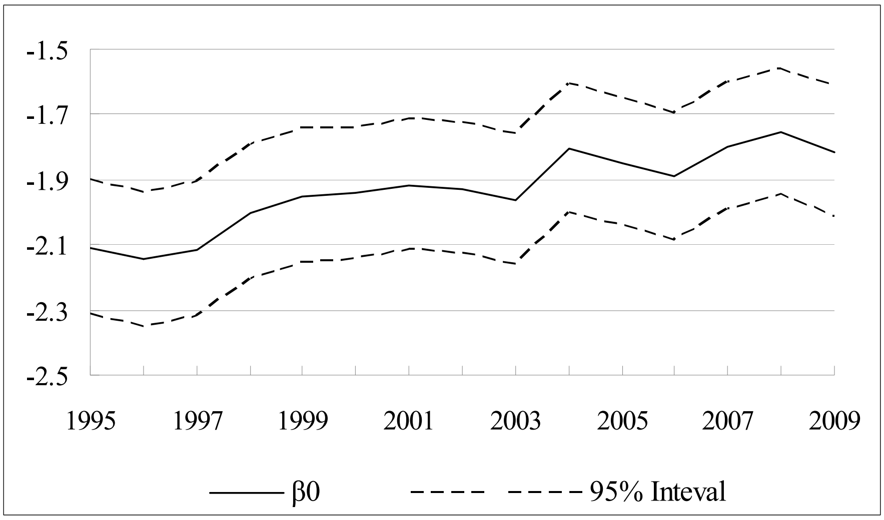
Table A.2 - I Regression for Bilateral Factor Export, Include Domestic Factor Use

	(1) Whole Sample Unrestricted				(2) Whole Sample with Constraint			
	L	M	H	K	L	M	H	K
β_1	0.989	0.998	1.023	1.003	0.992	0.986	0.967	0.983
	0.002	0.002	0.004	0.004	0.002	0.002	0.003	0.002
β_2	0.780	0.778	0.775	0.777	0.792	0.798	0.816	0.800
	0.018	0.019	0.019	0.019	0.018	0.019	0.019	0.019
ln(dist)								
Cons. (β_0)	-1.844	-2.039	-2.639	-2.161	-1.811			
	0.099	0.101	0.110	0.109	0.099			
Obs.	1681	1681	1681	1681	1681	1681	1681	1681
Adj-R^2	0.727	0.714	0.686	0.689	0.727	0.716	0.692	0.692

Table A.2 - II Regression for Bilateral Factor Export, Exclude Domestic Factor Use

	(3) Exclude the Use of Domestic Factor				(4) Control For Distance				(5) Europe Only			
	L	M	H	K	L	M	H	K	L	M	H	K
β_1	0.987	0.994	1.014	0.996	0.990	0.996	1.017	0.993	0.980	0.991	1.013	0.973
	0.002	0.002	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.006	0.006
β_2	0.797	0.796	0.794	0.795	0.920	0.918	0.916	0.907	0.828	0.822	0.821	0.822
	0.014	0.014	0.014	0.014	0.009	0.010	0.010	0.010	0.014	0.014	0.014	0.014
ln(dist)					-0.738	-0.735	-0.730	-0.673	-1.036	-1.020	-1.028	-1.003
					0.016	0.016	0.016	0.017	0.037	0.038	0.038	0.039
Cons. (β_0)	-1.877	-2.053	-2.599	-2.136	4.702	4.507	3.904	3.922	6.341	6.000	5.496	5.960
	0.077	0.078	0.083	0.087	0.148	0.149	0.154	0.163	0.273	0.279	0.287	0.291
Obs.	1640	1640	1640	1640	1640	1640	1640	1640	702	702	702	702
Adj-R^2	0.826	0.821	0.812	0.806	0.926	0.923	0.917	0.901	0.939	0.937	0.930	0.922

Changes of Home Bias (*β₀*) from 1995 to 2009 (Based on the Regression A.2 – I (2), Exclude Value-added and all upper-stream intermediate input in Agriculture, Food, Construction and Government Services Sectors)



The Derivation of the factor content trade with trade cost

The model with trade cost is similar as Anderson (1979), but I allow the trade under task level. I model trade cost as iceberg type. The trade cost from *i* to *j* is defined as $t_{ij} \geq 1$, i.e. in order to receive one unit of task in *j*, country *i* should ship t_{ij} units. So $t_{ij} = 1$ indicates zero trade cost. The existence of trade cost does not affect the optimal size of firm q_*^f (i.e. equation 4); it is dependent on the production function of tasks and the elasticity of substitution that are not affected by trade cost. So the model with trade cost is the same as the model without trade cost, till equation (5).

With trade cost, in general factor price equalisation does not hold. But the firms within a country are symmetric, so I denote the domestic output price for the type-*f* task of country *i* using p_i^f (the factor price in one country is normalized to one). The effective price a country *j* pays to receive one unit of task *f* from country *i* is the domestic price adjusted for trade cost, i.e. $p_{ij}^f = p_i^f t_{ij}$.

In the Armington demand structure, on the upper level nothing changes: each country spends a share of α^f of their expenditure on factor *f* (type-*f* tasks). On the lower stage, i.e. for

$$Q_i^f = \left(\sum_a \left(q_{a,i}^f\right)^{\rho^f}\right)^{\frac{1}{\rho^f}}$$

Country would make optimal choice concerning how much task it buys from each country. To have consistent notations, I investigate the task demand by county j, so I investigate $Q_j^f = \left(\sum_a \left(q_{a,j}^f\right)^{\rho^f}\right)^{\frac{1}{\rho^f}}$.

