Factor Productivity and Global Trade

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Abstract

The Heckscher-Ohlin-Vanek (HOV) model performs poorly in explaining the factor content of global trade. Previous studies that introduce Hicks-neutral productivity differences in the HOV model produce mixed results on the model's improvement in fit. We adopt an approach that uses factor earnings to measure effective factor quantities, which intends to capture both neutral and non-neutral factor productivity differences between countries. Applying this approach to a data set of 78 countries or country groups, we find that the model's fit to data improves significantly. Despite the improved fit, the model still shows large deviations in its predictions. We detect some systematic patterns in the deviations and explain them with a model of multiple diversification cones. Results from splitting the sample into income groups support our explanation.

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1. Introduction

Explaining global trade is a central task for trade economists. What explains the observed structure of global trade? Two widely used models are the Ricardian model and the Heckscher-Ohlin (HO) model. The former explains trade patterns with cross-country differences in productivity of a single production factor (labor), while the latter explains trade patterns with cross-country differences in factor endowments assuming that all countries have identical factor productivity.

A leading trade textbook, Krugman and Obstfeld (2003), tells students that empirical evidence broadly supports the Ricardian model's prediction that countries will export goods in which their labor is especially productive, but this single-factor model is too limited to serve as an analytical tool of many trade issues; by contrast, there is strong evidence against the HO model's prediction on trade patterns, but the model has long been used to analyze various important trade issues (p. 85).

Naturally one wonders if the empirically successful element of the Ricardian model can be introduced to the HO model to make it more successful empirically. The Ricardian model is empirically successful by considering differences in productivity of a single factor; one wonders if the multi-factor HO model can gain its empirical success by considering differences in productivity as well. The combination of factor productivity and factor endowment leads to a measure of *effective* factor endowment. The question becomes: how much an improvement will the Ricardian element bring to the explanatory power of the HO model? Clearly we no longer have the pure HO model; it is now an HO model with effective factor endowments. If this modified HO model gains significantly higher explanatory power, then trade students would feel a lot more comfortable to use the HO framework as the main analytical tool of trade issues.

The empirical trade literature offers different answers to this question. Trefler (1993) is one of the first to introduce factor productivity differences in empirical investigations of the HO theory.[1] Using the Heckscher-Ohlin-Vanek (HOV) model, a version of the HO model based on the idea that trade in goods implies trade in factor content embodied in the goods, Trefler (1993) examines the HOV theorem which claims that relative factor abundance of a country explains its net trade in factor content. Calculating international factor-augmenting productivity differences that make the HOV theorem perfectly fit the data on trade and endowments, Trefler (1993) finds that these international productivity differences are highly correlated with observed international factor price differences. This leads him to conclude that factor productivity adjustment alone makes the HOV theorem explain much of the factor content of trade.

Trefler (1995) goes further to test the modified HOV theorem (with factor productivity adjustment) against the standard HOV theorem which assumes identical factor productivity for all countries. The standard HOV theorem is at odds with the data, which Trefler (1995) summarizes as two puzzles. The first is an "Endowment Paradox": poor countries are revealed to be abundant in most production factors, while rich countries are revealed to be scarce in most production factors. In Trefer's (1995) sample of 33 countries and 9 factors in year 1983, the number of abundant factors is negatively correlated with GDP per capita at –0.89. The second is a "Missing Trade Mystery": the

[1] Trefler (1993) credits this to Leontief (1953), who finds the famous "Leontief Paradox" that the capital-abundant U.S. exported labor content and imported capital content. Leontief (1953) conjectured that factor productivity differences may be the main reason for this paradox. See Leamer (1980) for a theoretical examination of the Leontief test.

measured factor content of trade of many countries is found to be very small, much smaller than what their endowments would predict according to the standard HOV model. In Trefer's (1995) sample, the variance of measured factor content of trade is found to be only 0.032 that of the variance of HOV-predicted factor content of trade.

Trefler (1995) first performs Hicks-neutral factor-augmenting productivity adjustment, which assumes scalar factor productivity differences that are identical across factors. He finds that this adjustment improves the model quite significantly: although the number of abundant factors remains negatively correlated with GDP per capita, the correlation falls from –0.89 to –0.17. The variance ratio increases from 0.032 to 0.486. Trefler (1995) then divides the sample into a group of poor countries and a group of rich countries, allowing non-neutral productivity differences between these two groups. The results are essentially the same: the correlation is –0.22 and the variance ratio is 0.506 (for more results see Table 1 of Trefler, 1995).

The message from Trefler's (1993, 1995) studies is that factor productivity adjustment improves significantly the explanatory power of the HOV model. A recent study by Davis and Weinstein (2001), however, conveys a different message. Using a sample of 10 countries plus a "Rest of the World" of 20 other countries in year 1985, focusing on capital and labor as the two primary factors, they find that the variance ratio is 0.0005 for the standard HOV model but is only 0.008 for the modified HOV model with Hicks-neutral productivity adjustment. This leads them to conclude that the adjustment for factor productivity differences "has done next to nothing to resolve the failures in the trade model." (p. 1441) Trefler and Zhu (2000), after reviewing the representative studies in the literature, conclude that “international differences in choice of techniques cannot by themselves salvage the HOV theorem.” (p. 147)

The debate on the role of factor productivity has important implications. If the adjustment of factor productivity makes the HOV model largely fit the data, then the failure of the standard HOV model becomes only a measurement issue; we just need to measure production factors in effective units and keep using the HO model as a main analytical framework of global trade issues. However, if the adjustment of factor productivity does little in improving the model’s fit to data, then the failure becomes a more serious issue of model misspecification.

In this paper we investigate empirically the significance of factor productivity adjustment in improving the explanatory power of the HOV model. We use a new approach and a new data set. Previous studies only adjust factor endowments by Hicks-neutral productivity differences that are identical across factors, or non-neutral productivity differences limited to two income groups (e.g. Trefler, 1995). These studies may have underestimated the significance of factor productivity adjustment in improving the explanatory power of the HOV model. In this paper, we aim to adjust factor productivity differences by country and factor. The difficulty of obtaining accurate productivity measures is well-known. We argue, however, that effective factor quantities can be measured by factor earnings. Under the hypothesis of conditional factor price equalization (FPE conditional on productivity differences), if a factor in industry *X* of country *A* earns twice as much as the same factor in industry *X* of country *B*, then the factor in country *A* is twice as productive as the factor in country *B*. Thus, by choosing units effective factor quantities are simply measured by factor earnings. The advantage of this approach is that it does not require observing productivity. In fact, Trefler (1993, p. 981) suggested this approach in the concluding remarks of his paper: "An alternative method is to work in the opposite direction from factor prices to the HOV theorem…The modification of the HOV theorem under consideration would have been to replace factor endowments with factor endowment earnings." To our knowledge, we are the first to implement this approach.

The data set we use comes from the Global Trade Analysis Project (GTAP 5.4). The sample contains 66 countries and 12 country groups (211 countries in total) in 1997. Table A1 in the appendix shows the names of the 78 countries/country groups. For each country or country group there are an input-output table of 57 commodities (Table A2), input values of five primary factors (capital, land, natural resources, skilled labor, and unskilled labor), and data on bilateral trade volumes and barriers. The global coverage is one virtue of this data set compared to other data sets used in factor content studies. In the appendix we provide some information on the data.

We organize the paper as follows. In section 2 we lay out a modified HOV model that adjusts factor quantities by factor productivity, and provide a theoretical justification for using factor earnings as measures of effective factor quantities. In section 3 we apply various HOV tests to our sample and compare our results with those in the literature. In section 4 we use a model of factor price equalization clubs to interpret some of our results. In section 5 we summarize the main findings of the paper and conclude.

2. Theory

In this section we lay out the theoretical framework for our empirical investigation. Let c, i, and f index country, industry, and primary production factor, respectively. The world has C countries, N industries, and M primary factors. Each industry uses primary factors and intermediate goods from other industries to produce a final good. In country c, the production of one unit of good i requires b_{cif} units of factor f and a_{ij} units of intermediate good j. Denote the MxN matrix $\widetilde{\mathbf{B}}_c$ as the direct factor requirement matrix of country c, whose element is b_{cif}. Denote the NxN matrix $\mathbf{A}_c$ as the input-output matrix of country c, whose element is a_{ij}. Adding the direct factor input and the indirect factor input in intermediate goods yields total factor input. The total factor requirement matrix is given by $\mathbf{B}_c = \widetilde{\mathbf{B}}_c*(\mathbf{I} - \mathbf{A}_c)^{-1}$, where $\mathbf{I}$ is an identity matrix. In the literature $\mathbf{B}_c$ is usually called technology matrix, although a more precise name is technique matrix since its elements reflect the choice of production techniques that are based on both production technology and factor prices.[2]

The standard HOV model assumes that all countries have identical, constant returns to scale production technology and identical, homothetic preferences; all markets are perfectly competitive; zero trade barriers and transportation costs; all goods are produced in every country; the number of tradable goods is no less than the number of primary factors. Under these assumptions, the world is characterized by factor price equalization (FPE) and all countries share the same technology matrix $\mathbf{B}$. As discussed in the introduction, this standard HOV model performs poorly against data.

[2] See Davis and Weinstein (2003) for a recent survey of the factor content literature and a detailed discussion of the HOV model.

We deviate from the standard HOV model by allowing for cross-country differences in factor-augmenting factor productivity. Let $\mathbf{V}_c$ be the vector of factor endowments in country c, with V_{cf} denoting the amount of factor f in country c. Let the production function of industry i in country c be $Y_{ci}=G_i(\pi_{c1}V_{ci1}, \pi_{c2}V_{ci2}, \ldots, \pi_{cM}V_{ciM})$, where π_{cf}'s are factor-augmenting productivity parameters that are specific to country and factor. In effective units, industry i in country c employs $\pi_{cf}V_{cif}$ units of factor f, and country c has endowment of factor f equal to $\pi_{cf}V_{cf}$, where $V_{cf} = \sum V_{cif}$. Our null hypothesis is that FPE holds conditional on factors being measured in effective units. Following the literature we call it "Conditional FPE". Let w_{cf} be the price of factor f in country c. Conditional FPE implies that w_{cf} / π_{cf} is the same in all countries.

Consider country $c = 0$. Choosing factor units so that all factors in this country are priced at one dollar, $w_{0f} = 1$ for all f. If we measure factor-augmenting productivity differences using country 0 as the benchmark country, then $\pi_{0f} = 1$ for all f. It follows that $w_{0f} / \pi_{0f} = 1$. Thus, in the world of conditional FPE, $w_{cf} / \pi_{cf} = 1$. We can then use factor earnings to measure factor quantities in effective units; industry i in country c employs $w_{cf}V_{cif}$ units of factor f, and country c has endowment of factor f equal to $w_{cf}V_{cf}$.

