Per Capita Income and the Mystery of Missing Trade

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Abstract

The literature on the Heckscher-Ohlin-Vanek (HOV) model has concentrated on the production side, particularly the unrealistic assumptions of identical techniques and factor price equalization. However, less is known about the demand side. In this paper, we compare the supply side assumptions versus the demand side assumptions as a cause of the empirical failures in the HOV prediction. While the relaxation in the supply side assumptions is crucial to predict the direction of factor trade, the demand side assumptions are shown to play an important role in explaining why factor trade is "missing" in the sense of Trefler (1995) relative to the HOV prediction. For example of the slope test for labor, the supply side repair improves from 0.026 to 0.162, whereas the demand side repair improves significantly from 0.162 to 0.891.

F11: Neoclassical Model of Trade
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1. Introduction

Recent advances in empirical international trade have increased our understanding of how the Heckscher-Ohlin-Vanek (HOV) model fails to predict the direction and volume of global factor trade. Most of the literature (e.g., Davis and Weinstein, 2001; Hakura, 2001; Schott, 2003; Choi and Krishna, 2004; Lai and Zhu, 2007) has demonstrated that the unrealistic assumptions of identical techniques and factor price equalization are responsible for previous empirical failures.[1] In particular, since developed countries employ more capital-intensive techniques than developing countries do, we cannot measure accurately the direction and volume of factor trade under the assumption of identical techniques everywhere. So repairing the supply side of the general equilibrium HOV model has credibly restored its ability to predict the direction of factor trade.

However, these supply side repairs, while successfully accounting for the direction of trade, have been less successful in explaining why the volume of trade is still substantially overpredicted by the modified HOV model. That is, there is "missing trade." And this is particularly true of trade between richer and poorer countries. This predictive deficiency of missing trade was first noted empirically by Trefler (1995) and a potential explanation involving the demand side was explored by Markusen (1986) for non-homothetic tastes, Trefler (1995) for home market biases, and Davis and Weinstein (2001) for trade friction.[2]

In this paper, we pursue empirically this seemingly plausible demand side explanation of missing trade using a data set of 29 countries including both developed and developing countries.[3] By using Hakura's (2001) pair-wise HOV framework combined with Trefler and Zhu's (2010) specifications, we develop an empirical method to estimate the amount of missing factor trade caused by assuming identical and homothetic tastes and frictionless trade in conjunction with per capita income differences and compare it with that caused by assuming identical production techniques. Specifically, we first divide country pairs into North-North pairs, South-South pairs, and North-South pairs according to real GDP per capita. Next, we evaluate the standard HOV model performance by imposing all HOV assumptions. Then, we

[1] The history of the empirical HOV that concentrated on modifications of the assumptions started with Maskus (1985) followed by Bowen, Leamer, and Sveikauskas (1987).

[2] The HOV errors represent Trefler's (1995) missing trade. Factor services embodied in net exports are usually smaller than those predicted from the standard HOV model. The HOV errors in this paper are factor services embodied in net exports, measured factor content of trade, minus that predicted from factor abundance, or predicted factor content of trade.

[3] The data set consists of actual techniques, Input-Output tables, and bilateral imports for 29 countries.

relax the supply side assumptions by introducing each country's actual unit factor requirements and actual usages of domestic and foreign intermediate inputs. The improvement in the HOV prediction from the standard model to the relaxed model is the volume of missing trade explained by the supply side repair. Finally, we relax the assumption of identical and homothetic tastes and frictionless trade by introducing a vector of deviations between one country's actual consumption vector and its counterfactual one under these assumptions. Now the improvement in the HOV prediction from the second to the third specification is the volume of missing trade explained by the demand side repair. By comparing these deviations, we study the contributions of differences in the supply-related missing trade versus the demand-related missing trade in the HOV model.

The findings in this paper are both compelling and somewhat surprising. While the supply side repair improves the direction of factor content of trade, particularly for the North-South country pairs, it does not reduce the amount of missing trade. In fact, the demand-related missing trade is quantitatively more significant than the supply-related missing trade in North-South pairs. For example of the slope test, the supply side repair improves from 0.026 to 0.162 for labor and from 0.220 to 0.384 for capital, whereas the demand side repair improves significantly from 0.162 to 0.891 for labor and from 0.384 to 0.960 for capital. The missing trade explained by the demand side might be related to several important elements: trade friction (Davis and Weinstein, 2001), home market bias (Trefler, 1995), systematic difference in price and quality across countries (Schott, 2004), and non-homothetic preferences (Markusen, 1986; Fieler, 2011; Caron et al., 2014) might all be responsible for the improvement in accounting for missing trade.

The direction of the demand-related missing trade is consistent with the prediction from Markusen's (1986) model. According to Markusen's model, developed countries consume relatively less of labor-intensive (or income-inelastic) goods (e.g., agriculture products and food) and relatively more of capital-intensive (or income-elastic) goods (e.g., automobiles and office machinery) compared to developing countries and so the volume of factor trade decreases as the difference in per capita income increases. In a recent paper, Fieler (2011) modifies the Eaton and Kortum (2002) model and introduces various types of goods that are different in income elasticity of demand. In her specification, since developing countries have Ricardian comparative advantage in income inelastic goods, income per capita plays a significant role to explain the low volume of trade for developing countries. Caron et al. (2014) apply Fieler's (2011) demand system, which they denote constant relative income elasticity (CREI) tastes, into the HOV model and show that the overprediction of factor trade can be reduced by relaxing the assumption of identical and homothetic taste.

