Across-Industry Specialization as a Result of Capital Accumulation? Reconsidering the Success of the Heckscher-Ohlin-Vanek Model

Shuichiro Nishioka*

March 2009

Abstract

A capital abundant country exports capital services and imports labor services. This HOV prediction could be obtained from either across-industry or within-industry specialization once factor trade is measured bilaterally with producer countries' techniques. This paper studies how much across-industry specialization contributes to the recent evidence for the HOV model. I find that Davis and Weinstein's (2001) successful specifications depend exclusively on within-industry specialization: a capital abundant country employs capital-intensive techniques across all industries and any products exported from that country embody more capital than labor (Schott, 2004). In addition, this structure of techniques is conditional on the factor-neutral TFP adjustments. The unadjusted data on capital techniques has converged across countries. The Heckscher-Ohlin models allowing capital mobility (e.g., Mundell, 1957; Helpman, 1984) appear to be consistent with the global data.

F11: Neoclassical Model of Trade
O11: Macroeconomic Analyses of Economic Development
Keywords: Heckscher-Ohlin; Technology; TFP; Mobility in Capital

---

* Department of Economics, PO Box 6025, West Virginia University, Morgantown, WV, 26506-0625, Tel: +1(304) 293-7875, Fax: +1(304) 293-5652, E-mail: shuichiro.nishioka@mail.wvu.edu. I thank James Cassing, Stratford Douglas, Antoine Gervais, and the audience at the University of Pittsburgh (2009) and Midwest Economic Association Meeting (2009).

While the United States employs, on average, ten times more capital-intensive technique than China does, the most capital-intensive manufacturing industry in the United States, chemicals, is only two times more capital-intensive than U.S. apparel industry. The variation in technique is much greater across countries than industries. This simple observation is intuitive to explain the previous empirical failures of the Heckscher-Ohlin-Vanek (HOV) model (e.g., Bowen, Leamer, and Sveikauskas 1987; Davis and Weinstein 2001; Schott 2003 and 2004), particularly Trefler's (1995) missing trade.

Whether a country specializes in a particular subset of industries by the capital accumulation is a primary objective of testing the HOV model and its variants.[1] Davis and Weinstein (2001) found substantial improvements in prediction power of the HOV model when national techniques are modified according to the Dornbusch-Fischer-Samuelson (DFS) model (1980) and the multiple-cone production model of Helpman (1999).[2] These traditional trade theories predict the across-industry specialization; capital accumulation does not affect that country's techniques *per se* but does shift the domestic production towards more capital-intensive industries.

The objective of the paper is to exploit how much cross-industry technical difference, or across-industry specialization, does contribute to the recent evidence for the HOV model (e.g., Davis and Weinstein 2001; Hakura 2001; Maskus and Nishioka 2009). By using the data from 29 countries including both developed and developing countries for year 2000, I find evidence for the HOV prediction (i.e., a capital abundant country exports capital services and imports labor services). However, the evidence does not stem from across-industry specialization. In particular, Davis and Weinstein's success depends crucially on the country-specific technique; a capital-abundant country employs capital-intensive techniques across all industries and any products exported from that country embody more capital than labor.[3] The evidence can be

[1] Harrigan (1997) found both technology and factor abundance are important determinants of international specialization. By using the Rybzynski equation, Fitzgerald and Hallak (2004) found strong specialization in the process of development. However, they could not untangle the effect of factor-abundance from other development mechanisms.

[2] Recent literature on the factor proportions models of international trade concentrates on the models with the possibility of multiple-cone production that can arise due to large factor-endowment differences (e.g., Debaere and Demiroglu 2003; Schott 2003; Choi and Krishna 2004; Lai and Zhu 2007).

[3] This finding in techniques is consistent with the idea of within-product specialization (Schott 2004); capital-abundant countries use their capital-intensive techniques even for labor-intensive products to specialize vertically in capital-intensive high-quality varieties. The industry-aggregated capital intensity might depend on such mechanisms as the distributions of heterogeneous firms (e.g., Bernard, Redding, and Schott 2007), the complementarity across

derived only from country-level data: GDP, exports, bilateral imports, and factor endowments. Even though Davis and Weinstein provide evidence of how to account for factor contents of trade, industry-level data cannot deliver the prediction of how countries specialize in which industries simply from the accumulation of capital relative to labor (e.g., Schott 2003).

In this paper, I first repeat the empirical strategy taken by Davis and Weinstein; starting from the standard HOV model, international techniques and factor prices are gradually modified according to the factor-neutral TFP adjustment, the DFS model, and the multiple-cone production models. The standard HOV model performs poorly as widely known. There is no noticeable gain in prediction power of the HOV model when I introduce the factor-neutral TFP adjustment. What is most surprising is that the modification according to the DFS model provides strong evidence from the global data[4]; this success continues in the following specifications of multiple-cone production models. Indeed, these successful specifications eliminate the Leontief paradox (e.g., Leontief 1954; Leamer 1980) and predict precisely that a capital (labor) abundant country exports capital (labor) services. The United States, as well as most developed countries, is predicted as an importer of labor services and as an exporter of capital services. Even though the evidence is consistent with the HOV prediction, the improved prediction power does not depend on the traditional across-industry specialization. In fact, the success is obtained exclusively from the cross-country difference in techniques: a product exported from a developed country embodies more capital and less labor than the same product from a developing country (Schott 2004). This suggests that within-industry specialization and intra-industry trade are responsible for the success of the Davis-Weinstein model.[5]

