Beyond the Algebra of Explanation:

HOV for the Technology Age

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It is hard to believe that factor endowments theory could offer an adequate explanation of international trade patterns. While the theory adequately predicts Saudi Arabian oil exports, it hardly seems appropriate for explaining the revolutionary impact of new technologies on world trade. Yet to take this position is to misunderstand the thrust of recent empirical research in international trade, research that is giving shape to a new generation of Heckscher-Ohlin-Vanek (HOV) thinking. The core of this new thinking is a class of HOV predictions that allow for international differences in technology and choice of techniques.

The literature is in the process of rapid evolution. As a result, the key questions tend to get lost. There have been 3 of them. First, what empirical regularities account for the poor

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performance of the HOV model? Second, are there alternative assumptions about technology that lead to better test results for the model? Both of these are interesting questions, but they are hardly an end point for understanding the impacts of international trade. As Edward E. Leamer (1993, page 439) pointed out: “[E]conomists ought to abandon the idea that models are either true or false in favor of the notion that models are sometimes useful and sometimes misleading.” The third and most important question is whether the HOV model provides a useful framework for thinking about international technology differences. In spite of the defects of the model, the answer is a definite ‘yes.’

1. HOV Diagnostics

The HOV theorem states that $F_i = V_i - s_i V_w$ where i indexes countries, F_i is the factor content of trade, V_i is endowments, $V_w \equiv \Sigma_i V_i$, and s_i is i’s share of world consumption expenditures. For example, if a country is capital abundant ($V_i - s_i V_w > 0$) then it exports capital services ($F_i > 0$). The HOV model performs poorly in almost every imaginable way. Daniel Trefler (1995) offered two empirical regularities that explain why. The first is the ‘mystery of the missing trade,’ that is, the HOV model predicts far more trade than is actually observed. The second is international productivity differences as evidenced by the endowments ‘paradox.’ That is, poor countries are abundant in all factors and rich countries are scarce in almost every factor. The importance of productivity differences and choice-of-technique differences more generally was reinforced by Donald R. Davis *et. al* (1997). They observed that of all the standard HOV assumptions, identical techniques is the one most at odds with Japanese regional data.

2. Modifying and Testing HOV

Trefler (1995) modelled international technique differences using $\delta_i A_i = A_{US}$ where A_i is country i's technique matrix (the amount of inputs needed per unit of output) and δ_i is country i's gross domestic product per worker. This leads to a prediction of the form

$$F_i = \delta_i V_i - s_i \Sigma_j \delta_j V_j \qquad \text{where } F_i \equiv A_{US} T_i. \tag{1}$$

Rows 1-2 of table 1 report on the performance of the standard HOV model ($\delta_i = 1$) and its equation (1) modification. The first column of table 1 reports the correlation between the left- and right-hand sides of equation (1). The second column reports the 'missing trade' statistic which is the variance of the right-hand side divided by the variance of the left-hand side. From the table, the HOV model performs poorly. Trefler's modification performs better, but hardly perfectly.

Dalia Hakura (1996), Davis and David E. Weinstein (1998), and Alexander Wolfson (1999) each took the extra step of looking at actual data for the A_i. I will return to Hakura shortly. Wolfson (using data of dubious legitimacy) and Davis and Weinstein examined the prediction $F_i = V_i - s_i V_w$ where $F_i \equiv A_i X_i - \Sigma_j A_j M_{ij}$, X_i is country i's exports, and M_{ij} is i's imports from country j. From rows 3-4 of table 1, they obtained improvements similar to that in Trefler (1995).

There are 2 problems with this analysis. First, Davis and Weinstein (1998) treated investment as if it were a component of consumption. Second, under the maintained assumptions, $F_i \equiv A_i X_i - \Sigma_j A_j M_{ij}$ is not the factor content of trade. The problem is that by empirical construction, A_i treats imported intermediate inputs as if they were produced domestically. It thus does not calculate the actual factors used worldwide to produce i's final output. Note that $A_i X_i - \Sigma_j A_j M_{ij}$ is the factor content of trade if one assumes that there is no trade in intermediate inputs. Also note that in criticizing this element of Davis and Weinstein (1998), it is easy to miss the big picture: it is an excellent paper.