Expressed in effective units, the technology matrix is given by $\overline{\mathbf{B}}_c$ for country c. Let $\overline{\mathbf{V}}_c$ be the vector of effective factor endowments in country c. Full employment implies $\overline{\mathbf{B}}_c\mathbf{Y}_c=\overline{\mathbf{V}}_c$, where $\mathbf{Y}_c$ is net output of country c. With identical and homothetic preferences, we have $\mathbf{D}_c=s_c\mathbf{Y}_w$, where $\mathbf{D}_c$ is demand for final goods and s_c is country c's share in world spending. Under conditional FPE, $\overline{\mathbf{B}}_c=\overline{\mathbf{B}}$ for all countries. Thus $\overline{\mathbf{B}}\,\mathbf{Y}_w=\overline{\mathbf{V}}_w$ for the world. Multiplying both sides by s_c, we have $\overline{\mathbf{B}}\,\mathbf{D}_c= s_c\overline{\mathbf{V}}_w$. It follows that $\overline{\mathbf{B}}\,\mathbf{T}_c= \overline{\mathbf{V}}_c - s_c\overline{\mathbf{V}}_w$, where $\mathbf{T}_c= \mathbf{Y}_c - \mathbf{D}_c$ is the net trade vector.

Theoretically, $\overline{\mathbf{B}}_c = \overline{\mathbf{B}}$ should hold under conditional FPE. As Davis and Weinstein (2001) show, however, due to aggregating goods of heterogeneous factor content within industry categories, observed $\overline{\mathbf{B}}_c$ may be different across countries even if conditional FPE is approximately correct. Because of this consideration, empirically we use country-specific technology matrix $\overline{\mathbf{B}}_c$ to calculate factor content of trade. Specifically, factor content of net exports of country *c* is calculated from $\mathbf{F}_c = \overline{\mathbf{B}}_c \mathbf{X}_c - \sum_j \overline{\mathbf{B}}_j \mathbf{M}_{cj}$, where $\mathbf{F}_c$ is the *M*x1 vector of measured factor content of trade of country *c*, $\overline{\mathbf{B}}_c$ is the *M*x*N* technology matrix of country *c*, $\mathbf{X}_c$ is the *N*x1 vector of exports of country *c*, $\overline{\mathbf{B}}_j$ is the *M*x*N* technology matrix of country *j* from whom country *c* imports, and $\mathbf{M}_{cj}$ is the *N*x1 vector of imports from country *j* of country *c*.

With factors measured in effective units, we state the modified HOV theorem as

$$\mathbf{F}_c = \overline{\mathbf{V}}_c - s_c \overline{\mathbf{V}}_w. \qquad (1)$$

The left side of equation (1) is the measured factor content of trade. The right side of equation (1) is the factor content of trade predicted by the modified HOV model. The modified HOV theorem predicts that if country *c* is abundant in factor *f* in effective units (i.e. $\overline{V}_{cf} / \overline{V}_{wf} > s_c$), then it will be a net exporter of factor content of *f* (i.e. $F_{cf} > 0$).

3. Testing the Modified HOV Model

In this section we test the modified HOV theorem using a sample of 78 countries or country groups, five primary factors, and 57 industries. The appendix provides information about the data used in constructing the sample.

The modified HOV theorem claims that measured factor content of trade in effective factor units, $\mathbf{F}_c$, should equal predicted factor content of trade in effective factor units, $\overline{\mathbf{V}}_c - s_c\overline{\mathbf{V}}_w$. We first perform three simple tests.[3]

(1) Correlation Test

This is simply looking at the correlation between $\mathbf{F}_c$ and $\overline{\mathbf{V}}_c - s_c\overline{\mathbf{V}}_w$. The theoretical value of the correlation is unity.

(2) Sign Test

This test asks if sign ($\mathbf{F}_c$) = sign ($\overline{\mathbf{V}}_c - s_c\overline{\mathbf{V}}_w$). It compares the sign pattern of $\mathbf{F}_c$ and the sign pattern of $\overline{\mathbf{V}}_c - s_c\overline{\mathbf{V}}_w$. An unweighted sign test gives the percentage that the two have the same sign. A weighted sign test attaches more weight to observations with large net factor contents of trade. The theoretical value of the sign test is unity. A completely random pattern of signs would generate correct signs 50% of the time in a large sample.

(3) Rank Test

This test involves a pairwise comparison of all factors for each country. If the computed factor contents of one factor exceed that of a second factor (e.g. $F_{cf} > F_{ck}$), then we check if the relative abundance of the first factor also exceeds that of the second factor ($V_{cf} - s_cV_{wf} > V_{ck} - s_cV_{wk}$). The theoretical value of the rank test is unity. A completely random large sample would yield 50%.

[3] Bowen, Leamer, and Sveikauskas (1987) developed these tests.

Table 1: Results from Simple HOV Tests

	Productivity Differences	Correlation	Sign Test (unweighted)	Sign Test (weighted)	Rank Test
Trefler (1995)	None	0.28	0.50	0.71	0.60
	Neutral	0.59	0.62	0.78	0.62
	Non-Neutral (Rich vs. Poor)	0.63	–	0.76	–
Current Paper	Factor-Specific	0.81	0.78	0.91	0.76

Table 1 reports the results from the three tests. For comparison, we also display the results of Trefler (1995). When there is no productivity adjustment, Trefler (1995) finds that the predicted factor content of trade has little correlation with measured factor content of trade, and the HOV model's prediction is no better than a coin toss. By introducing Hicks-neutral productivity differences that are identical across factors, Trefler (1995) finds that the correlation increases to 0.59. By considering neutral and non-neutral productivity differences (limited to two income groups), the correlation increases to 0.63. In both cases, the sign test and rank test show only moderate improvement. Using a different data set, Davis and Weinstein (2001) find that the correct signs only account for 32-45 percent when there is no productivity adjustment. With Hicks-neutral productivity differences, the correct signs account for 50 percent, precisely a coin toss. This leads them to conclude that "the adjustment for efficiency…has done next to nothing to resolve the failures in the trade model." (p. 1441)

The last row of Table 1 reports the test results of our study. Previous studies consider Hicks-neutral productivity differences or at best non-neutral productivity differences between two income groups. As explained in last section, factor earnings can be measures of effective factor quantities. This measurement of effective factor quantities takes into account factor-specific productivity differences between countries. Using this approach, we find the correlation between measured factor content of trade and predicted factor content of trade to be 0.81. The unweighted sign test indicates that 78 percent of the signs are correct. When more weights are attached to observations with large net factor contents of trade, the sign test result is 0.91. The rank test result is 0.76. Taken together, these results show that our consideration of factor-specific productivity differences improves significantly the model's fit to data. They provide support for our using factor earnings as a proxy for effective factor quantities.

To go beyond the simple tests, we examine the following two puzzles identified by Trefler (1995).

(1) Endowment Paradox

This paradox is shown in the correlation between real GDP per capita of country *c* and the number of abundant factors ($V_{cf} - s_c V_{wf} > 0$) in country *c*. In theory, there should be little correlation between the two because poor countries are abundant in some factors and rich countries are abundant in some other factors.

(2) Missing Trade Mystery

This mystery is shown in the ratio of the variance of $\mathbf{F}_c$ to the variance of $\overline{\mathbf{V}}_c - s_c \overline{\mathbf{V}}_w$. If the modified HOV model fits the data perfectly, then the ratio is unity. If this ratio is found close to zero, then we have a "Missing Trade Mystery".

Table 2: Endowment Paradox and Missing Trade Mystery

	Productivity Differences	Endowment Paradox	Missing Trade Mystery
Trefler (1995)	None	–0.89	0.032
	Neutral	–0.17	0.486
	Non-Neutral (Rich vs. Poor)	–0.22	0.506
Current Paper	Factor-Specific	–0.50	0.447

Table 2 reports the results. Regarding "Endowment Paradox", Trefler (1995) finds that the correlation between the number of abundant factors and per capital GDP is a high –0.89, but it decreases to about –0.20 after adjusting for neutral productivity differences and non-neutral productivity differences between two income groups. Regarding "Missing Trade Mystery", Trefler (1995) finds that the variance ratio is only 0.032; there is simply no variation in the measured factor content of trade. With neutral and non-neutral productivity adjustments the variance ratio increases to about 0.5, which is a significant improvement.

The last row of Table 2 reports results from our sample. The correlation is –0.50, indicating that the endowment paradox still exists. The variance ratio is 0.447, lower than the 0.5 obtained by Trefler (1995). Why are our results poorer than that of Trefler (1995) considering that we take into account more productivity differences? How do we reconcile the less successful results in Table 2 with the more successful results in Table 1?

As a first step towards answering these questions, we examine plots of measured factor content of trade (MFCT), $\mathbf{F}_c$, against predicted factor content of trade (PFCT), $\overline{\mathbf{V}}_c - s_c\overline{\mathbf{V}}_w$. Figure 1 shows the plots in six panels.

(1) All Five Factors

Figure 1(a) shows plots of all five factors. The 45-degree line is the theoretical prediction of the modified HOV theorem. There are some large deviations such as India (Id = 15), but the positive correlation between MFCT and PFCT is quite clear. While many points are close to MFCT = 0, there are quite many points with MFCT not close to zero. The point (Id = 65) is eye-catching, which is the country group "Rest of Middle East". Obviously this point is associated with oil.