To test the driving forces of the success for the HOV model, I propose two technique-restricted models: the first restricts technical variations to be industry-specific by adjusting factor-specific efficiency units to be the same as in the United States, and the second allows technical variations only across countries by imposing identical technique across industries for each country. The former is identical to the factor-augmenting efficiency adjustment (e.g., Trefler 1993); all countries share the same techniques as the United States and factor abundances

---

factors (e.g., Krusell et al. 2000; Caselli and Coleman 2006; Maskus and Nishioka 2009), and the domestic price of capital relative to labor.

[4] In particular, evidence on the sign tests. The direction of factor trade is precisely predicted from factor abundance.

[5] Romalis (2004) combined the DFS model with Krugman's (1980) model of monopolistic competition. The insight of Davis and Weinstein's successful model is similar to that of Romalis because both models allow the intra-industry trade within each industry in the context of the factor abundance models.

are adjusted to agree with U.S. factor-specific efficiencies. In this specification, since there is no variation in techniques across countries, the HOV prediction stems solely from the endowment-driven specialization. For example, labor-abundant China exports labor-intensive apparel and imports capital-intensive automobiles so that China is predicted from the HOV model as an exporter of effective labor and an importer of effective capital. The latter introduces the industry-neutral technique for each country; there is single labor or capital requirement for all industries in a country. Labor-abundant Indonesia employs labor-intensive techniques not only for apparel and toys but also for chemicals and electronics. Therefore, capital-abundant France and labor-abundant Indonesia both produce apparel but French apparel embodies more capital and less labor than Indonesian apparel does.

I find both restricted models provide evidence for the standard HOV tests: weaker evidence for across-country restriction and stronger evidence for the across-industry restriction. The most important finding is that the across-industry restriction provides the best performance for the data among all models in this paper. Moreover, the measured factor contents of trade are almost identical to those measured from the multiple-cone production specification in Davis and Weinstein. These results suggest that the success of the Davis-Weinstein model depends exclusively on cross-country differences in techniques and across-industry specialization does not play any role for the success. Given the findings with the across-industry restriction, it is surprising to see the evidence for the HOV model with the across-country restriction, or the factor-augmenting efficiency adjustments. Interestingly, this specification predicts something different from Davis and Weinstein's successful models: some countries export both labor and capital and others import both factors. More precisely, measured factor contents of trade strongly reflect countries' trade balances since there are no significant variations in techniques across industries particularly for capital. Again, the global data cannot deliver clear evidence for capital-endowment-driven across-industry specialization.[6]

Finally, a capital-abundant country employs more capital and less labor and this structure of technique depends on the factor-neutral efficiency (TFP) adjustments. Developing countries employ, on average, three times more labor, but there are no significant differences in capital usage without any efficiency adjustments. Because TFP is roughly the average of these two

[6] My findings in the paper are consistent with those in Romalis (2004). The Romalis model predicts that countries capture the larger share of U.S. imports for commodities that use their abundant factors intensively. Romalis found the strong evidence with skill abundance but the weak evidence with capital abundance.

factor performances, the TFP adjustment generates a clear distinction in techniques between developed and developing countries; developing countries employ two times more labor and developed countries employ two times more capital.[7] If the previous empirical failures of the HOV model are due to the inability to introduce countries' actual techniques (Hakura 2001), it is rather appropriate to take the strong cross-country convergence in capital technique into account. This convergence is consistent with the evidence provided by Caselli and Feyrer (2007) who showed macroeconomic data on aggregate output, physical capital, and capital share supports the view that international financial markets are efficient at allocating production capital across countries. Indeed, capital might be a mobile factor across borders. The Heckscher-Ohlin models allowing the possibility of capital mobility (e.g., Mundell 1957; Helpman 1984) are further discussed. The HOV predictions with the factor-augmenting efficiency adjustments appear to be consistent with these models.

The remainder of this paper is organized into three sections. In Section I, I develop the various HOV specifications that Davis and Weinstein proposed and provide evidence for these models from the global data. Section II introduces the restricted models and provides empirical results. I discuss how much cross-industry differences in technique contribute to Davis and Weinstein's success. I present concluding remarks in the last section.

I. The Success of the Davis-Weinstein Model

A. Empirical Models

The Standard HOV Model

I begin by deriving the standard HOV model in a world with F factors, C countries, and N products. Assume that all countries have identical techniques; markets for products and factors are perfectly competitive; there are no barriers to trade and zero transport cost; factor inputs move freely within a country but not across countries; and the distribution of factors is consistent with integrated equilibrium so that factor prices equalize.

[7] For example, the labor productivity of Hungary is one third of that of the United States but there is no significant difference for the capital productivity. Since the TFP measure is the average of these two factor-specific productivities, Hungarian TFP is roughly two thirds of American TFP. Hungary employs three times more workers but each worker can produce only two thirds of a U.S. worker does. Therefore, with the TFP adjustment, Hungary employs two times more workers than the United States does. Hungary uses the same amounts of capital but each unit of capital can produce only two thirds as much as U.S. capital. Once again, if I adjust Hungarian technique with the TFP measure, Hungary employs two thirds as much capital as the United States does. Thus, because of the TFP adjustment, Hungary employs more labor and less capital than the United States.