To remedy these problems, let R be a set of countries for which data are available, let $V_R \equiv \Sigma_{j\in R} V_j$, let C_{ij} be i's consumption of j's goods, and let $C_{Rj} \equiv \Sigma_{i\in R} C_{ij}$. An equation that is necessarily satisfied by the data (it is a manipulation of basic input-output identities) is

$$F_i = (V_i - s_i V_R) - \Sigma_{j\in R} A_j (C_{ij} - s_i C_{Rj}) \tag{2}$$

where s_i is i's share of the region's income and where the complicated definition of F_i is relegated to a footnote.[1] Following Davis and Weinstein and many others we assume that $C_{ij} = s_i C_{Rj}$. Since $V_i - s_i V_R$ is then the factor content of trade, it follows from the assumption-free equation (2) that F_i is also the factor content of trade. See Trefler (1996) for a complete discussion. It is easy to get buried in details. The main point is that F_i must be correctly defined.

We empirically examine $F_i = V_i - s_i V_R$ using Hakura's data on Belgium, France, Ger-

[1] Let X_i^k be i's exports of type k goods and let M_{ij}^k be i's imports from j of type k goods. k indexes either final consumption goods ($k = c$) or intermediate inputs ($k = y$). Let $M_i^y \equiv \Sigma_j M_{ij}^y$. Then $F_i \equiv F_i^c + F_i^y + F_i^R$ where $F_i^c \equiv A_i X_i^c - \Sigma_{j\in R} A_j M_{ij}^c$, $F_i^y \equiv A_i(X_i^y - M_i^y) - s_i \Sigma_{j\in R} A_j (X_j^y - M_j^y)$, and $F_i^R \equiv -s_i \Sigma_{j\in R} A_j \Sigma_{k\notin R} M_{kj}^c$.

many, and the Netherlands. We are indebted to Hakura for providing us with her unique database. We combined her data with U.S. data and restricted ourselves to capital, land, and aggregate labor. We also correctly integrated investment into A_i (investment is a depreciable intermediate input) by using the 1982 U.S. capital flows table to allocate each country's industry-level investment to the industries that use the investment. This is the first proper treatment of investment in the history of factor content studies.

The results appear in row 5 of table 1. In view of the importance of missing trade, it is not surprisingly that we obtain only a modest improvement. Note that we observe M_{ij} but not its division among intermediate inputs and final consumption goods. In row 5, we used our baseline assumption that the share of final goods in total trade is $(\Sigma_j C_{ij})/(Q_i + \Sigma_j M_{ij})$ where Q_i is country i's output. (This is an abuse of vector notation: we mean element-wise division of vectors.) In row 6, we use the assumption implicit in Davis and Weinstein (1998) and Wolfson (1999) that all intermediate inputs are non-tradeable. There is substantial improvement, but it is inappropriate.

To summarize, table 1 makes it clear that international differences in choice of techniques cannot by themselves salvage the HOV theorem. Missing trade remains a central problem.

3. HOV Diagnostics Revisited

One approach to diagnosing what went wrong in table 1 is to include an economically meaningful piece of the equation (2) error term $\Sigma_{j \in R} A_j (C_{ij} - s_i C_{Rj})$ as a right-hand side explanatory variable. Typically, this leads to a remarkable improvement in the performance of the model. For example, Hakura's preferred model dramatically reduces missing trade. See row 2 of table 2. Davis and Weinstein (1998) considered equation (2) with the error $\Sigma_{j\in R}A_j(C_{ij} - s_iC_{Rj})$ replaced by its component dealing with consumption of non-tradeables i.e., replaced by $A_iC_{ii}^N - s_i\Sigma_{j\in R}A_jC_{jj}^N$ where C_{ii}^N is i's consumption of non-tradeables. From row 3 of table 2, there is again a significant improvement.

Davis and Weinstein saw this as a 'striking confirmation of the HOV theory.' We are less sure of this. First, the components of $\Sigma_{j\in R}A_j(C_{ij} - s_iC_{Rj})$ are not exogenous and hence do not belong on the right-hand side of an HOV prediction. Second, when we examine the same non-tradeables specification using the modified Hakura data set, we obtain different results. See row 4 of table 2. We obtain the same high correlation, but missing trade remains significant. Row 5 repeats the exercise under the Davis-Weinstein implicit assumption of no intermediate inputs trade. Here we replicate their result.

How do we choose between rows 3 and 4 of table 2. Who is right? The problem is that no one knows how to define the factor content of trade in the presence of non-tradeables. In particular, all the factor content definitions used in table 2 are wrong. If there is a conclusion from table 2, it is that decomposing the error term $\Sigma_{j\in R}A_j(C_{ij} - s_iC_{Rj})$ is a useful tool for getting inside the black box of missing trade. However, it does not salvage the HOV model.

4. Beyond the Algebra of 'Explanation'

Like good clinicians, we have tested HOV and diagnosed its ailments. Much of this involved mechanical manipulation of equations like equation (2). Unfortunately, in many ways this is simply an algebra of 'explanation.' The real interest in HOV and its empirical ailments is that together they paint a useful picture of the sources of international technique differences. As well, they paint a useful picture of the allocative mechanisms at work in the global economy. We turn to this now.