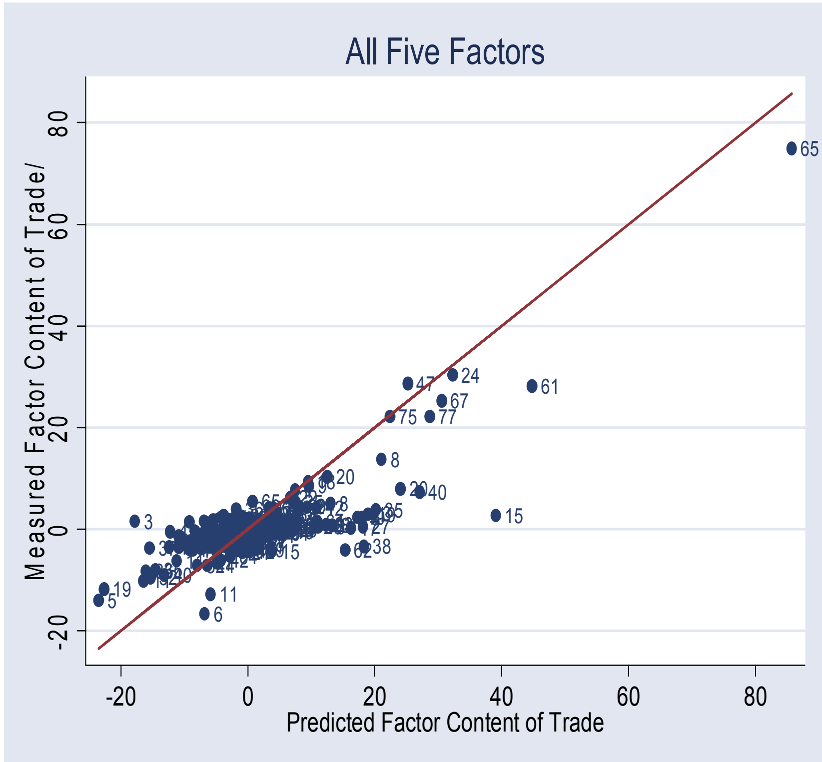

Figure 1 (a)

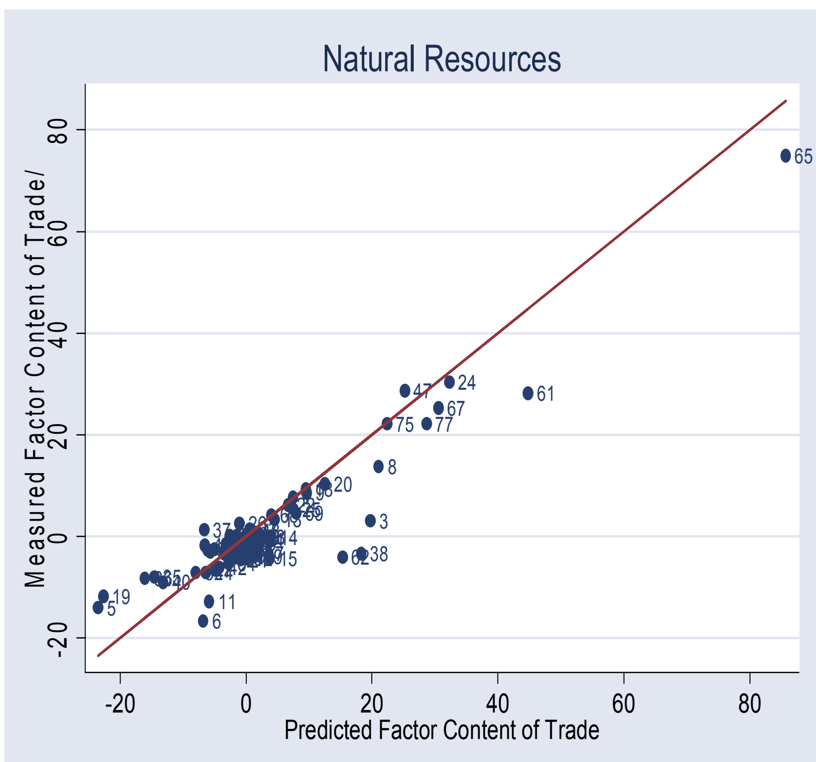

Figure 1 (b)

(2) Natural Resources

In our data, natural resources refer to cost value of non-producible natural source inputs used in sectors of coal, oil, natural gas, minerals, fisheries and forestry. Figure 1(b) shows that the modified HOV model explains the natural resource content of trade very well. Our interpretation is that most of these natural resource items are traded in the world market and hence have similar prices across countries. Because of this, factor earnings of natural resources are good proxies for quantities of natural resources.

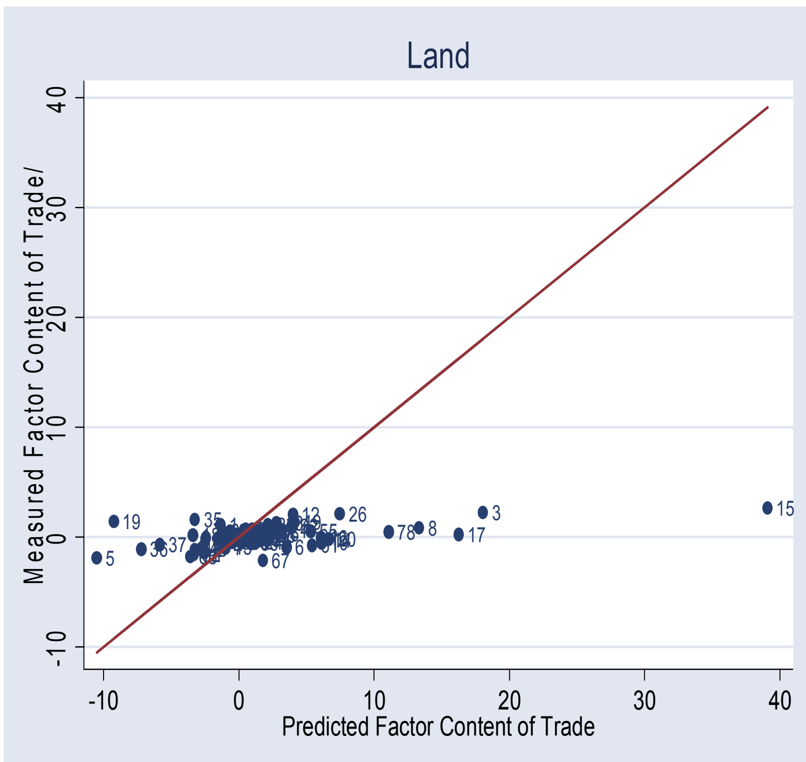

Figure 1 (c)

(3) Land

In sharp contrast to natural resources, we find in Figure 1(c) that measured land content of trade is close to zero for the sample. This is "missing trade" big time. The countries with the highest predicted land content of trade (predicted to export land services) are India (Id = 15) and China (Id = 3). The countries with the lowest predicted land content of trade (predicted to import land services) are the U.S. (Id = 19) and Japan (Id = 5). This finding is at odds with the fact that China is scarce in land and the U.S. is abundant in land. It suggests that the effective amount of land is greatly overestimated for India and China, and greatly underestimated for the U.S. We will discuss this later.

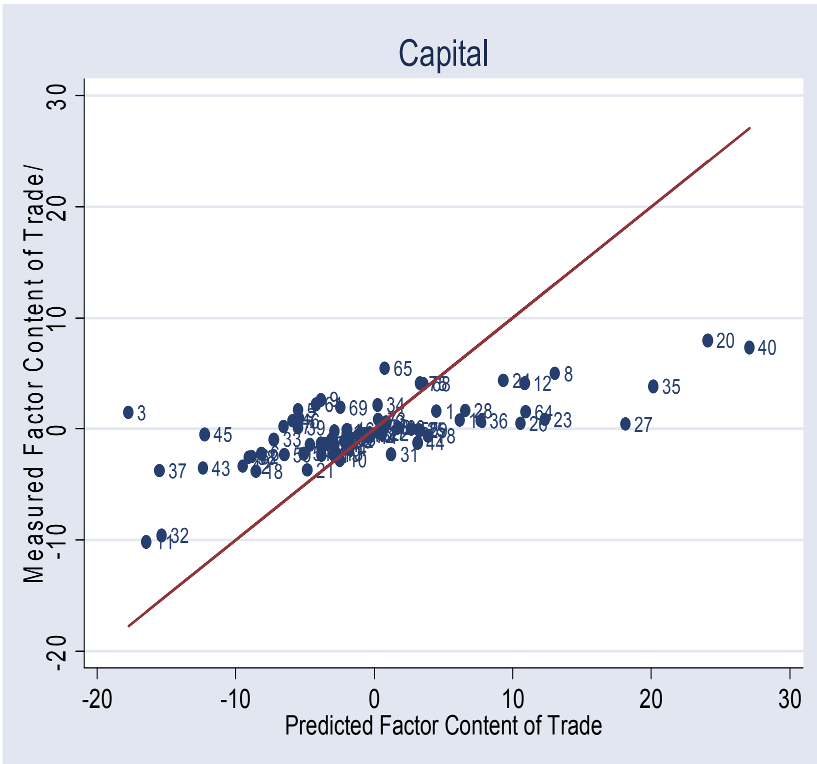

Figure 1 (d)

(4) Capital

"Missing Trade" is clear in of capital content of trade as shown in Figure 1(d). The figure also shows some puzzling observations. Mexico (Id = 20) is shown to be capital-abundant and exporting capital content. China (Id = 3) is shown to be capital-scarce and yet exporting capital content.

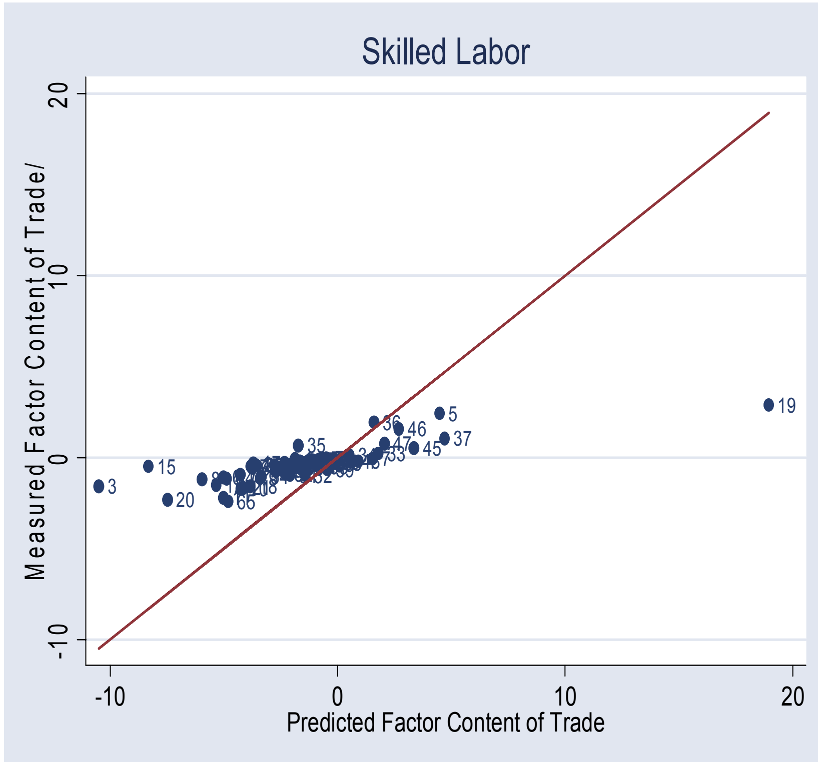

Figure 1 (e)