For each country c, the net-export vector is the difference between net production ($\mathbf{Y}^c$) and final consumption ($\mathbf{D}^c$):

(1) $$\mathbf{X}^c - \left[\sum_{c'\neq c}\mathbf{M}^{cc'}\right] = \mathbf{Y}^c - \mathbf{D}^c$$

where $\mathbf{X}^c$ is an $N\times 1$ vector of total exports for country c and $\mathbf{M}^{cc'}$ is an $N\times 1$ vector of imports from country c' to country c.

$\mathbf{B}^c$ is the $F\times N$ technical matrix and each element (a^c_{fi}), unit factor requirement, corresponds to the amount of a factor (f) required to produce one unit of net output for sector i.[8] I multiply equation (1) by technical matrix $\mathbf{B}^c$ and apply the factor-exhaustion assumption $\mathbf{B}^c\mathbf{Y}^c=\mathbf{V}^c$ where $\mathbf{V}^c$ is an $F\times 1$ vector of factor endowments. A country's factor contents of trade are the difference between a country's factor endowments ($\mathbf{B}^c\mathbf{Y}^c=\mathbf{V}^c$) and factors absorbed in final consumption ($\mathbf{B}^c\mathbf{D}^c$):

(2) $$\mathbf{B}^c\mathbf{X}^c - \left[\sum_{c'\neq c}\mathbf{B}^c\mathbf{M}^{cc'}\right] = \mathbf{V}^c - \mathbf{B}^c\mathbf{D}^c$$

Assuming identical and homothetic preferences, along with identical prices of goods and services, the final consumption vector is proportional to the world net output vector ($\mathbf{Y}^w$):

(3) $$\mathbf{D}^c = s^c\mathbf{Y}^w$$

where s^c is a scalar representing the share of country c in world expenditure. Because the production technique is identical worldwide in the standard HOV model, the U.S. technique ($\mathbf{B}^c=\mathbf{B}^{c'}=\mathbf{B}^{US}$) is traditionally used to derive $\mathbf{B}^{US}\mathbf{D}^c=s^c\mathbf{B}^{US}\mathbf{Y}^w=s^c\mathbf{V}^w$.

(4) $$\mathbf{B}^{US}\mathbf{X}^c - \left[\sum_{c'\neq c}\mathbf{B}^{US}\mathbf{M}^{cc'}\right] = \mathbf{V}^c - s^c\mathbf{V}^w$$

where $\mathbf{B}^{US}\mathbf{X}^c - [\Sigma_{c'\neq c}\,\mathbf{B}^{US}\mathbf{M}^{cc'}]$ is measured factor contents of trade with the U.S. technique and $\mathbf{V}^c$-$s^c\mathbf{V}^w$ is predicted factor contents of trade.

The standard HOV model predicts measured factor contents of trade for a country from that country's factor endowments, world factor endowments, and its final consumption share. The success of this HOV prediction depends not only on across-industry specialization driven by factor abundance but also on the U.S. technique. If the United States employs the capital-intensive technique across all industries, we cannot distinguish labor-intensive from capital-

[8] I derive the total technical matrix $\mathbf{B}^c$ for each country from an $F\times N$ direct technical matrix ($\mathbf{B}^{*c}$) and an $N\times N$ input-output matrix ($\mathbf{A}^c$) such that $\mathbf{B}^c = \mathbf{B}^{*c}\,(\mathbf{I}\text{-}\mathbf{A}^c)^{-1}$ where $\mathbf{I}$ is $N\times N$ identity matrix. Fisher and Marshall (2008) show the inconsistency of developing techniques from this traditional method. In spite of their caution, this paper employs this standard procedure so that I can compare my results with those of previous works.

intensive sectors and measured factor contents of trade for any country reflect that country's trade balance.

I summarize the standard HOV model with the set of three equations: the first equation tests the validity of the factor-exhaustion condition for the domestic production (S1-1); the second is the trade test (S1-2); the last equation summarizes the estimation strategy (S1-3).

(S1-1) Production: $\mathbf{B}^{US}\mathbf{Y}^{c} = \mathbf{V}^{c}$

(S1-2) Trade: $\mathbf{B}^{US}\mathbf{X}^{c} - \left[\sum_{c' \neq c} \mathbf{B}^{US}\mathbf{M}^{cc'}\right] = \mathbf{V}^{c} - s^{c}\mathbf{V}^{w}$

(S1-3) Technique: $a_{fi}^{c} = a_{fi}^{US}$

The Factor-Neutral Efficiency Adjustment

As documented in the previous literature (e.g., Maskus 1985; Bowen, Leamer, and Sveikauskas 1987; Trefler 1995; Davis and Weinstein 2001), the standard HOV model is hopeless without adjusting for efficiency differences across countries. Factor- and industry-neutral efficiency, or TFP, is the simplest measure to adjust the unobserved differences in factor performances across countries. To incorporate efficiency into the standard HOV model, it is convenient to normalize productivity differences to the United States (θ^{US}=1).