Trefler (1993) argued that the usual HOV allocative mechanism, namely Rybczynski quantity adjustments, are relevant provided one works with productivity-adjusted factor price equalization (FPE). For an economy with only a single factor, this is modelled precisely as in equation (1). In this case δ_i is set equal to the single factor's price, namely, gross domestic product per worker. From row 2 of table 1, this description of how an economy adjusts is not entirely persuasive: it misses missing trade. Xavier Gabaix (1997) also criticized Trefler (1993), but his paper is so fraught with basic econometric mistakes that it is seriously misleading. At bottom, Gabaix is simply re-stating what appears in row 2 of table 1. (This is TC_1 in Trefler 1995). That is, missing trade is a serious problem.

Harrigan (1997) argued that the source of international technique differences is total factor productivity (TFP) differences. This takes us far beyond what can be garnered simply by looking at the A_i, that is, by looking at an economy's intra-industry purchases. He further argued that the pattern of international TFP differences is inconsistent with the Rybczynski-FPE allocative mechanism.

Davis and Weinstein (1998) showed that if country 1 is relatively more capital abundant than country 2, then country 1 uses relatively more capital-intensive techniques in *all* industries. They explained this by arguing that the capital abundant country should have a lower price of capital. As a result, there should be substitution towards more capital intensive techniques. We find strong evidence for this channel as well as an additional channel in the Hakura data set. If there are trade impediments, then the capital abundant country should also have cheaper product prices for goods that are capital intensive. This in turn should lead consumers to substitute towards capital-intensive goods. Indeed, we find exactly this consumption substitution in the data. Note that it is inconsistent with the Hakura (1996) and Davis *et. al* (1997) claims about consumption similarity.

It is worth noting that the Davis-Weinstein finding might be driven by a very different mechanism, one in which the capital abundant country actually has high capital prices (the opposite of the above mechanism). This is precisely what appears in the literature on skill-biased endogenous technical change.

Finally, in a remarkable paper Paul A. David and Gavin Wright (1996) examined the factor content of U.S. trade over the last 150 years. For each country in each year they calculated discovery rates i.e., the percentage of mineral resources that had been discovered. They found that in the period when U.S. trade was most mineral intensive, the U.S. had the highest discovery rates in the world. David and Wright explained this by appeal to endogenous technical change that raised discovery rates.

In thinking about the new HOV literature it is important to bear in mind that the HOV theorem is neither true nor false. The HOV model has some significant problems, most notably missing trade. However, the model is most certainly useful for thinking about the sources of international differences in choice of techniques and for thinking about the impact of international trade on factor prices, product prices, the composition of output, and induced technical change. It is these observations - rather than more tests of HOV - that are establishing the usefulness of HOV for thinking about international trade in the technology age.

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Table 1. HOV Predictions with International Technique Differences

	Correlation of F_i with $V_i - s_i V_w$	Missing Trade $\sigma_F^2/\sigma_{V-sV_w}^2$
1. Standard HOV	.28	.032
2. Trefler	.59	.330
3. Davis-Weinstein	.59	.070
4. Wolfson	.67	.009
5. Trefler-Zhu	.74	.012
6. No intermediates	.84	.090

Notes: Row 1 is from Trefler (1995, H_0) Row 2 is based on equation (1). All other rows use $F_i = V_i - s_i V_w$ where F_i is defined as follows. Rows 1-2: $F_i \equiv A_{US} T_i$ where T_i is net exports. Rows 3, 4, and 6: $F_i \equiv A_i X_i - \Sigma A_j M_{ij}$. Row 5: see text.

Table 2. HOV Predictions with Additional Consumption 'Predictors'

	Correlation of F_i with $V_i - s_i V_w$	Missing Trade $\sigma_F^2/\sigma_{V-sV_w}^2$
1. Standard HOV	.28	.032
2. Hakura	.90	.706
3. Davis-Weinstein	.96	.380
4. Trefler-Zhu	.90	.061
5. No intermediates	.90	.445

Notes: In row 2, $F_i \equiv A_i T_i$ where T_i is net exports. For F_i in the remaining rows see the notes to table 1. Row 2 uses $F_i/s_i - F_j/s_j = (V_i/s_i - V_j/s_j) - (A_i - A_j)\Sigma_j C_{ij}/s_i$. Rows 3-5 use $F_i = (V_i - s_i V_w) - (A_i C_{ii}^N - \Sigma_j A_j C_{jj}^N)$ where C_{ii}^N is i's consumption of non-tradeables. See also the notes to table 1.