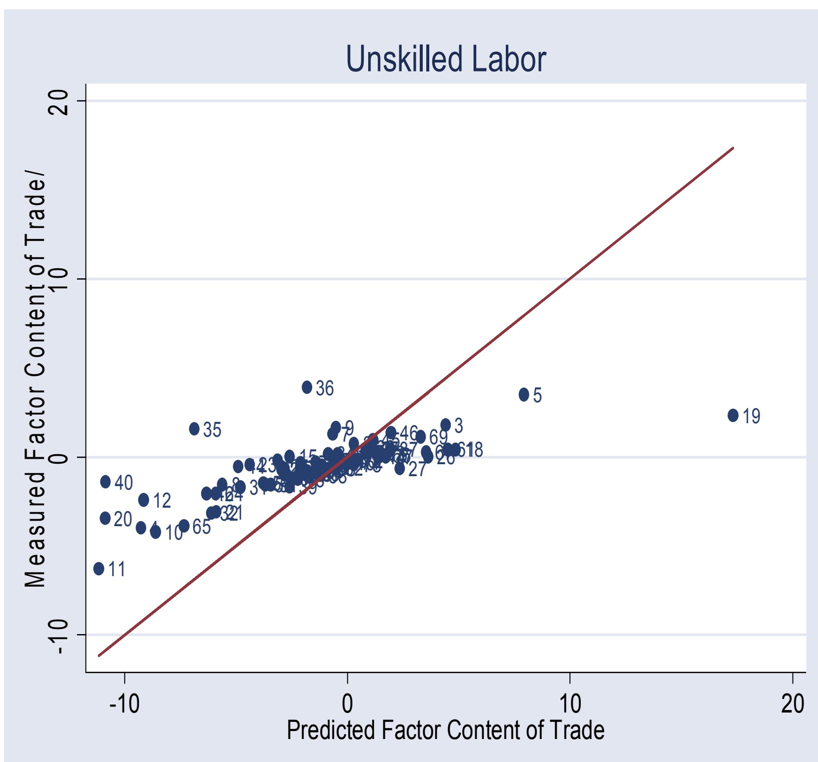

Figure 1 (f)

(5) Labor

Figures 1(e) and 1(f) illustrate the model's predictions on skilled and unskilled labor, respectively. The U.S. (Id = 19) is a clear outlier. The effective labor measured by labor earnings must have overestimated the true effective labor of the U.S. The same applies to Japan (Id = 5) to a less degree. On the other hand, the effective labor measured by labor earnings must have underestimated the true effective unskilled labor of Mexico (Id = 20). "Missing Trade" is quite serious in both labor categories.

The inspection of the graphs suggests two useful points. First, the conditional FPE assumption is crucial for using factor earnings as measures of effective factor quantities. In the case of natural resources in which the assumption is likely to hold, the measured natural resource content of trade is almost exactly what predicted by the modified HOV model. This result is quite significant since it is not automatic. It is worth noting that the natural resource factor is not entirely responsible for the results in Table 1. When we exclude natural resources, the unweighted sign test indicates that 75 percent of the signs are correct as opposed to 78 percent when we include natural resources, although the simple correlation between MFCT and PFCT does drop from 0.81 to 0.52.

Second, the inspection of the graphs suggests a systematic pattern of deviations. Factor earnings overestimate effective labor amount of developed countries such as the U.S. and Japan, and underestimate effective land and capital amount of these countries. By contrast, factor earnings overestimated effective land and capital amount of less developed countries such as India, China, and Mexico, but underestimate labor amount of these countries. This leads us to the next section.

4. Factor Price Equalization Clubs

In this section we examine further the systematic deviations in our data. We argue that a model of factor price equalization clubs may explain much of the deviations.

One crucial assumption of the modified HOV model is conditional FPE. Suppose this assumption does not hold; instead, assume that countries are located in multiple diversification cones which we call "Conditional FPE Clubs" or "FPE Clubs" for simplicity. How does this affect our results? To see the logic, we use a simple example. Under conditional FPE, we have wL and rK measuring effective labor and capital of China, w^*L^* and r^*K^* measuring effective labor and capital of the U.S. Here $w/a=w^*/a^*=\overline{w}=1$ and $r/b=r^*/b^*=\overline{r}=1$, where $\overline{w}$ and $\overline{r}$ are the factor prices in the reference country normalized to be one, and a, a^*, b, b^* are productivity parameters. Now consider the case with no conditional FPE. Labor is so abundant in China and capital is so abundant in the U.S. that $w/a<w^*/a^*$ and $r/b>r^*/b^*$ in equilibrium. With the reference country having the world average factor abundance, we have $w<a$, $w^*>a^*$, $r>b$, and $r^*<b^*$. Therefore, wage earning (wL) underestimates China's effective labor (aL) while capital earning (rK) overestimates China's effective capital (bK). For the same logic, wage earning (w^*L^*) overestimates U.S.'s effective labor (a^*L^*) while capital earning (r^*K^*) underestimates U.S.'s effective capital (b^*K^*).

It is difficult to identify FPE clubs from the data. What we do is to divide the sample into groups according to real GDP per capita and examine results from the subsamples to gain some insight. As a first step, we divide the sample into three groups. The high-income group contains 24 countries with real GDP per capita (Penn World Table 6.1) in 1997 exceeding $15,000. The middle-income group contains 30 countries with real GDP per capita between $5,000 and $15,000. The low-income group contains 24 countries with real GDP per capita below $5,000.

Table 3: Results from Three Income Groups

	Endowment Paradox	Missing Trade Mystery
Full Sample (78)	–0.50	0.447
High-Income Sample (24)	0.08	0.499
Middle-Income Sample (30)	–0.12	0.552
Low-Income Sample (24)	0.001	0.600

Note: The number in parentheses is the number of countries in the sample.

Table 3 reports the results. Once we divide the sample into three income groups, we find that the endowment paradox is largely resolved. Recall that the endowment paradox refers to a strong negative correlation between the number of abundant factors and GDP per capita—poor countries are found to be abundant in almost all factors and rich countries are found to be scarce in almost all factors. Table 3 shows that there is little correlation between the number of abundant factors and GDP per capita in all three income groups. Notice also that the variance ratio, which is a measure of "Missing Trade", sees an improvement in all three groups.

The result on the endowment paradox can be explained as follows. As we discussed above, in a multi-cone world, our measures of effective factor quantity overestimate or underestimate factor abundance. For two countries in different FPE clubs, the measurement biases apply to different factors. For countries in the same FPE club, however, the measurement biases apply to the same factors. Thus the measurement biases can affect significantly the correlation between the number of abundant factors and GDP per capita in a sample of countries that belong to different income groups, but it would have little effect on this correlation in a sample of countries that belong to a FPE club. The evidence reported in Table 3 is consistent with this reasoning.

Table 3 shows the variance ratio of 0.5-0.6, which is quite remarkable considering that the missing trade mystery has a lot to do with the preference side, which has not been considered so far. As a robustness check of the results in Table 3, we report in Table 4 the results when the sample is divided equally into four income groups.

Table 4: Results from Four Income Groups

	Endowment Paradox	Missing Trade Mystery
High-Income Sample (19)	–0.098	0.548
High Middle-Income Sample (20)	0.122	0.380
Low Middle-Income Sample (19)	–0.020	0.451
Low-Income Sample (20)	–0.058	0.675

Note: The number in parentheses is the number of countries in the sample. The income thresholds are \$20500, \$8000, and \$4000.

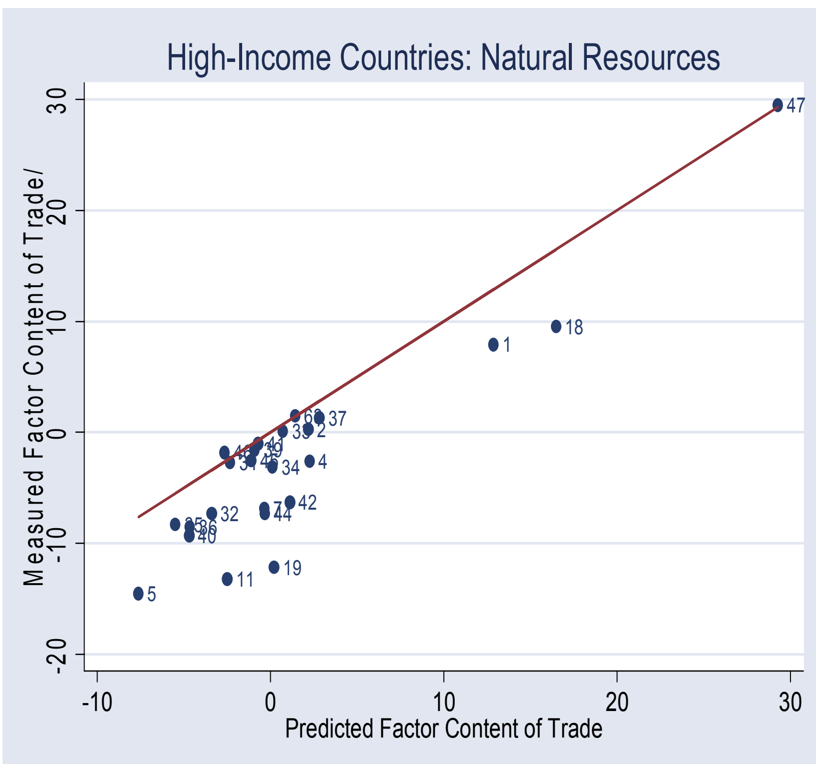

Figure 2 (a)

Arguably the high-income group is the closest to a FPE club, so we examine plots of MFCT against PFCT for this group. Figure 2(a) shows natural resources. The model predicts well. The three resource-rich countries are Norway (Id = 47; more precisely this is a country group named “Rest of EFTA” that also includes Iceland and Liechtenstein), Canada (Id = 18) and Australia (Id = 1). Measured natural resource contents of trade of these three countries are close to what the model predicts. Not surprisingly, the majority of high-income counties are net importers of natural resource content.