(S2-1) Production: $\mathbf{B}^{H}\mathbf{Y}^{c} = \mathbf{V}^{cE}$

(S2-2) Trade: $\mathbf{B}^{H}\mathbf{X}^{c} - \left[\sum_{c' \neq c} \mathbf{B}^{H}\mathbf{M}^{cc'}\right] = \mathbf{V}^{cE} - s^{c}\mathbf{V}^{wE}$

(S2-3) Technique: $\ln(a_{fi}^{c}) = \ln(\theta^{c}) + \ln(\alpha_{fi}) + \varepsilon_{fi}^{c}$

Here, α_{fi} are parameters to be estimated corresponding to common factor input requirement for factor *f* in industry *i*. Technique $\mathbf{B}^{H}$ is developed from the estimated coefficients from equation (S2-3), α_{fi}, by normalizing efficiency to the United States. At the same time, factor endowments are adjusted to the U.S. efficiency: $\mathbf{V}^{cE}=\theta^{c}\mathbf{V}^{c}$. The world endowment ($\mathbf{V}^{wE}$) is the sum of $\mathbf{V}^{cE}$. Weighted least squares are employed to estimate equation (S2-3).[9]

The Dornbusch-Fischer-Samuelson Model

The Dornbusch-Fischer-Samuelson (1980) model is the first specification that modifies the unrealistic assumption of identical technique. The DFS model predicts the endowment-

[9] In contrast to Davis and Weinstein, I do not employ the seemingly unrelated regression (SUR) model.

driven specialization: a capital abundant country exports capital-intensive goods, imports labor-intensive goods, and non-traded goods are those of intermediate capital-intensity. Exports from a capital abundant country in a given industry are more capital-intensive than the world production in that industry because of the presence of these non-traded sectors. These insights are introduced into the following specification, in which the factor contents of exports in tradable industries vary systematically with a country's capital abundance, and the factor contents of imports must be measured bilaterally with the producer countries' techniques. This is the first estimation that modifies the assumption of identical technique.

(S3-1) Production: $\mathbf{B}^{cD}\mathbf{Y}^{c} = \mathbf{V}^{cE}$

(S3-2) Trade: $\mathbf{B}^{cD}\mathbf{X}^{c} - \left[\sum_{c'\neq c}\mathbf{B}^{c'D}\mathbf{M}^{cc'}\right] = \mathbf{V}^{cE} - s^{c}\mathbf{V}^{wE}$

(S3-3) Technique: $\ln(a_{fi}^{c}) = \ln(\theta^{c}) + \ln(\alpha_{fi}) + \gamma_{f}^{D}\ln(K^{c}/L^{c})D_{i}^{T} + \varepsilon_{fi}^{c}$

D^{T}_{i} is a dummy variable that takes on a value of one if the sector is tradable and zero if the sector is non-tradable. I introduce a restriction, $\Sigma_f \gamma^D_f = 0$, so that industry input coefficients in tradable industries do not affect each country's single efficiency level (θ^c). In addition, $\mathbf{B}^{cD}$ is now efficiency-adjusted and is developed from the estimated coefficients from (S3-3), $\exp\left[\ln(\hat{\alpha}_{fi}) + \hat{\gamma}_{f}^{D}\ln(K^{c}/L^{c})D_{i}^{T}\right]$.

The Multiple-Cone Production Model

As suggested by Helpman (1999), a capital abundant country might specialize in capital-intensive subsets of products if the factor price equalization (FPE) theorem does not hold. Hence, countries specialize in different cones of production according to their levels of capital abundances. This affects unit factor requirements (a^c_{fi}) systematically by that country's capital abundance for both tradable and non-traded products.

For this specification, I separate factors employed for tradable production from those for non-tradable production because the prices of non-traded products might be different across countries. To specify the multiple-cone production model, I define a country *c*'s technique at equilibrium factor prices as $\mathbf{B}^{cM}$=[$\mathbf{B}^{cMT}$ $\mathbf{B}^{cMNT}$] where the partition is between tradable (*T* industries) and non-tradable sectors (*NT* sectors = *N*-*T* sectors). The net output vector is also partitioned as $\mathbf{Y}^{c}$=[$\mathbf{Y}^{cT}$ $\mathbf{Y}^{cNT}$]'. Then, the factor market clearing condition is $\mathbf{B}^{cM}\mathbf{Y}^{c}$=$\mathbf{V}^{cE}$. If this equation is rewritten with tradable and non-tradable sectors, I get $\mathbf{V}^{cET}$=$\mathbf{V}^{cE}$-$\mathbf{V}^{cENT}$ where

$\mathbf{V}^{cET}$=$\mathbf{B}^{cMT}\mathbf{Y}^{cT}$ and $\mathbf{V}^{cENT}$=$\mathbf{B}^{cMNT}\mathbf{Y}^{cNT}$. Assuming that preferences in all countries between tradable and non-tradable products are identical and homothetic, s^c remains country c's share of world spending on both tradable and non-tradable sectors. As in Leamer (1984), the existence of non-tradable sectors does not affect the prediction of the HOV model as long as countries share identical techniques in non-tradable sectors because of $\mathbf{V}^{cENT}$-$s^c\mathbf{V}^{wENT}$=0. However, under multiple-cone production model this condition does not hold strictly. Therefore, it is important to partition out factors employed in the non-tradable sectors from countries' factor endowments.