As in Davis and Weinstein (2001), the modification in identical techniques remains central in order to obtain the right direction of factor trade relative to the HOV prediction. By relaxing the restriction of identical techniques and using each country's actual techniques, the sign tests for North-South pairs improve from 40.4 to 89.9 percent for labor and from 76.3 to 88.9 percent for capital. The HOV model with the supply side adjustments precisely predicts that a developed country is an exporter of capital service and an importer of labor service relative to a developing country.[4] The supply side relaxation is important even for the North-North or the South-South country pairs since measured factor content of trade involves all trade-partners' techniques through bilateral imports of intermediate inputs. The difference in consumption patterns, on the other hand, does not change the direction of factor trade but matters for the volume of factors traded for all country pairs.

The remainder of this paper is organized into three sections. In Section 2, we develop the three HOV specifications developed from Hakura (2001) and Trefler and Zhu (2010), and provide the empirical strategy to measure the volume of missing trade attributable to the supply side and the demand side assumptions. Section 3 studies empirical regularities by sorting country pairs according to the differences in two countries' per capita incomes. We present concluding remarks in the last section.

2. Theoretical Framework

We begin by deriving the HOV model (Trefler and Zhu, 2010) in a world with *F* factors, *C* countries, and *N* products. Note that we use capital *C* to denote the number of countries and small *c* as an index for a particular country, $c = 1, 2, \ldots, C$. The following equation represents the identity of global production and consumption:

$$(1) \quad \begin{bmatrix} \mathbf{X}^1 & \cdots & -\mathbf{M}^{C1} \\ \vdots & \ddots & \vdots \\ -\mathbf{M}^{1C} & \cdots & \mathbf{X}^C \end{bmatrix} =$$

[4] This statement is true for the case of the pair-wise model we employ. We still have the result that a developed country imports both capital service as well as labor service as in the standard prediction of Trefler and Zhu (2010). Also, see Leontief's original paradox (1954) and Leamer's (1980) and Davis and Weinstein's (2001) solutions.

$$\begin{bmatrix}\mathbf{Q}^1 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \mathbf{Q}^C\end{bmatrix} - \begin{bmatrix}\overline{\mathbf{B}}^{11} & \cdots & \overline{\mathbf{B}}^{1C}\\ \vdots & \ddots & \vdots\\ \overline{\mathbf{B}}^{C1} & \cdots & \overline{\mathbf{B}}^{CC}\end{bmatrix}\begin{bmatrix}\mathbf{Q}^1 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \mathbf{Q}^C\end{bmatrix} - \begin{bmatrix}\mathbf{D}^{11} & \cdots & \mathbf{D}^{C1}\\ \vdots & \ddots & \vdots\\ \mathbf{D}^{1C} & \cdots & \mathbf{D}^{CC}\end{bmatrix}$$

where $\mathbf{X}^c$ is an N×1 vector of exports, $\mathbf{M}^{c\dot{c}}$ is an N×1 vector of bilateral imports of country c from $\dot{c}$, $\mathbf{Q}^c$ is an N×1 vector of gross output of country c, $\overline{\mathbf{B}}^{\dot{c}c}$ is an N×N matrix of intermediate inputs from country $\dot{c}$ required for country c to produce one unit of gross outputs, and $\mathbf{D}^{c\dot{c}}$ is an N×1 vector of country c's consumption of final goods from country $\dot{c}$. Further, we can define the following matrices: $\mathbf{T} = \begin{bmatrix}\mathbf{X}^1 & \cdots & -\mathbf{M}^{C1}\\ \vdots & \ddots & \vdots\\ -\mathbf{M}^{1C} & \cdots & \mathbf{X}^C\end{bmatrix}$, $\mathbf{Q} = \begin{bmatrix}\mathbf{Q}^1 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \mathbf{Q}^C\end{bmatrix}$, $\overline{\mathbf{B}} = \begin{bmatrix}\overline{\mathbf{B}}^{11} & \cdots & \overline{\mathbf{B}}^{1C}\\ \vdots & \ddots & \vdots\\ \overline{\mathbf{B}}^{C1} & \cdots & \overline{\mathbf{B}}^{CC}\end{bmatrix}$, and $\mathbf{D} = \begin{bmatrix}\mathbf{D}^{11} & \cdots & \mathbf{D}^{C1}\\ \vdots & \ddots & \vdots\\ \mathbf{D}^{1C} & \cdots & \mathbf{D}^{CC}\end{bmatrix}$. Thus, equation (1) can be simplified to

$$\mathbf{T} = (\mathbf{I} - \overline{\mathbf{B}})\mathbf{Q} - \mathbf{D}$$

where $\mathbf{I}$ is the CN×CN identity matrix.