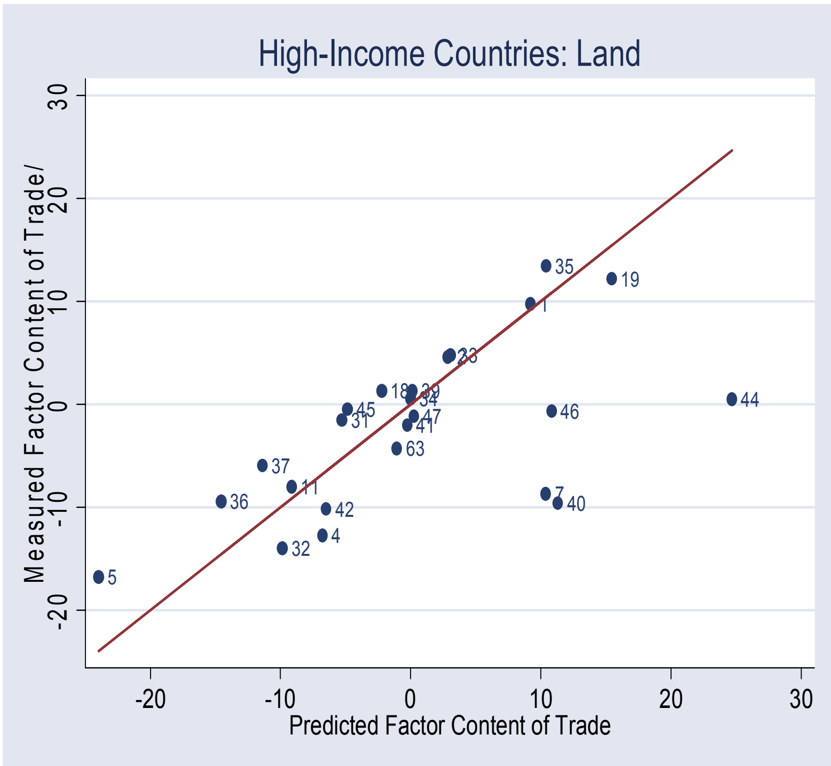

Figure 2 (b)

Figure 2(b) shows the model’s prediction of land content of trade. The three countries with largest deviations (Spain=44, Italy=40, Taiwan=7) are less wealthy countries in this group, which may belong to a different FPE club. The model predicts other countries very well. The land-abundant countries are U.S. (19), France (35), and Australia (1). The most land-scarce country is Japan (5). The results displayed in Figure 2(b) are quite remarkable if one recalls that missing trade in land is extremely severe in the full sample displayed in Figure 1(c).

Figure 2 (c)

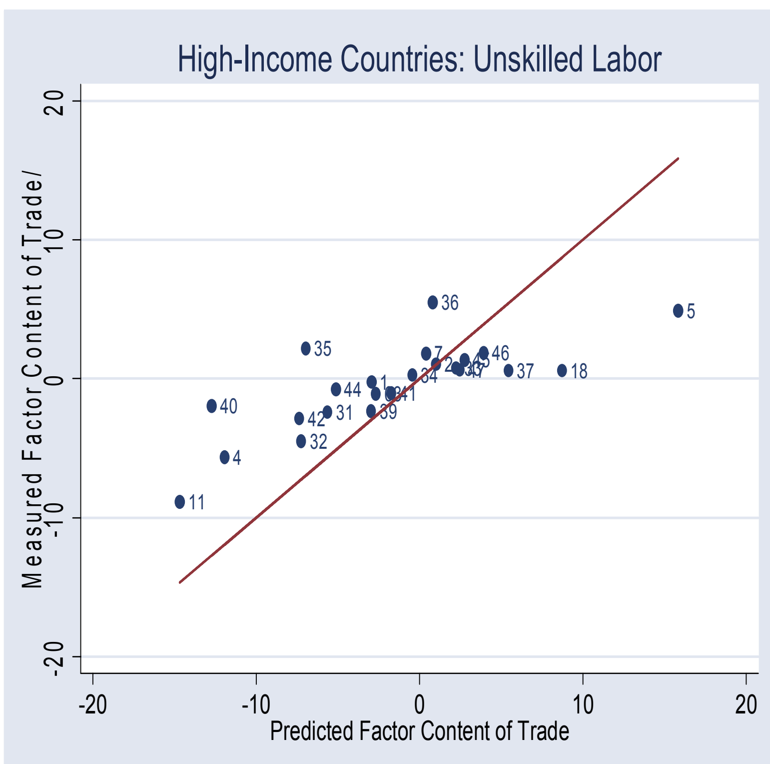

Figure 2 (d)

Figures 2(c) and 2(d) show the model's predictions on skilled labor and unskilled labor in the high-income sample excluding the U.S. In both figures, the model's predictions are quite successful. As we discussed above, with FPE clubs, our measure of labor abundance overestimates that of high-income countries; if they belong to the same FPE club, however, the overestimation bias tends to be the same for all the countries and hence we can still have MFCT and PFCT close to equality as in Figures 2(c) and 2(d). This does not necessarily happen, however. Figure 2(e) shows that the model's prediction is less successful with regard to capital.

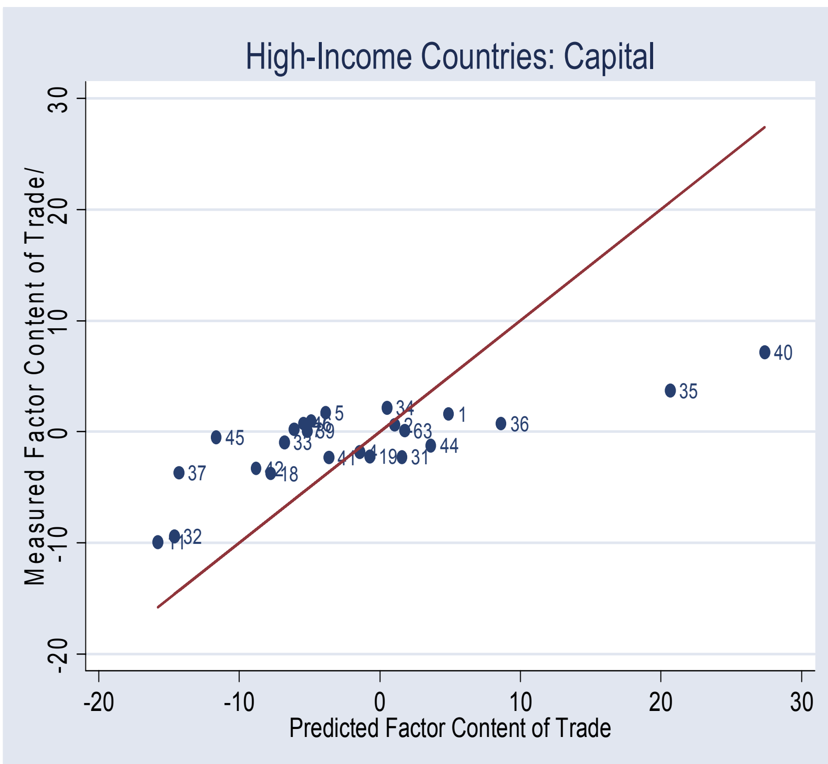

Figure 2 (e)

The graphs for middle-income and low-income samples do not look as successful as those for the high-income groups, which we show in the appendix. The reason may be that each of these two groups itself contains multiple FPE clubs.

5. Summary and Conclusion

This paper examines the role of factor productivity differences in explaining global trade. Trade economists have used the Heckscher-Ohlin model as a main analytical framework for trade issues, but data does not support the model's empirical predictions on factor content of trade. One explanation for its failure is that it does not consider cross-country differences in factor productivity. Empirical evidence for this explanation is mixed. There is evidence that factor productivity adjustment improves significantly the model's fit to data (e.g. Trefler, 1993, 1995), and there is evidence that it helps little of the model's fit (e.g. Davis and Weinstein, 2001).

One limitation of the existing studies is that productivity adjustment is limited to Hicks-neutral productivity differences which are identical across factors, or at most productivity differences that are non-neutral only between two country groups. This limitation may have resulted in inaccurate measurement of effective factor quantities of a country, partially responsible for the empirical failure of the model.

In this paper we aim to capture a wider range of factor productivity differences. We adopt an approach that uses factor earnings to measure effective factor quantities. The theoretical basis of this approach is that, under conditional FPE (factor price equalization conditional on factor productivity differences), the relative productivity of a factor in two countries equals the relative price of the factor in the two countries, so the effective factor prices of the two countries are the same. This approach has an empirical advantage: it does not require data on factor productivities or factor prices; all is needed is the information on payments to factors.

The Global Trade Analysis Project (GTAP 5.4) provides such data. We use the GTAP data to perform some standard tests on the HOV model modified with factor productivity differences. Our results show that the correlation between measured factor content of trade and predicted factor content of trade is 0.81. The sign of measure factor content of trade matches the sign of predicted factor content of trade 78 percent of the time when unweighted or 91 percent of the time when weighted by the size of factor content of trade, a significant improvement over previous estimates based on Hicks-neutral or two-group productivity adjustments. These results seem to suggest that adjustment of factor-specific productivity differences can lead to a significant improvement in the HOV model's fit to data.

A further examination of the data identifies important deviations of the empirical estimates from the model. The "Endowment Paradox" and "Missing Trade Mystery", two puzzles identified by Trefler (1995), still exist in our data with productivity adjustment. The number of abundant factors of a country is smaller the higher the country's GDP per capita; the correlation between the two is –0.5. The variance of measured factor content of trade is only 44.7 percent of the variance of the predicted factor content of trade, while much higher than the "missing trade" value of 3.2 percent in Trefler's data with no productivity adjustment, fares no better than the 48.6 percent in Trefler's data with Hicks-neutral productivity adjustment.

Inspection of the deviations of the estimated factor content of trade allows us to identify some patterns. Our measures of productivity-adjusted factor endowments tend to overestimate the labor endowments of high-income countries but underestimate their land and capital endowments. Our measures of productivity-adjusted factor endowments tend to underestimate the labor endowments of low-income countries but overestimate their land and capital endowments. In addition, for the production factor of natural resources, we find that the model's prediction fits the data extremely well.

We explain the regularities and anomalies in our results with a multi-cone model in which countries belong to different "conditional FPE clubs". Because many natural resource items are traded, the assumption of conditional FPE holds for this factor and hence we see a success of the HOV model with regard to this production factor. Because in a multi-cone world labor scarcity of the high-income countries drives wage rates way above those of the low-income countries, wage earnings in the high-income countries overestimate productivity-adjusted labor quantities, while the opposite is true for land and capital, our measures of effective factor quantities are biased, which explains why they do not fare well with the "Endowment Paradox" test and "Missing Trade" test which are based largely on between-country factor quantity comparisons. On the other hand, the correlations and sign matches are more successful because they are affected less by between-country factor quantity comparisons.

We find further evidence to support our explanation. When we split the sample into three or four income groups, we find that the endowment paradox disappears. This is because our factor measures are biased in a systematic way; the bias is the same for the countries in the same FPE club and hence the measurement of factor abundance between them does not exhibit a correlation between factor abundance and GDP per capita. We also find some improvement in resolving the missing trade mystery; the variance ratios increase to 0.5-0.6 when we apply the variance test to income-group samples.