(S4-1) Production: $\mathbf{B}^{cM}\mathbf{Y}^{c} = \mathbf{V}^{cE}$

(S4-2) Trade: $\mathbf{B}^{cM}\mathbf{X}^{c} - \left[\sum_{c'\neq c}\mathbf{B}^{c'M}\mathbf{M}^{cc'}\right] = \mathbf{V}^{cET} - s^c\mathbf{V}^{wET}$

(S4-3) Technique: $\ln(a_{fi}^{c}) = \ln(\theta^c) + \ln(\alpha_{fi}) + \gamma_f^T \ln(K^c / L^c)D_i^T + \gamma_f^{NT} \ln(K^c / L^c)(1 - D_i^T) + \varepsilon_{fi}^{c}$

I introduce a restriction, $\Sigma_f\,(\gamma^T{}_f + \gamma^{NT}{}_f)$=0, to estimate (S4-3). $\mathbf{B}^{cMT}$ and $\mathbf{B}^{cMNT}$ are efficiency-adjusted and developed from the estimated coefficients from (S4-3) so that each unit factor requirement corresponds to $\exp\left[\ln(\hat{\alpha}_{fi}) + \hat{\gamma}_f^T \ln(K^c / L^c)D_i^T\right]$ and $\exp\left[\ln(\hat{\alpha}_{fi}) + \hat{\gamma}_f^{NT} \ln(K^c / L^c)(1 - D_i^T)\right]$.

In addition, equation (S4-3) can be further relaxed so that countries' capital-labor ratios have a different effect on each industry. In this unrestricted technology specification, factor prices do not equalize since a country employs the optimal techniques according to domestic factor abundances. I introduce a restriction $\Sigma_{fi}\ \gamma_{fi}$=0 to estimate equation (S5-3):

(S5-1) Production: $\mathbf{B}^{cM'}\mathbf{Y}^{c} = \mathbf{V}^{cE}$

(S5-2) Trade: $\mathbf{B}^{cM'}\mathbf{X}^{c} - \left[\sum_{c'\neq c}\mathbf{B}^{c'M'}\mathbf{M}^{cc'}\right] = \mathbf{V}^{cET} - s^c\mathbf{V}^{wET}$

(S5-3) Technique: $\ln(a_{fi}^{c}) = \ln(\theta^c) + \ln(\alpha_{fi}) + \gamma_{fi} \ln(K^c / L^c) + \varepsilon_{fi}^{c}$

B. Data and Empirical Results

I develop the data for year 2000 from the OECD publications such as the STAN Industry (2005), the Input-Output database (2007), and the STAN bilateral trade database (2006).[10] The data provides me with intermediate input usages, gross and net outputs, final consumption, factor inputs, and bilateral trade for 30 industries for 19 developed and 10 developing countries. In contrast to Davis and Weinstein's data that consists of ten OECD countries and the rest of the

[10] The detailed methodology to develop the data is in the appendix.

world aggregate for year 1985, I am able to disaggregate the rest of the world into each of 19 countries. However, my results might not be directly comparable with those of Davis and Weinstein (2001) since the globalization in service trade, foreign direct investment (FDI), and technology diffusion has progressed over the last three decades (e.g., Hanson, Mataloni, and Slaughter 2005; Keller 2002).

Technology Estimations

The technique, a^c_{fi}, represents the amount of a factor required to produce one unit of net output in each sector.[11] Table 1 provides the summary statistics of a^c_{fi} for labor and capital. The primary objective of the table is to compare technical differences across industries to those across countries. I summarize the cross-industry means and standard errors for each country in the first panel (Table 1 I).[12] The developing countries employ, on average, three times more labor, 0.056 for developing countries and 0.018 for developed countries, and the developed countries employ 37 percent more physical capital, 0.014 for developed countries and 0.010 for developing countries. The second panel (Table 1 II) instead provides the within-industry means and standard errors for each industry. The service sector employs 18 percent more of labor, 0.030 for manufacturing and 0.035 for services, but there is no significant difference for capital. Moreover, within-industry standard deviations to means ratios for labor are uniformly greater, indicating larger variations in techniques across countries than those across industries.

Table 2 reports the coefficients and associated summary statistics for technology estimations (S2-3), (S3-3), (S4-3), and (S5-3) with the weighted least squares. Even though I do not report the results, almost all coefficients measuring techniques and country-specific efficiency units are statistically significant. In terms of the Schwarz Information Criteria (SIC), the technology estimation with multiple-cone production model (S4-3) is the best specification; the second is the unrestricted technology model without FPE (S5-3). These results indicate the importance of allowing the country capital to labor ratios in the technology estimations. Figure 1 provides the coefficients on the capital to labor ratios for the specifications (S3-3), (S4-3), and

[11] a^c_{fi} for labor (f=L) is hour-adjusted thousands of workers and that for capital (f=K) is 100 million international dollars (2000) of capital stock required to produce one million international dollars (2000) of net output for each industry i.