We define the matrix of net output as $\mathbf{Y} = (\mathbf{I} - \overline{\mathbf{B}})\mathbf{Q}$ where $\mathbf{Y} \equiv \begin{bmatrix}\mathbf{Y}^{11} & \cdots & \mathbf{Y}^{1C}\\ \vdots & \ddots & \vdots\\ \mathbf{Y}^{C1} & \cdots & \mathbf{Y}^{CC}\end{bmatrix}$. An N×1 vector of net output of country $\dot{c}$ will be the sum of net output across trading-partner countries:

(2) $$\mathbf{Y}^{\dot{c}} \equiv \textstyle\sum_c \mathbf{Y}^{c\dot{c}}.$$

Now, we assume that $\mathbf{A}^c$ is the F×N technical matrix and each element represents the unit factor requirement, which is the amount of a factor required to produce one unit of *gross* output of a sector. Using $\mathbf{A} \equiv [\mathbf{A}^1 \quad \cdots \quad \mathbf{A}^C]$, we can define the following equation:

$$\mathbf{B} \equiv \mathbf{A}(\mathbf{I} - \overline{\mathbf{B}})^{-1}$$

where $\mathbf{B} \equiv [\mathbf{B}^1 \quad \cdots \quad \mathbf{B}^C]$, and $\mathbf{B}^c$ in $\mathbf{B}$ is the F×N technical matrix for country c whose element corresponds to the unit factor requirement for *net* output. We pre-multiply equation (1) by the technical matrix $\mathbf{B}$, and use the factor-exhaustion assumption: $\mathbf{AQ} \equiv \mathbf{V}$, or $\mathbf{BY} \equiv \mathbf{V}$, where $\mathbf{V} \equiv [\mathbf{V}^1 \quad \cdots \quad \mathbf{V}^C]$ and $\mathbf{V}^c$ is an F×1 vector of factor endowment of country c, to obtain:

(3) $$\mathbf{BT} \equiv \mathbf{V} - \mathbf{BD}.$$

That is, a country's factor content of trade is the difference between a country's factor endowment ($\mathbf{V}$) and factor absorbed in final consumption ($\mathbf{BD}$). Here, equation (3) is an *identity equation* for each country by data construction.

Assuming identical and homothetic tastes, identical prices of the goods, and frictionless trade as in Trefler and Zhu (2010), final consumption vector for country c is proportional to the net output vector of country $\dot{c}$ from equation (2):

$$\mathbf{D}^{c\dot{c}} = s^c \mathbf{Y}^{\dot{c}} \tag{4}$$

where s^c is a scalar representing the share of country c in world expenditure. Any net output from a country $\dot{c}$ would be consumed proportional to income share. These demand side assumptions are quite strong for the structure of world consumption. For example, if the income share of the United States is 30%, the United States will purchase 30% of net outputs not only in the United States but also in South Africa. Thus, home market consumption bias, trade frictions, non-homothetic taste, and cross-country differences in price and quality are all responsible for the errors in equation (4).

By enforcing these assumptions in equation (3) and replacing $\mathbf{D}$ with $\overline{\mathbf{D}} = \begin{bmatrix} s^1\mathbf{Y}^1 & \cdots & s^C\mathbf{Y}^1 \\ \vdots & \ddots & \vdots \\ s^1\mathbf{Y}^C & \cdots & s^C\mathbf{Y}^C \end{bmatrix}$, we have $\mathbf{B}\overline{\mathbf{D}} = [s^1\mathbf{V}^w \quad \cdots \quad s^C\mathbf{V}^w]$ where $\mathbf{V}^w = \sum_c \mathbf{V}^c$ and we can derive the model proposed by Trefler and Zhu (2010):

$$\mathbf{B}^c\mathbf{X}^c - \textstyle\sum_{\dot{c}\neq c} \mathbf{B}^{\dot{c}}\mathbf{M}^{c\dot{c}} = \mathbf{V}^c - s^c\mathbf{V}^w \tag{5}$$

for all country c. $\mathbf{B}^c\mathbf{X}^c - \sum_{\dot{c}\neq c} \mathbf{B}^{\dot{c}}\mathbf{M}^{c\dot{c}}$ is the *measured factor content* of trade[5] and $\mathbf{V}^c - s^c\mathbf{V}^w$ is the *predicted factor content* of trade. The HOV theorem predicts that the measured factor content of trade for any country must equal the difference between the country's factor endowment and the product of that country's consumption share and world factor endowment.

The standard HOV model is further modified to develop the pair-wise model (e.g., Staiger, Deardorff, and Stern 1987; Hakura 2001). Although the pair-wise model tests the HOV equation bilaterally, it does not test bilateral factor content of trade (e.g., Choi and Krishna, 2004). That is, while the pair-wise HOV equation is a bilateral relationship, it is derived from the worldwide general equilibrium system. For any two arbitrarily chosen countries c and $\ddot{c}$, we take the ratio of consumption shares:

$$s^{c\ddot{c}} \equiv s^c / s^{\ddot{c}} \tag{6}$$

[5] Although the 29 countries in the data set cover more than 70 percent of world trade, there are still many countries outside the data coverage. In particular, we need to measure the factor content of imports for each of 29 countries from the rest of the world for equation (5). Since the rest of the world consists mostly of developing countries, we employ production techniques of China to measure factor content of bilateral imports.