Arguably the group of high-income countries is the closest among all country groups to a conditional FPE club. Our results support this view. We find that the modified HOV model gives much better predictions for the high-income sample than the full sample or the middle-income or low-income samples.

We draw two conclusions: (1) Productivity adjustment needs to be adequately done to judge the validity of the HOV model. Previous studies may have underestimated the significance of factor productivity adjustment in improving the fit of the HOV model. (2) There are patterns in the deviations of the estimates from the HOV model with conditional FPE, which may be explained by considering “conditional FPE clubs”.

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Appendix

1. Data Summary

Table A1: Countries/Country Groups in GTAP 5.4 Data Base

Id	High-Income	RGDPL	Id	Middle-Income	RGDPL	Id	Low-Income	RGDPL
41	Luxembourg	37917	6	Korea	14786	23	Peru	4649
19	United States	30190	43	Portugal	14024	55	Romania	4640
4	Hong Kong	26524	53	Malta	13908	67	Rest of North Africa	4319
47	Rest of EFTA	25862	57	Slovenia	13787	62	Rest of Former Soviet Union	4265
11	Singapore	24939	51	Czech Republic	13454	8	Indonesia	3990
46	Switzerland	24834	38	Greece	13187	78	Rest of World	3896
33	Denmark	24776	75	Other Southern Africa	11976	21	Central America and the Caribbean	3752
5	Japan	24428	26	Argentina	11354	66	Morocco	3627
18	Canada	24080	56	Slovakia	10556	25	Rest of Andean Pact	3413
1	Australia	23614	29	Uruguay	9715	10	Philippines	3358
42	Netherlands	22146	28	Chile	9518	3	China	3110
32	Belgium	21845	9	Malaysia	9491	16	Sri Lanka	3011
31	Austria	21717	52	Hungary	9111	48	Albania	2763
36	Germany	21379	58	Estonia	8231	74	Zimbabwe	2682
45	Sweden	21266	54	Poland	8142	15	India	2162
40	Italy	20879	50	Croatia	7843	17	Rest of South Asia	1837
37	United Kingdom	20710	20	Mexico	7639	13	Vietnam	1812
34	Finland	20672	69	Rest of South African Customs Union	7189	14	Bangladesh	1546
35	France	20511	61	Russian Federation	7149	77	Rest of Sub Saharan Africa	1009
39	Ireland	20323	24	Venezuela	7038	71	Mozambique	943
2	New Zealand	17710	12	Thailand	7029	76	Uganda	885
7	Taiwan	16434	27	Brazil	7014	73	Zambia	871
44	Spain	16141	60	Lithuania	6826	70	Malawi	787
63	Cyprus	15813	64	Turkey	6763	72	Tanzania	424
			59	Latvia	6698			
			68	Botswana	6428			
			22	Colombia	5645			
			49	Bulgaria	5457			
			65	Rest of Middle East	5073			
			30	Rest of South America	5064			

Notes: Id is country code in GTAP 5.4 Data Base. RGDPL is real GDP per capita in 1997 (Penn World Table 6.1). For a country group, RGDPL is the sum of real GDP of all countries in the group divided by total population of countries in the group. For names of the countries in a country group, see "Guide to the GTAP Data Base", in *GTAP 5 Data Package Documentation*, Chapter 8.

Table A2: Sectors in GTAP 5.4 Data Base

Code	Sectors	Code	Sectors
1	Paddy rice	30	Wood products
2	Wheat	31	Paper products, publishing
3	Cereal grains nec	32	Petroleum, coal products
4	Vegetables, fruit, nuts	33	Chemical, rubber, plastic products
5	Oil seeds	34	Mineral products nec
6	Sugar cane, sugar beet	35	Ferrous metals
7	Plant-based fibers	36	Metals nec
8	Crops nec	37	Metal products
9	Bovine cattle, sheep and goats, horses	38	Motor vehicles and parts
10	Animal products nec	39	Transport equipment nec
11	Raw milk	40	Electronic equipment
12	Wool, silk-worm cocoons	41	Machinery and equipment nec
13	Forestry	42	Manufactures nec
14	Fishing	43	Electricity
15	Coal	44	Gas manufacture, distribution
16	Oil	45	Water
17	Gas	46	Construction
18	Minerals nec	47	Trade
19	Bovine meat products	48	Transport nec
20	Meat products nec	49	Water transport
21	Vegetable oils and fats	50	Air transport
22	Dairy products	51	Communication
23	Processed rice	52	Financial services nec
24	Sugar	53	Insurance
25	Food products nec	54	Business services nec
26	Beverages and tobacco products	55	Recreational and other services
27	Textiles	56	Public Administration, Defense, Education, Health
28	Wearing apparel	57	Dwellings
29	Leather products		

2. Input-Output Data

The input-output matrix gives the value of 57 domestic commodities used in the 57 domestic production sectors. There are five production factors used in domestic production. We compute domestic factor values contained in domestic net output. Net output of a sector is gross output less the good of that sector used as intermediate goods in all other sectors of the country.

3. Trade Data

For each country, there are data of exports of 57 domestic sectors to 77 other countries, measured in world prices. We use the data to compute factor content of a country's exports to all other countries. From this we obtain factor content of imports of a given country.

4. Factor Units

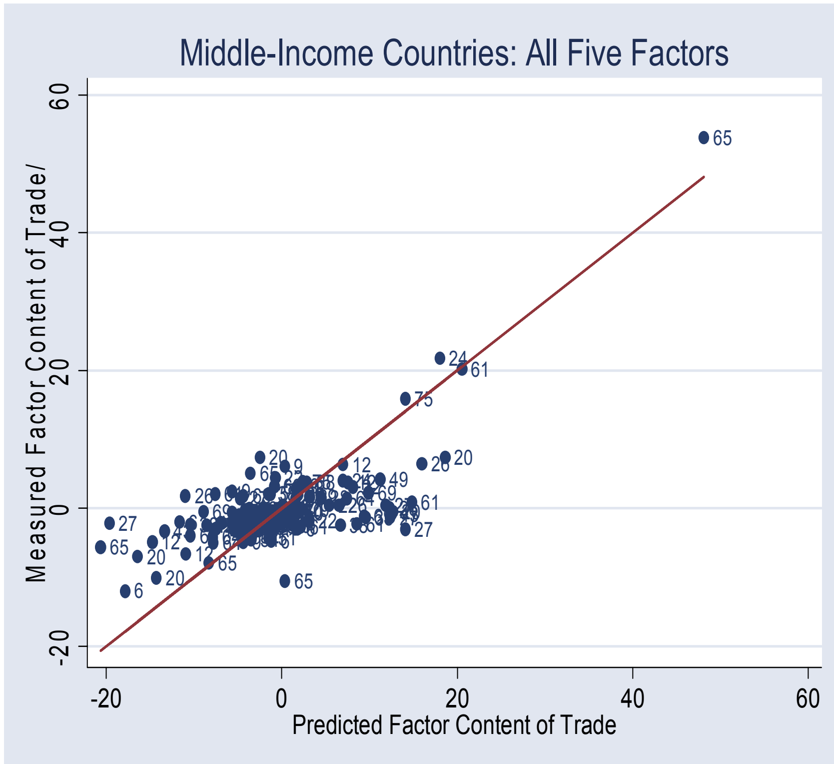
For factors to be expressed in comparable units (to satisfy the statistical hypothesis of homoscedasticity), we follow Trefler (1995) to scale the data by $\sigma_f s_c^{1/2}$, where σ_f is the standard error of $\varepsilon_{cf} = F_{cf} - (V_{cf} - s_c V_{wf})$.

5. Primary Factors

The split between skilled and unskilled labor is on the basis of occupational classifications of the International Labor Organization (ILO). For details, see "Skilled and Unskilled Labor Data", in *GTAP 5 Data Package Documentation*, Chapter 18.D. For natural resources, see "Primary Factor Shares", Chapter 18.C. For capital stock data, see "Capital Stock and Depreciation", Chapter 18.B.

6. Additional Results

The following are graphs for the Middle-Income Sample and Low-Income Sample.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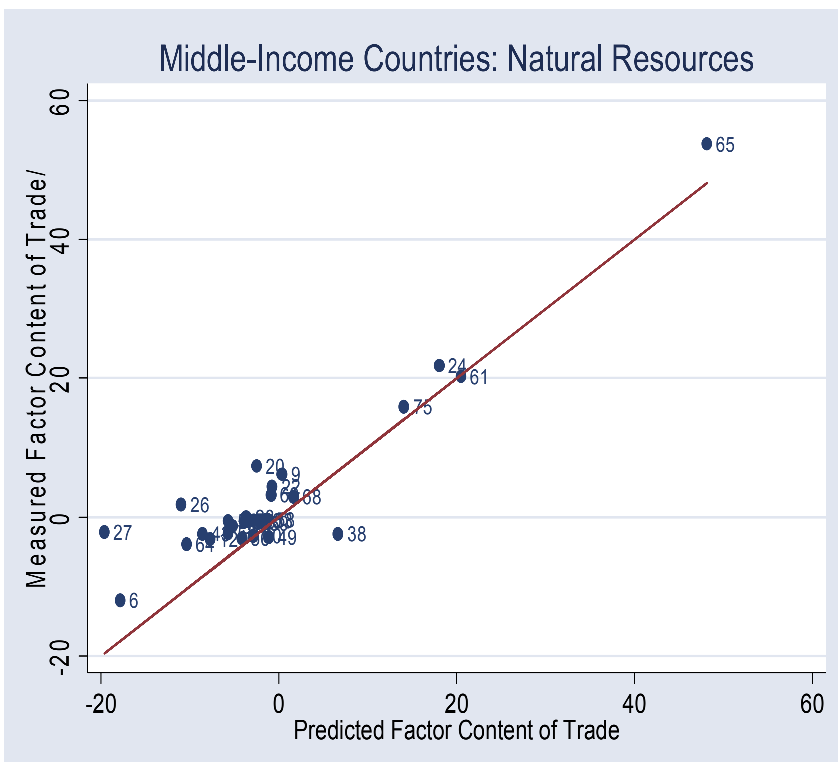
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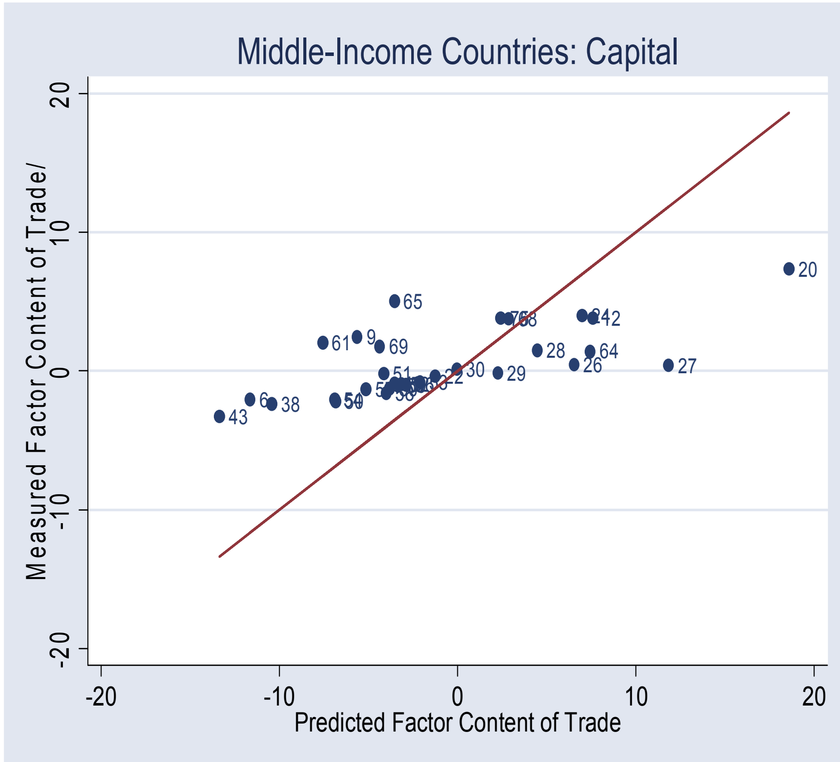