[12] I first develop the mean and standard deviation for each country in Table 1.I. and the mean and standard deviation for each industry in Table 1.II. The statistics reported in the Table 1 is the arithmetic means and standard deviations of the subsets of corresponding countries or industries.

(S5-3). Regardless of the tradable versus non-tradable restrictions on γ_{fi}, these coefficients are quite stable across industries: around -0.45 for labor and 0.50 for capital; a capital-abundant country employs more capital and less labor across all sectors after controlling for the average techniques and TFP levels.

Performance of the HOV Models

To check the performance of trade tests for 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 obtains the probability of sign coincidences between measured and predicted factor contents of trade. If the specification holds perfectly, the sign coincidence would be 100 percent. A slope test involves regressing measured factor contents of trade on predicted ones without an intercept. If the HOV specification holds, the regression coefficient would be unity. Finally, variance ratios are developed for each factor, computing the variance of measured factor contents of trade over the variance of predicted ones. The ratio should be unity but previous literature has shown that this number tends to be close to zero, reflecting Trefler's (1995) missing trade.

Before studying the trade tests, I discuss some important findings observed in the production tests shown in Table 3 I. The slope test of production regresses measured factor contents of domestic production (e.g., $\mathbf{B}^{US}\mathbf{Y}^{c}$ for the standard HOV model) on predicted ones (e.g., $\mathbf{V}^{c}$ for the standard HOV model) without an intercept. The examination of production tests with the standard HOV equation (S1-1) suggests that while the U.S. technique for labor is an outlier the U.S. technique for capital is not. The slope with the U.S. technique is 0.149 for labor and 0.920 for capital. The slope tests improves to 0.919 for labor and 0.927 for capital with the DFS specification even though measured factor contents of production are systematically undervalued to predicted ones, indicating the importance of allowing for the country-specific technique for non-tradable sectors in the technology estimations. Davis and Weinstein provide the similar tendencies with their 1985 data. Moreover, the production tests fit almost perfectly when the technology estimations involve the capital to labor ratios across all industries (S4-1) and (S5-1).

Table 3 II provides the results for the trade tests. The standard HOV model (S1-2) without any technology adjustment performs poorly as previously documented. The sign fits are

37.9 percent for labor and 62.1 percent for capital, the slope coefficients are 0.005 for labor and 0.023 for capital, and the variance ratios are 0.000 for labor and 0.066 for capital. The sign fit is no better than the coin-flip probability and the slope and the variance ratio tests indicate significant missing trade particularly for labor. Indeed, the variance ratio of the predicted labor contents of trade is about sixteen thousand times that of measured ones.[13] Table 1 gives us intuition. The developing countries employ three times more labor than developing countries do. Moreover, China uses on average ten times more labor than the United States does. Because the U.S. technique is used to measure factor contents of trade for (S1-2), the labor services embodied to imports from China are ten times smaller than actual labor contents of these imports.

There is no noticeable gain in prediction power when I introduce a factor-neutral TFP adjustment. Even though the sign fit is slightly improved, the slope and variance ratio tests still indicate significant missing trade. There is a systematic change in variance ratio. While the variance ratio for labor is twenty times greater than that without the TFP adjustment, the variance ratio for capital is four times smaller than that without the TFP adjustment. In addition, the TFP adjustments create an important change for factor endowment shares (Table 3 III). The share of developed countries for labor increases from 27.9 percent to 46.2 percent and that for capital increases slightly from 75.9 percent to 86.0 percent, indicating North-South efficiency gap for labor.

What is most surprising is that the DFS specification (S3-2) improves the sign fits almost perfectly. The proportion of correct signs rises sharply to 93.1 percent for labor and 89.7 percent for capital. Even though the trade variance ratios (0.077 for labor and 0.058 for capital) are not perfectly close to the theoretical predictions, the improvements in sign tests are impressive. The great success continues to the following two specifications, the multiple-cone production (S4-2) and unrestricted technology (S5-2) models, even though there are no significant improvements for sign, slope and variance ratio tests. These three specifications eliminate the Leontief paradox and predict precisely that a capital (labor) abundant country exports capital (labor) services. Figures 2-1 and 2-2 are the scatter plots of measured factor contents of trade in terms of predicted ones for the unrestricted technology model (S5-2). The United States, as well as almost all developed countries, is predicted as an importer of labor and as an exporter of capital.

[13] Compared to Davis and Weinstein, my data provides strong evidence for missing trade. One reason might be the fact that my dataset includes China and its 732 million workers.

In addition, most developing countries are predicted as importers of capital and as exporters of labor. This evidence is consistent with the HOV prediction since countries export abundant factors and import scarce factors.

II. Across-Industry Versus Across-Country Difference in Technique

In the previous section, I repeated the empirical exercise proposed by Davis and Weinstein. The data for year 2000 from 29 countries is consistent with the HOV prediction when the HOV assumptions, identical technique and factor price equalization, are relaxed. Table 4 summarizes the techniques employed for the unrestricted technology model (S5-2). Here the techniques are adjusted to the U.S. TFP unit. Compared to the original data on unit factor requirements provided in Table 1, the efficiency adjustment generates a clear distinction in techniques between the developed and developing countries. The developing countries employ, on average, two times more labor, 0.027 for developing countries and 0.014 for developed countries, and the developed countries employ two times more capital, 0.011 for developed countries and 0.006 for developing countries. The efficiency adjustment mitigates the North-South technical difference for labor and creates the clear difference for capital. The detailed data on technique is provided in Figures 3-1 and 3-2; Belgium employs the most capital-intensive technique and China employs the most labor-intensive technique. The difference in capital intensity between these two countries is 16-fold.