Then, by combining equation (5) for these two countries with equation (6), we eliminate the world endowment in equation (5) and derive the pair-wise version of the HOV model:

(7) $$\left[\mathbf{B}^{c}\mathbf{X}^{c} - \sum_{\dot{c}\neq c}\mathbf{B}^{\dot{c}}\mathbf{M}^{c\dot{c}}\right] - s^{c\ddot{c}}\left[\mathbf{B}^{\ddot{c}}\mathbf{X}^{\ddot{c}} - \sum_{\dot{c}\neq \ddot{c}}\mathbf{B}^{\dot{c}}\mathbf{M}^{\ddot{c}\dot{c}}\right] = \mathbf{V}^{c} - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}$$

$\left[\mathbf{B}^{c}\mathbf{X}^{c} - \sum_{\dot{c}\neq c}\mathbf{B}^{\dot{c}}\mathbf{M}^{c\dot{c}}\right] - s^{c\ddot{c}}\left[\mathbf{B}^{\ddot{c}}\mathbf{X}^{\ddot{c}} - \sum_{\dot{c}\neq \ddot{c}}\mathbf{B}^{\dot{c}}\mathbf{M}^{\ddot{c}\dot{c}}\right]$ is the measured *relative* factor content of trade and $\mathbf{V}^{c} - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}$ is the predicted *relative* factor content of trade. Equation (7) reveals that the measured relative factor content of trade can be predicted from the relative factor abundance between any two countries. The primary advantage of the two-country HOV model is that the testing equation does not include any world aggregate. In addition, since our data set consists of 29 countries, we have 406 observations for each factor, which can be organized into combinations of country pairs with various stages of development.

The Supply Side Deviations

Davis and Weinstein (2001) found substantial improvements in the predictive power of the HOV model when national techniques are relaxed according to technical differences and a breakdown in factor price equalization. Since a capital abundant country employs capital-intensive production techniques, exports from a capital abundant country in a given industry are more capital-intensive than world production in that industry. These insights have been introduced into equation (5) by taking accounts not only of country-specific direct factor usages but also of country-specific global transactions in intermediate inputs. Before their contribution, the empirical papers on the HOV model assume that all countries employ identical production techniques. The following specification applies when the factor content of trade is measured with country *c*'s production techniques.

(8) $$\mathbf{B}^{c}(\mathbf{X}^{c} - \sum_{\dot{c}\neq c}\mathbf{M}^{c\dot{c}}) = \mathbf{V}^{c} - s^{c}\mathbf{V}^{w}.$$

By combining equation (8) for two countries with equation (6), the pair-wise HOV model that introduces identical production techniques follows:

(9) $$\left[\mathbf{B}^{c}(\mathbf{X}^{c} - \sum_{\dot{c}\neq c}\mathbf{M}^{c\dot{c}})\right] - s^{c\ddot{c}}\left[\mathbf{B}^{c}(\mathbf{X}^{\ddot{c}} - \sum_{\dot{c}\neq \ddot{c}}\mathbf{M}^{\ddot{c}\dot{c}})\right] = \mathbf{V}^{c} - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}$$

Thus, a comparison of equation (9) with equation (7) will allow an assessment of the role of the supply side assumptions in explaining errors in the HOV prediction.

The Demand Side Deviations

As discussed previously (e.g., Trefler, 1995; Davis and Weinstein, 2001; Trefler and Zhu, 2010; Reimer and Hertel, 2010; Caron et al., 2014), the demand side assumptions are not realistic from the actual data. Low-income countries seem to spend more on labor-intensive goods, suggesting a violation of identical and homothetic preferences or identical prices of the goods. Of course, this could also owe to trade friction and home market bias. In this paper, we try to evaluate the importance of the demand side deviations versus the supply side deviations in evaluating missing trade.

To study the demand side errors in the HOV prediction, we introduce the following identity equation where the **E** matrix simply renders the empirical data an identity:

$$(10)\qquad \begin{bmatrix} \mathbf{D}^{11} & \cdots & \mathbf{D}^{C1} \\ \vdots & \ddots & \vdots \\ \mathbf{D}^{1C} & \cdots & \mathbf{D}^{CC} \end{bmatrix} + \begin{bmatrix} \mathbf{E}^{11} & \cdots & \mathbf{E}^{C1} \\ \vdots & \ddots & \vdots \\ \mathbf{E}^{1C} & \cdots & \mathbf{E}^{CC} \end{bmatrix} \equiv \begin{bmatrix} s^{1}\mathbf{Y}^{1} & \cdots & s^{C}\mathbf{Y}^{1} \\ \vdots & \ddots & \vdots \\ s^{1}\mathbf{Y}^{C} & \cdots & s^{C}\mathbf{Y}^{C} \end{bmatrix}$$

If countries' preferences are identical and homothetic, prices of goods are identical, and there are no frictions in trade, $\mathbf{E}^{c\dot{c}}$ must be an N×1 zero-vector. The deviation in the consumption bundle relative to the HOV assumptions is captured by $\mathbf{E}^{c\dot{c}}$. By using equation (3) and replacing $\begin{bmatrix} \mathbf{D}^{11} & \cdots & \mathbf{D}^{C1} \\ \vdots & \ddots & \vdots \\ \mathbf{D}^{1C} & \cdots & \mathbf{D}^{CC} \end{bmatrix}$ with $\begin{bmatrix} s^{1}\mathbf{Y}^{1} & \cdots & s^{C}\mathbf{Y}^{1} \\ \vdots & \ddots & \vdots \\ s^{1}\mathbf{Y}^{C} & \cdots & s^{C}\mathbf{Y}^{C} \end{bmatrix} - \begin{bmatrix} \mathbf{E}^{11} & \cdots & \mathbf{E}^{C1} \\ \vdots & \ddots & \vdots \\ \mathbf{E}^{1C} & \cdots & \mathbf{E}^{CC} \end{bmatrix}$ from identity equation (10), then equation (11) follows:

$$(11)\qquad \mathbf{B}^{c}\mathbf{X}^{c} - \textstyle\sum_{\dot{c}\neq c}\mathbf{B}^{\dot{c}}\mathbf{M}^{c\dot{c}} \equiv \mathbf{V}^{c} - s^{c}\mathbf{V}^{w} + \textstyle\sum_{\dot{c}}\mathbf{B}^{\dot{c}}\mathbf{E}^{c\dot{c}}$$

where $\sum_{\dot{c}}\mathbf{B}^{\dot{c}}\mathbf{E}^{c\dot{c}}$ captures the errors associated with the demand side assumptions. Note that equation (11) is the identity equation since both equations (3) and (10) are identity equations by data construction.

By combining equation (11) for two countries with equation (6), the pair-wise HOV model that relax the demand side assumptions follows:

$$(12)\qquad \left[\mathbf{B}^{c}\mathbf{X}^{c} - \textstyle\sum_{\dot{c}\neq c}\mathbf{B}^{\dot{c}}\mathbf{M}^{c\dot{c}} - \textstyle\sum_{\dot{c}}\mathbf{B}^{\dot{c}}\mathbf{E}^{c\dot{c}}\right] - s^{c\ddot{c}}\left[\mathbf{B}^{\ddot{c}}\mathbf{X}^{\ddot{c}} - \textstyle\sum_{\dot{c}\neq\ddot{c}}\mathbf{B}^{\dot{c}}\mathbf{M}^{\ddot{c}\dot{c}} - \textstyle\sum_{\dot{c}}\mathbf{B}^{\dot{c}}\mathbf{E}^{\ddot{c}\dot{c}}\right] = \mathbf{V}^{c} - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}$$

Because equation (7) imposes a restriction of $\mathbf{E}^{c\dot{c}} = 0$, the difference between these two equations (7) and (12) represents the deviations in the HOV prediction generated from the demand side assumptions. Thus, now we succeed to decompose the missing trade into two important components of the assumptions: errors caused by imposing the supply side HOV assumptions (i.e., identical production techniques and identical usages of intermediate inputs) and those caused by the demand side HOV assumptions (i.e., identical and homothetic taste, identical prices of the goods, and frictionless trade).

Empirical Strategy

To study the empirical failures of the HOV model caused by the supply side assumptions, we first define the pair-wise HOV errors from equations (9) and (7). In the empirical exercises below, we concentrate on tradable sectors since the consumption vector in nontraded sectors are subject to the violation of the demand side assumptions. These HOV errors are then given by:

(9') $$\tilde{\mathbf{E}}_S^{c\ddot{c}} = \left[\mathbf{B}^{cT}(\mathbf{X}^c - \textstyle\sum_{\dot{c}\neq c}\mathbf{M}^{c\dot{c}})\right] - s^{c\ddot{c}}\left[\mathbf{B}^{cT}(\mathbf{X}^{\ddot{c}} - \textstyle\sum_{\dot{c}\neq \ddot{c}}\mathbf{M}^{\ddot{c}\dot{c}})\right] - \left(\mathbf{V}^c - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}\right)$$

(7') $$\tilde{\mathbf{E}}_B^{c\ddot{c}} = \left[\mathbf{B}^{cT}\mathbf{X}^c - \textstyle\sum_{\dot{c}\neq c}\mathbf{B}^{\dot{c}T}\mathbf{M}^{c\dot{c}}\right] - s^{c\ddot{c}}\left[\mathbf{B}^{\ddot{c}T}\mathbf{X}^{\ddot{c}} - \textstyle\sum_{\dot{c}\neq \ddot{c}}\mathbf{B}^{\dot{c}T}\mathbf{M}^{\ddot{c}\dot{c}}\right] - \left(\mathbf{V}^c - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}\right)$$

where the superscript *T* indicates the matrix that contains zeros in non-tradable sector.

The improvement in the HOV equation from equation (9) to (7), or $\tilde{\mathbf{E}}_S^{c\ddot{c}} - \tilde{\mathbf{E}}_B^{c\ddot{c}}$, is the amount of missing trade caused by the supply side assumptions.

Second, to study the empirical failures of the HOV model caused by the demand side assumptions, we define the pair-wise HOV errors for equation (12):

(12') $$\tilde{\mathbf{E}}_D^{c\ddot{c}} = \left[\mathbf{B}^{cT}\mathbf{X}^c - \textstyle\sum_{\dot{c}\neq c}\mathbf{B}^{\dot{c}T}\mathbf{M}^{c\dot{c}} - \textstyle\sum_{\dot{c}}\mathbf{B}^{\dot{c}T}\mathbf{E}^{c\dot{c}}\right] - s^{c\ddot{c}}\left[\mathbf{B}^{\ddot{c}T}\mathbf{X}^{\ddot{c}} - \textstyle\sum_{\dot{c}\neq \ddot{c}}\mathbf{B}^{\dot{c}T}\mathbf{M}^{\ddot{c}\dot{c}} - \textstyle\sum_{\dot{c}}\mathbf{B}^{\dot{c}T}\mathbf{E}^{\ddot{c}\dot{c}}\right] - \left(\mathbf{V}^c - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}\right)$$