The marginal effect of an incremental variety-*a* task *f* is:

$$\frac{\partial Q_j^f}{\partial q_{a,j}^f} = \left(\sum\nolimits_a \left(q_{a,j}^f\right)^{\rho^f}\right)^{\frac{1}{\rho^f}-1} \left(q_{a,j}^f\right)^{\rho^f-1} = \left(\frac{q_{a,j}^f}{Q_j^f}\right)^{\rho^f-1}$$

Under optimal choice, for two variety *a* from country *i* and variety *b* from country *k*, we have $\frac{\partial Q_j^f}{\partial q_{(a\in i),j}^f} \Big/ \frac{\partial Q_j^f}{\partial q_{(b\in k),j}^f} = p_{ij}^f / p_{kj}^f$. This implies

$$\left(\frac{q_{(a\in i),j}^f}{q_{(b\in k),j}^f}\right)^{\rho^f-1} = \frac{p_{ij}^f}{p_{kj}^f} \quad \rightarrow \quad \frac{p_{ij}^f q_{(a\in i),j}^f}{p_{kj}^f q_{(b\in k),j}^f} = \left(\frac{p_{ij}^f}{p_{kj}^f}\right)^{-\frac{\rho^f}{1-\rho^f}}$$

Country i and k has N_i^f and N_k^f type-f firms, so the ratio of factor *f* export from *i* to *j* and from *k* to *j* is:

$$\frac{E_{ij}^f}{E_{kj}^f} = \frac{N_i^f p_{ij}^f q_{(a\in i),j}^f}{N_k^f p_{kj}^f q_{(b\in k),j}^f} = \frac{N_i^f}{N_k^f}\left(\frac{p_{ij}^f}{p_{kj}^f}\right)^{-\frac{\rho^f}{1-\rho^f}} = \frac{N_i^f}{N_k^f}\left(\frac{p_i^f}{p_k^f}\right)^{-\frac{\rho^f}{1-\rho^f}}\left(\frac{t_{ij}}{t_{kj}}\right)^{-\frac{\rho^f}{1-\rho^f}}$$

For each country i, the total imports (and domestic use) of factor *f* equals its expenditure on *f*. Since the ratio of factor export from each country is obtained above, we have:

$$\sum_i E_{ij}^f = c_j^f \sum_i \left(N_i^f \left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}}\right) = \alpha^f t b_j Y_j$$

$$c_j^f = \frac{\alpha^f t b_j Y_j}{\sum_i \left(N_i^f \left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}}\right)}$$

Here c_j^f is a scaling parameter for *f*, *j* which makes sure that total factor use equals total expenditure.

So we have the expression for E_{ij}^f:

$$E_{ij}^f = c_j^f N_i^f \left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}} = \frac{\alpha^f t b_j Y_j N_i^f \left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}}}{\sum_i \left(N_i^f \left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}}\right)}$$

$$= \left[\left(\alpha^f t b_j\right)\left(\frac{N_i^f p_i^f q^{*f}}{Y_i}\right) Y_i Y_j\right]\left[t_{ij}^{-\frac{\rho^f}{1-\rho^f}} \left(p_i^f\right)^{-\frac{1}{1-\rho^f}}\right]\left(\varrho_i^f\right)^{-1}$$

$$= s_i^f \alpha^f t b_j Y_i Y_j \left[t_{ij}^{-\frac{\rho^f}{1-\rho^f}} \left(p_i^f\right)^{-\frac{1}{1-\rho^f}} \right] \left(\varrho_i^f\right)^{-1}$$

Here $\varrho_i^f = \sum_i \left(N_i^f \left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}} \right)$, can be viewed as the supply of varieties from each country (N_i^f) weighted by the cost to reaching country *j* ($\left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}}$). The inverse of ϱ_i^f captures the "proximity" with world supply of factor *f*: to illustrate this point more clearly, I assume the majority of world factor *f* is concentrated in a country i. When the country j is close to the world supply of *f*, t_{ij} is smaller. And since $\left(p_i^f t_{ij}\right)^{-\frac{\rho^f}{1-\rho^f}}$ is decreasing on t_{ij}, the proximity with world supply of *f* implies a higher value of ϱ_i^f and hence smaller $1/\varrho_i^f$.

In E_{ij}^f, the term $s_i^f \alpha^f t b_j Y_i Y_j$ is the same as the model in the main paper. And E_{ij}^f is decreasing on the transport cost from *i* to *j*, and decreasing on the price of factor *f* in country *i*. Lastly, E_{ij}^f is smaller when the country is close to the world supply of that factor (i.e. a smaller $1/\varrho_i^f$). The reasoning is that when a country have cheaper and larger suppliers nearby, its incentive of purchasing "remote" factors decreases. Country in the Europe are geographically closely located, therefore should have similar distance with the world abundance of factors and ϱ_i^f for different European countries can be viewed as the same, and factor price should equal for the common EU market. If this is the case, the factor trade within EU country pairs is just $s_i^f \alpha^f t b_j Y_i Y_j$ adjusted for a common scalar. So we can safely use $s_i^f \alpha^f t b_j Y_i Y_j$ to evaluate the direction of net factor export between EU countries, and run the regression for consumption similarity as in section 5, without caring for $1/\varrho_i^f$.

Note that the model is not closed yet. It can be closed by introducing further conditions on the factor supply side, i.e. factor export to all countries (including domestic use) equals factor abundance: $\sum_j E_{ij} = sY_i$. But deriving an exact or numerical solution is beyond the scope of this paper.