The success in the Davis-Weinstein model could be obtained without cross-industry specialization since any products exported from the developed countries embody more capital than labor and those imported from the developing counties embody more labor than capital. Schott (2004) first suggested the systematic cross-country difference in techniques within a product by using the product-level import data of the United States. The United States imports the same products from both high- and low-wage countries and unit values within products vary systematically with exporter's factor abundances and production techniques. The objective of this section is to exploit how much two variations in techniques, cross-industry versus cross-country, contribute to the evidence of the HOV model. First, unit factor requirements are specific for each sector and constant across countries; this assumption is the foundation for the across-industry specializations such as the HO model, the DFS model, and the multiple-cone production model. These theories predict that capital-abundant Japan exports capital-intensive automobiles and chemicals while labor-abundant China specializes in labor-intensive apparel and toys. Second, the techniques within a country might be similar across sectors; labor-abundant Indonesia employs labor-intensive techniques not only for apparel and toys but also for chemicals and electronics. Therefore, capital-abundant France and labor-abundant Indonesia both produce apparel but France employs more capital-intensive technique than Indonesia does. This is consistent with within-product specialization in Schott (2004).

A. Restricted Models

Across-Industry Difference in Techniques

The HO model, the DFS model, and the multiple-cone production model all assume that factors required to produce one unit of a product are different across industries. Therefore, the capital accumulation does not change technique *per se* but spurs countries to specialize in capital-intensive industries. To understand the contribution of the across-industry country-neutral technical difference in the success of the Davis-Weinstein model, it is a good idea to implement the standard HOV model with factor-augmenting productivity adjustments proposed by Trefler (1993) and Maskus and Nishioka (2009). Trefler introduces a Hicks-neutral efficiency at the individual factor level to measure endowments in the U.S. factor-specific efficiency units. If the labor supplies of Spain and Italy were the same but Italian workers were 20 percent more productive, then Spain requires 20 percent more labor than Italy does to produce one unit of the same product. This simple modification is consistent with the standard HOV model after adjusting for international differences in factor efficiency. While all countries share the same technique for each sector, efficiency-adjusted factor endowments differ across countries.

To introduce the factor-augmenting productivity adjustment, I simply allow $\theta^c \neq \theta^c_f$ from the factor-neutral efficiency adjustment model (S2-3).

(S6-1) Production: $\mathbf{B}^F \mathbf{Y}^c = \mathbf{V}^{cF}$

(S6-2) Trade: $\mathbf{B}^F \mathbf{X}^c - \left[\sum_{c' \neq c} \mathbf{B}^F \mathbf{M}^{cc'}\right] = \mathbf{V}^{cF} - s^c \mathbf{V}^{wF}$

(S6-3) Technique: $\ln(a^c_{fi}) = \ln(\theta^c_f) + \ln(\alpha_{fi}) + \varepsilon^c_{fi}$

where $\mathbf{B}^F$ is developed from the estimated coefficients from (S6-3): $\hat{\alpha}_{fi}$. I normalize $\mathbf{V}^c$ to the U.S. factor-by-factor efficiency units such that $\mathbf{V}^{cF}=[L^c/\theta^c_L \; K^c/\theta^c_K]'$. The world endowment vector ($\mathbf{V}^{wF}$) is the sum of $\mathbf{V}^{cF}$.

Across-Country Difference in Techniques

To eliminate the cross-industry variation in techniques, I introduce strong assumptions on the unrestricted technology specification (S5-1), (S5-2), and (S5-3). The first restriction is imposed on the average unit factor requirements across industries: $a_{fi}=a_f$. The average labor and capital requirements for any products are the same across industries and countries. If the empirical success is due to technical difference across industries or the industry-specific capital intensities, there must be huge missing trade with the fitted techniques from this specification. Second, I restrict the country capital to labor ratio to affect uniformly on all industries: $\gamma^{M'}{}_{fi} = \gamma^R{}_f$ with the restriction $\Sigma_f \gamma^R{}_f = 0$. These two restrictions ensure that there are no technical variations within a country. For example, both apparel and chemical industries in France employ the identical capital-intensive technique; those industries in Indonesia use the identical labor-intensive technique. Then, I have the following set of the equations:

(S7-1) Production: $\mathbf{B}^{cR}\mathbf{Y}^c = \mathbf{V}^{cE}$

(S7-2) Trade: $\mathbf{B}^{cR}\mathbf{X}^c - \left[\sum_{c'\neq c}\mathbf{B}^{c'R}\mathbf{M}^{cc'}\right] = \mathbf{V}^{cET} - s^c\mathbf{V}^{wET}$

(S7-3) Technique: $\ln(a^c_{fi}) = \ln(\theta^c) + \ln(\alpha_f) + \gamma^R_f \ln(K^c / L^c) + \varepsilon^c_{fi}$

Interestingly, this system of three equations consists only of macroeconomic data. $\mathbf{B}^{cR}$ is the average technique of country c and is approximately equal to $\overline{\mathbf{V}}^{cE}(\overline{\mathbf{Y}}^c)^{-1}$, which is further rewritten to $[L^c/GDP^c\ K^c/GDP^c]$' due to the definition of GDP. $\mathbf{X}^c$ is the total exports of country c, EX^c, and $\mathbf{M}^{cc'}$ is the total imports of country c from country c', $IM^{cc'}$. Therefore, the success of this specification provides evidence against across-industry specialization.