Here, we compare the pair-wise HOV model that imposes the demand side assumptions, equation (7), with equation (12) that drops this assumption. Again, the improvement, $\tilde{\mathbf{E}}_B^{c\ddot{c}} - \tilde{\mathbf{E}}_D^{c\ddot{c}}$, is the amount of missing trade explained by the violation of the demand side assumptions. By comparing these deviations, $\tilde{\mathbf{E}}_S^{c\ddot{c}} - \tilde{\mathbf{E}}_B^{c\ddot{c}}$ and $\tilde{\mathbf{E}}_B^{c\ddot{c}} - \tilde{\mathbf{E}}_D^{c\ddot{c}}$, we discover the contributions of supply side versus demand side biases for the missing trade of the HOV model. We next divide the 406 country pairs into North-North pairs, North-South pairs, and South-South pairs and apply the three specifications of the pair-wise HOV models to each subset. This will allow us to isolate the contributions of the supply side differences and demand side differences.

3. Empirical Results

Evaluating the three equations (9), (7), and (12) requires data on actual techniques, Input-Output tables, and bilateral imports for multiple countries. Thus, we employ a data set for a group of 29 countries in the year 2000.[6] There are two factors, aggregate labor and physical capital, and 30 industrial sectors.

Performance of the Pair-Wise HOV Models

To study the performance of the HOV model, standard testing procedures are developed (e.g., Bowen, Leamer, and Sveikauskas, 1987; Trefler, 1995; Davis and Weinstein, 2001). First, a sign test is used to elicit the probability of sign coincidences between measured and predicted relative factor content of trade. If the specification holds perfectly, the sign would fit with 100 percent probability. A slope test involves regressing measured relative factor content of trade on the predicted one without an intercept. If the pair-wise HOV specification holds, the regression coefficient would be unity. Finally, variance ratios are developed for each factor, computing the variance of measured relative factor content of trade over the variance of the predicted one. The ratio should be unity but previous literature has shown that this number tends to be close to zero. Here, we sort the countries from the richest, the United States, to the poorest, Indonesia, by real GDP per capita so that country c is always richer than country $\ddot{c}$.

Table 1 provides the results for the HOV tests. The HOV model with the standard assumptions, equation (9), performs poorly as previously shown. For the combinations of all countries, the sign fits are 55.2 percent for labor and 69.7 percent for capital, the slope coefficients are 0.026 for labor and 0.220 for capital, and the variance ratios are 0.003 for labor and 0.198 for capital. The results are slightly better than in the previous literature, reflecting the importance of discarding nontraded sectors. The slope and the variance ratio tests indicate Trefler's (1995) missing trade, particularly for labor. Specifically, the poor performance of labor services stems from the country pairs consisting of one developed country and one developing country; the sign fit is only 40.4 percent and the variance ratio is 0.001.

One of the most important contributions of Trefler and Zhu (2010) is the introduction of global transactions of intermediate inputs. As shown by them, equation (7), which allows country-specific production techniques, improves the sign fits tremendously. In other words, the HOV model predicts precisely the direction of measured factor trade. The same thing happens

[6] The detailed methodology is in the Appendix of Nishioka (2012).

here. While the proportions of correct signs significantly improve to 81.0 percent for labor and 83.7 for capital, the slopes are 0.162 for labor and 0.384 for capital. Of note, the great improvement in the direction of factor trade comes mainly from the success of the North-South country pairs; the sign fits improve to 89.9 percent for labor and 88.9 percent for capital. These results indicate not only the importance of allowing technical differences but also that technical gaps are significant between developed and developing countries. And, one might suspect that demand patterns are consistently different as well. We now turn to this issue.

Since equation (12) is the identity equation, all the HOV testing statistics fit almost perfectly. The deviations from the strict equality come from the truncation of nontradable sectors from the whole economy. We impose the demand side assumptions on equation (12) to derive equation (7). That is, we mandate $\mathbf{E}^{c\ddot{c}} = 0$. Therefore, the improvement in testing statistics from equation (7) to (12) reported in Table 1 casts suspicion on the validity of the demand side assumptions. As it happens, the significant change is observed in all types of country pairs. For all country pairs, while the proportion of correct signs does not change so much, the slope improves from 0.162 to 0.891 for labor and from 0.384 to 0.960 for capital. Therefore, the difference in demand does not change the direction of factor trade but matters for the amount of factor trade between developed and developing countries.

Table 2 provides the statistics for the direction and volume of missing trade explained respectively by supply or demand. For the supply side relaxation, the volume of missing trade is reduced for labor and capital since ($\tilde{\mathbf{E}}_S^{c\ddot{c}} - \tilde{\mathbf{E}}_B^{c\ddot{c}}$) and $\tilde{\mathbf{E}}_S^{c\ddot{c}}$ correlate negatively:
-0.871 for labor and -0.765 for capital. But there is also a strong negative correlation between $\tilde{\mathbf{E}}_B^{c\ddot{c}} - \tilde{\mathbf{E}}_D^{c\ddot{c}}$ and $\tilde{\mathbf{E}}_S^{c\ddot{c}}$ for labor (-0.994) and capital (-0.921), which indicates the relaxation in the demand assumptions is critical in accounting for the volume of missing trade. Furthermore, this tendency is stronger for the country pairs with larger per capita income differences. This seems to give more weight to our demand side explanation of missing trade, which may include any types of violation in the demand side assumptions in Trefler and Zhu (2010). Thus, home biases (Trefler, 1995) and trade frictions – e.g. transport costs – (Davis and Weinstein, 2001) could explain the biases if those biases and frictions are systematically linked to per capita income differences between nations. Moreover, the volume of missing trade explained by demand is much greater than that explained by supply; while the ratio of the variance of $\tilde{\mathbf{E}}_S^{c\ddot{c}} - \tilde{\mathbf{E}}_B^{c\ddot{c}}$ relative to $\tilde{\mathbf{E}}_S^{c\ddot{c}}$ is 0.027 for labor and 0.150 for capital, the ratio of the variance of $\tilde{\mathbf{E}}_B^{c\ddot{c}} - \tilde{\mathbf{E}}_D^{c\ddot{c}}$ relative to