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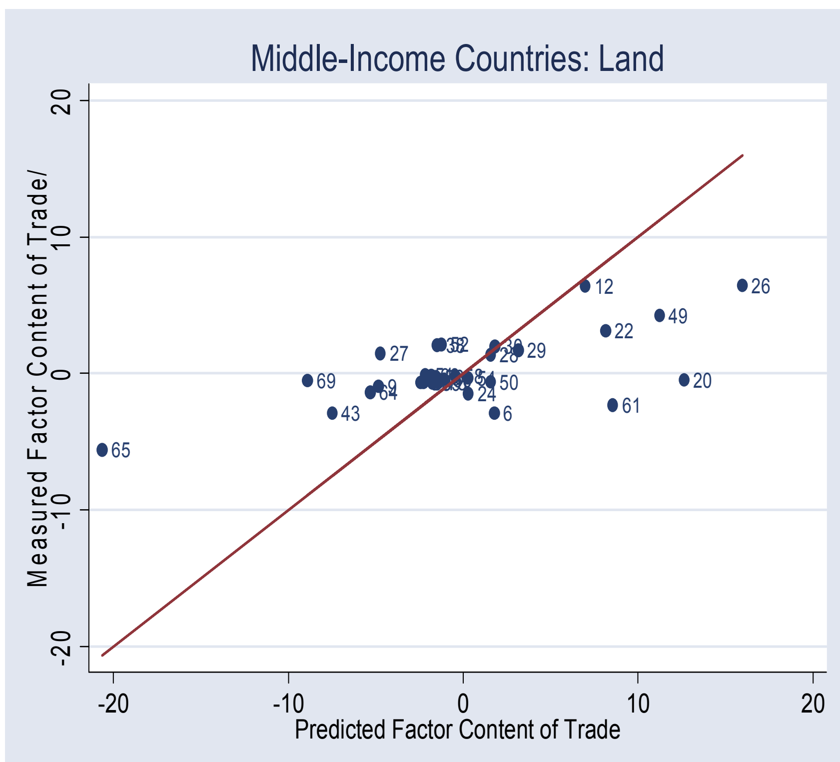
Predicted Factor Content of Trade