$\tilde{\mathbf{E}}_S^{c\ddot{c}}$ is 0.560 for labor and 0.509 for capital. That is, the development-related biases in consumption present here are significant as previous literature showed (e.g., Hunter and Markusen, 1988; Hunter, 1991; Caron et al., 2014).

Figures 1-1 and 1-2 provide a picture of the HOV errors generated from our three equations by plotting equations (9'), (7'), and (12') on the vertical axis and the predicted relative factor content of trade ($\mathbf{V}^c - s^{c\ddot{c}}\mathbf{V}^{\ddot{c}}$) on the horizontal axis. In these figures, the negative 45-degree line is the case of zero factor trade -- error equals prediction -- and the horizontal line is the case of a perfect fit -- no error -- for the HOV models. Previous literature showed that these errors with the standard HOV model tend to be on the zero-trade line, which is confirmed by our data. The improvements in the predictive power of the HOV model are clearly illustrated by the clock-wise rotations in trend-lines of each equation. As in Trefler (1995) and Davis and Weinstein (2001), the relaxation from the strict HOV assumptions gradually mitigates the errors in the HOV prediction. In particular, Figures 1-1 and 1-2 confirm that the improvement from demand is as significant -- actually more so -- as that from supply.

As is well known and recounted above, the strict HOV model results in prediction errors. Table 3 provides the signs of HOV errors generated from the supply side assumptions ($\tilde{\mathbf{E}}_S^{c\ddot{c}} - \tilde{\mathbf{E}}_B^{c\ddot{c}}$) and the demand side assumptions ($\tilde{\mathbf{E}}_B^{c\ddot{c}} - \tilde{\mathbf{E}}_D^{c\ddot{c}}$). As discussed before, the directions of these errors are expected to be systematic in the North-South context: negative errors for labor and positive errors for capital.[7] Concerning the supply-driven HOV errors for North-South pairs, 99.5 percent are negative signs for labor and 71.7 percent are positive signs for capital. These results support the idea that developed countries employ less labor and more capital than developing countries do. The relaxation in demand generates 100.0 percent negative errors in $\tilde{\mathbf{E}}_B^{c\ddot{c}} - \tilde{\mathbf{E}}_D^{c\ddot{c}}$ for labor, suggesting that missing factor trade arises from the demand side assumptions.

4. Conclusion

[7] Since we sort the countries from the richest to the poorest by per capita GDP, country c is always richer than country $\ddot{c}$, which is consistent with the discussion in the previous section.

We compare the volume of the demand-related missing trade with that of the supply-driven missing trade, and find that the imposition of the demand side assumptions causes more missing trade than does that of the supply side assumptions. Past empirical studies of the HOV model focus heavily on the modification of production functions. Although these modifications improve the prediction accuracy of directions of factor trade, we show that the demand side assumptions are shown to play an important role in explaining why factor trade is “missing” in the sense of Trefler (1995) relative to the HOV prediction. In the current paper, we did not enforce any structure in the demand side errors. Thus, our results simply indicate that there are many other possibilities to explain the demand side HOV errors; trade friction (Davis and Weinstein, 2001), home market bias (Trefler, 1995), systematic difference in price and quality across countries (Schott, 2004) and non-homothetic preferences (Markusen, 1986; Fieler, 2011; Caron et al., 2014) might all be responsible for the improvement in accounting for demand side missing trade.

Although the recent influential papers focus on non-homothetic tastes (Fieler, 2011; Caron et al., 2014), we cannot ignore some other potential reasons why there are systematic development-related biases in consumptions. For example, capital-intensive goods could be cheaper in capital-abundant countries whereas labor-intensive goods could be cheaper in labor-abundant countries. In reality, these goods from different countries could be different in quality as well. In this case, even without the non-homothetic tastes, the demand structure could be different systematically across countries. For the future study, it is important to incorporate the information on quality and price of the product into the empirical HOV model and further understand why structure of demand differ systematically across countries.

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Figures and Tables

Table 1: Sign, Slope, and Variance Ratio Tests for Country Pairs

		All pairs		North pairs		South pairs		North-South pairs	
		Labor	Capital	Labor	Capital	Labor	Capital	Labor	Capital
	Observations	406	406	153	153	55	55	198	198
	Sign test	55.2%	69.7%	63.4%	66.7%	85.5%	54.5%	40.4%	76.3%
Standard HOV model: Eq. (9)	Slope test	0.026	0.220	0.368	0.252	0.007	0.073	0.023	0.121
(Both the supply- and demand-side	Standard error	0.003	0.019	0.025	0.026	0.012	0.057	0.002	0.037
assumptions are imposed.)	R-squared	0.172	0.244	0.535	0.360	-0.288	-0.022	0.417	0.002
	Variance ratio	0.003	0.198	0.236	0.179	0.006	0.195	0.001	0.311
	Sign test	81.0%	83.7%	68.0%	84.3%	85.5%	63.6%	89.9%	88.9%
Trefler and Zhu model: Eq. (7)	Slope test	0.162	0.384	0.086	0.415	0.070	0.252	0.164	0.288
(The supply-side assumptions	Standard error	0.003	0.010	0.041	0.015	0.015	0.026	0.003	0.018
are relaxed from Eq.(9).)	R-squared	0.859	0.775	0.028	0.835	0.031	0.630	0.935	0.480
	Variance ratio	0.030	0.190	0.289	0.209	0.014	0.114	0.028	0.140
	Sign test	96.6%	94.8%	91.5%	97.4%	98.2%	78.2%	100.0%	97.5%
Identity equation model: Eq. (12)	Slope test	0.891	0.960	0.968	0.998	0.778	0.751	0.892	0.845
(The demand-side assumptions	Standard error	0.002	0.007	0.010	0.005	0.014	0.058	0.003	0.015
are relaxed from Eq.(7))	R-squared	0.997	0.980	0.983	0.995	0.982	0.732	0.998	0.937
	Variance ratio	0.793	0.939	0.951	0.996	0.593	0.759	0.795	0.750

Table 2: Directions and Amounts of Improvements in HOV Errors

1. Supply-side modification		[(7')-(9'), (9')]			
		All pairs	North pairs	South pairs	North-South pairs
Sign mismatch	Labor service	86.2%	71.9%	78.2%	99.5%
	Capital service	85.0%	86.3%	74.5%	86.9%
Variance ratio	Labor service	0.027	0.941	0.006	0.022
	Capital service	0.150	0.149	0.094	0.175
Correlation	Labor service	-0.871	0.074	-0.747	-0.956
	Capital service	-0.765	-0.769	-0.841	-0.762
2. Demand-side modification		[(12')-(7'), (9)']			
		All pairs	North pairs	South pairs	North-South pairs
Sign mismatch	Labor service	86.0%	65.4%	92.7%	100.0%
	Capital service	92.9%	94.8%	81.8%	94.4%
Variance ratio	Labor service	0.560	1.992	0.497	0.560
	Capital service	0.509	0.547	0.346	0.414
Correlation	Labor service	-0.994	-0.732	-0.998	-0.998
	Capital service	-0.921	-0.935	-0.599	-0.885

Table 3: Expected Sign Matches of Improvements in HOV Errors

		All pairs	North pairs	South pairs	North-South pairs
Supply-side errors	Labor service (-)	74.9%	45.8%	67.3%	99.5%
(7')-(9')	Capital service (+)	59.1%	39.9%	67.3%	71.7%
Demand-side errors	Labor service (-)	83.5%	60.1%	89.1%	100.0%
(12')-(7')	Capital service (+)	70.4%	45.8%	85.5%	85.4%

Figure 1-1: Errors in Labor Service for Three Specifications relative to Predicted Relative Labor Content of Trade

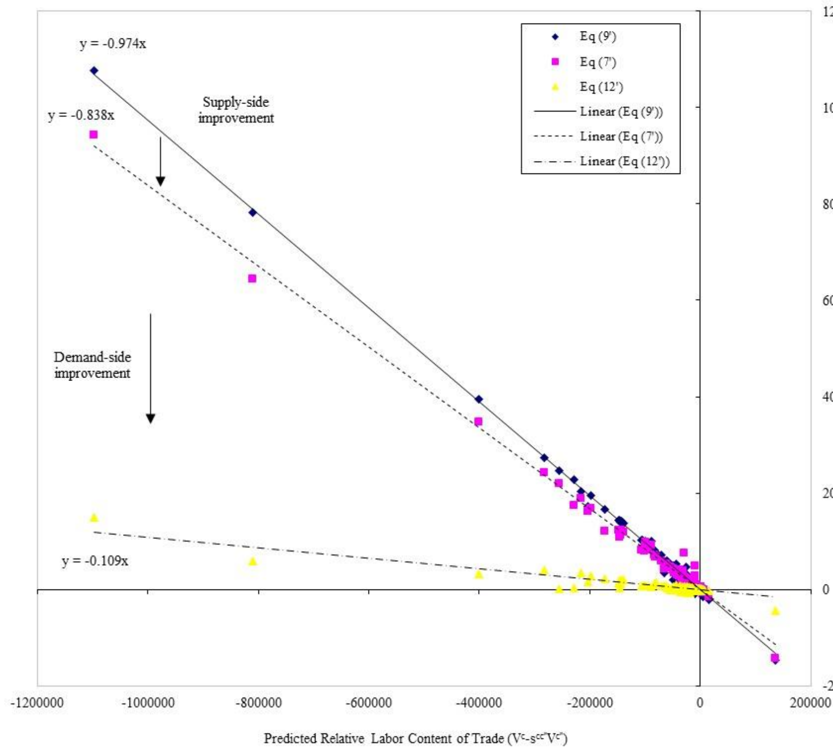

Figure 1-2: Errors in Capital Service for Three Specifications relative to Predicted Relative Capital Content of Trade