Middle-Income Countries: Land
Measured Factor Content of Trade/
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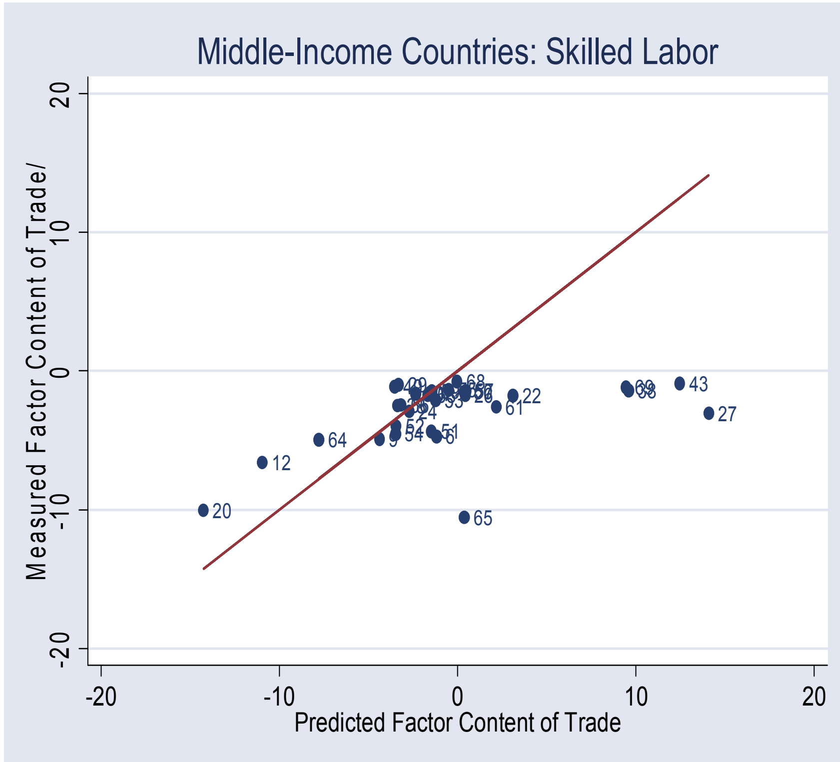
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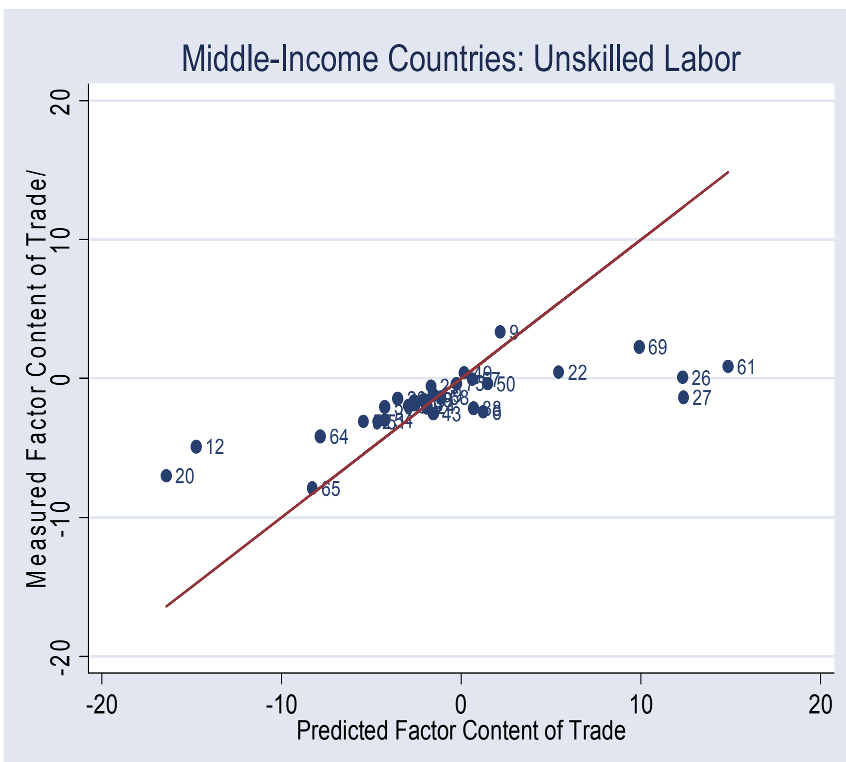
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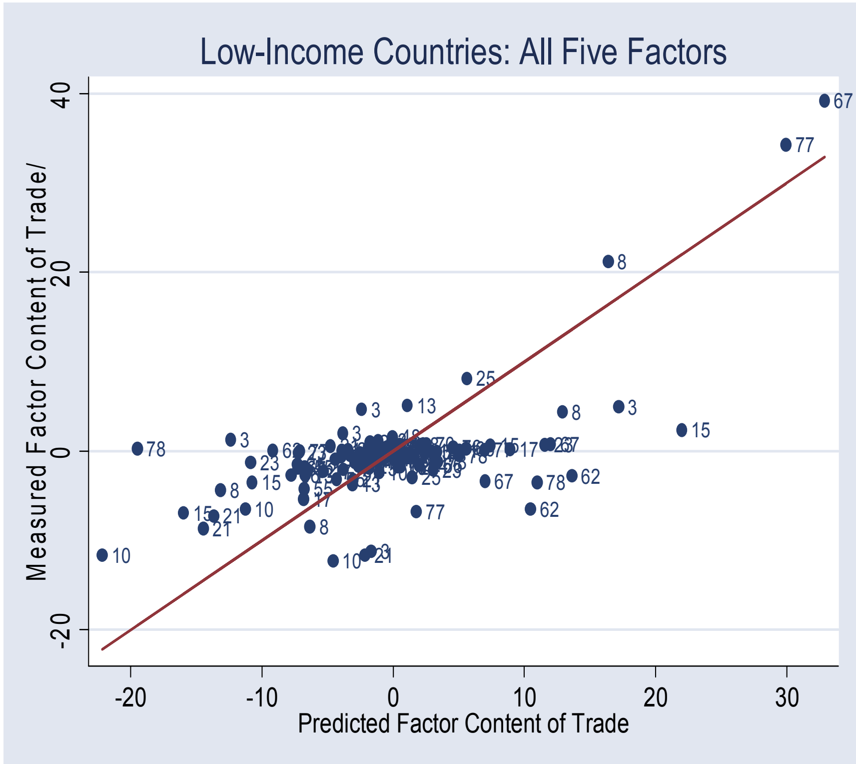
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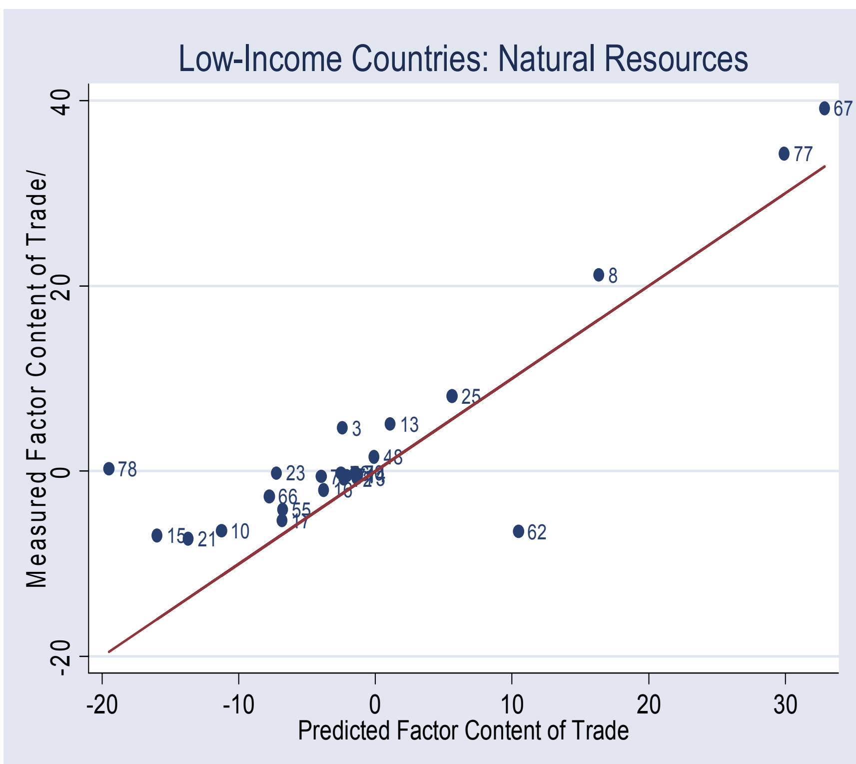
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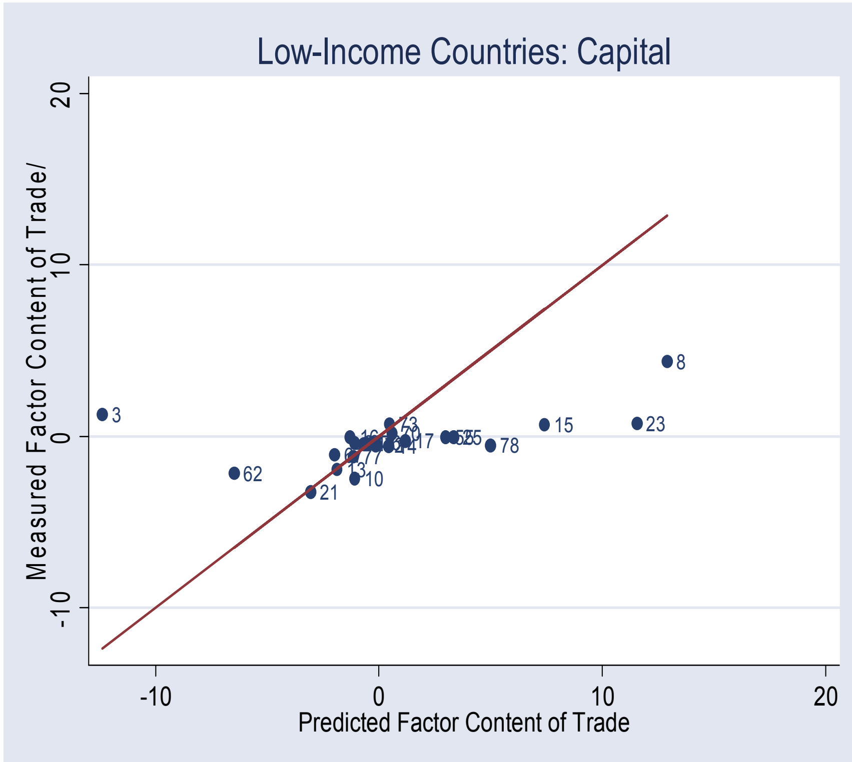
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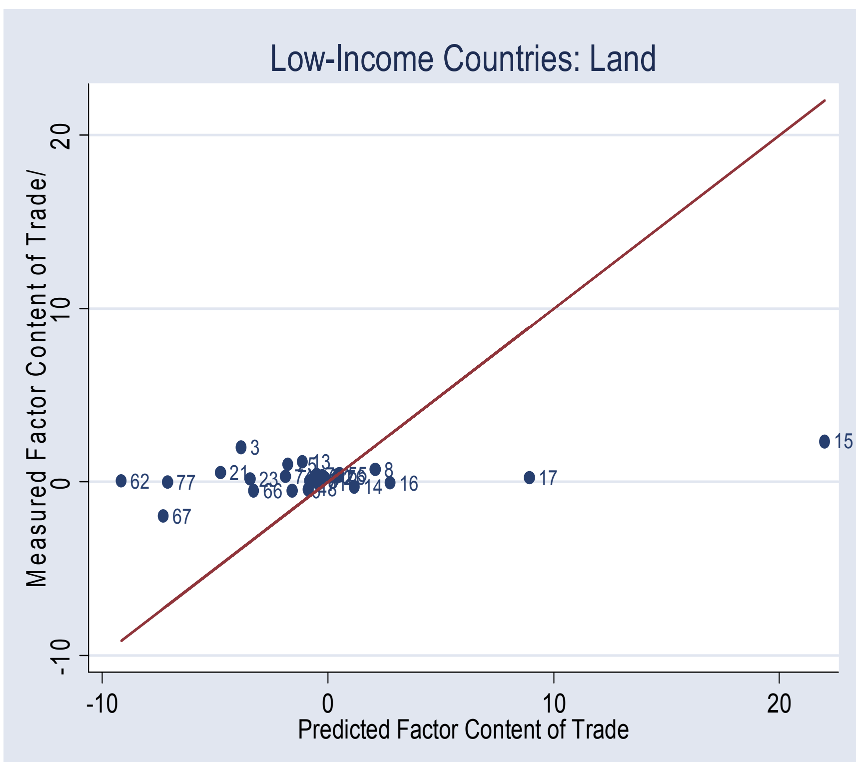
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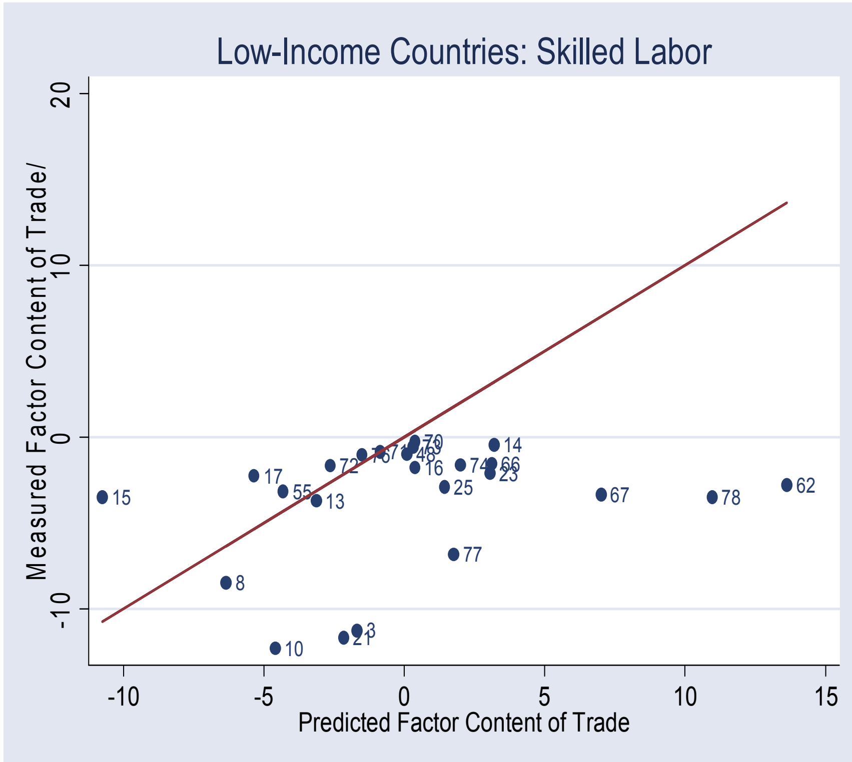
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Predicted Factor Content of Trade
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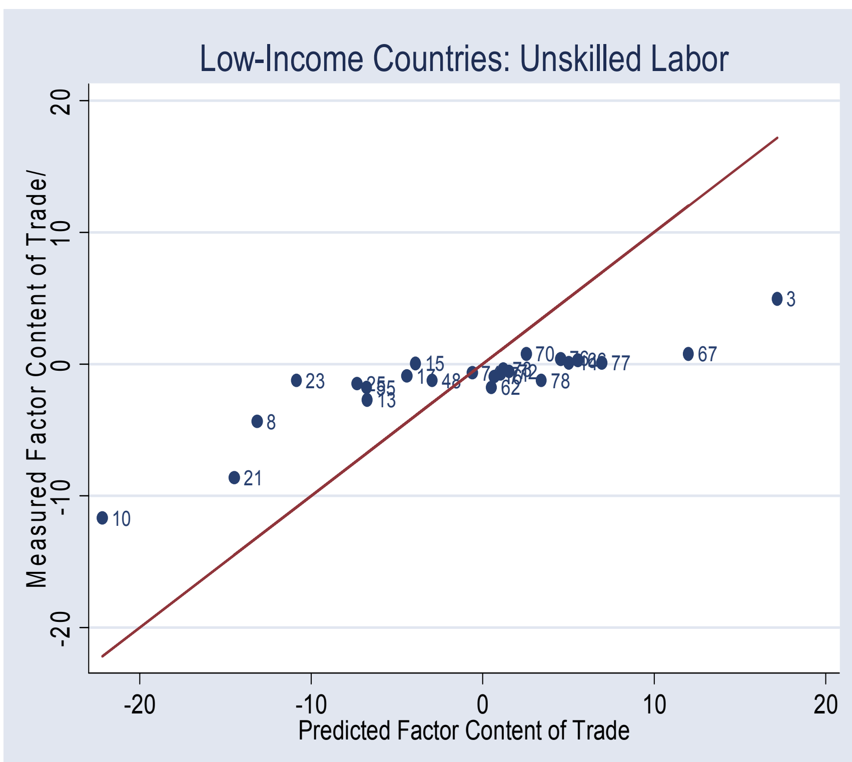
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