B. Contributions on the Success: Industry versus Country Difference in Technique

Estimations on Restricted Models

Table 2 II reports the technology coefficients and associated summary statistics for equations (S6-3) and (S7-3). According to the SIC, the technology estimation with the factor-augmenting productivity differences (S6-3) is statistically superior to that with the unrestricted technology model without FPE (S5-3), and those two restricted models fits better than the DFS specification (S3-3). Moreover, these specifications predict the domestic production quite precisely as in Table 3 even though measured capital contents of production overestimates by 23 percent with the country-specific techniques. It might be surprising that these restricted specifications fit the technology estimations and the production tests quite well since previous empirical evidence suggests the relaxation in techniques and factor prices are responsible for the success of the HOV model. Hakura (2001) stressed the importance of using original techniques for the success of the HOV model.[14]

Before moving to the trade tests, it is important to understand how techniques differ for these two restricted specifications. First, Figure 4 summarizes the unit labor requirement, unit capital requirement, and capital intensity across 30 industries. Since I adjust each factor endowment by factor-specific efficiency, all countries share the same technique across industries. Overall, electricity, mining, petroleum products, and business services are the four most capital-intensive industries. The most capital-intensive industry in manufacturing is chemicals and the most labor-intensive industry in manufacturing is textiles. The ratio of the capital intensity for chemicals to that for textiles is around two. This technical difference mainly comes from labor: while the textile sector employs twice more labor than the chemical sector does, these two sectors use similar amounts of capital to produce the same value of net output. The unit labor requirement, unit capital requirement, and capital intensity across 29 countries for the specification (S7-3) are in Figure 5. Belgium employs the most capital-intensive technique and China does the most labor-intensive technique. More precisely, the labor required to produce one unit of final products for Belgium is one-fourth of that for China; Belgium uses four times more capital than China does. Therefore, Belgium capital-intensity is 16-fold of Chinese capital-intensity, which is equal to the country capital to labor ratio.

Performance of the Restricted Models

Table 3 provides the results of testing the restricted specifications. With the factor-augmenting productivity adjustments, the proportion of correct sign is 75.9 percent for labor and 69.0 percent for capital; the variance ratio is 0.19 for labor and 0.50 for capital. These statistics sufficiently improves from the standard HOV model (e.g., Trefler 1993; Maskus and Webster

[14] Hakura (2001) showed unrestricted techniques as a source of success for the HOV model. However, because she introduced only one condition, identical and homothetic preference, in equation (2) in this paper, the evidence does not necessarily depend on unrestricted techniques. Rather, it merely provides the evidence for the identical and homothetic preference across four European countries. Indeed, once factor contents of imports are measured bilaterally with producers' techniques, her unrestricted technology specification does not support the data. These results are available upon request.

1999; Maskus and Nishioka 2009); however, the success in the sign test is not as impressive as specifications (S3-2), (S4-2), and (S5-2). The results with the across-industry restriction (S7-2) are quite surprising. The proportion of the correct sign is 86.2 percent for labor and 86.2 percent for capital. The slope tests improve to 0.417 for labor and 0.388 for capital; trade variance ratios also improve to 0.178 for labor and 0.175 for capital. Judging from the standard HOV tests, these two restricted specifications provide evidence for the HOV model.

To understand what underlies the success, I further study measured factor contents of trade and factor abundances for these restricted specifications and the unrestricted technology model (S5-2). Table 5 provides the statistical association of measured factor contents of trade between the three specifications. The across-industry restriction model (S7-2) measures factor contents of trade sufficiently similar to that of the unrestricted technology model (S5-2); the sign concordance is 89.7 percent for labor and 96.6 percent for capital, the correlation is 0.997 for both labor and capital, and the variance ratio of (S7-2) to that of (S5-2) is 2.078 for labor and 1.526 for capital. Not only does the restriction keep the predictions in signs, as the unrestricted model does, it also improves the variance ratios and slopes. In other words, there are no gains in prediction power even if the industry-specific capital intensities are introduced. The almost-identical performances of these two specifications imply that the impressive performances of the sign concordances and variance ratios stem from cross-country difference in techniques; the industry-specific techniques do not play any role for the success of the Davis-Weinstein model.

On the other hand, the across-country restriction in technique (S6-2) predicts something different from the unrestricted technology model without FPE (S7-2). The sign concordance between measured factor contents of trade for (S6-2) and those for (S5-2) is 44.8 percent for labor and 72.4 percent for capital; the correlation is 0.635 for labor and -0.602 for capital. Moreover, the variance ratio is only 0.012 for labor but 0.590 for capital. Two notable findings are involved. First, the relaxation in across-country technical difference is crucial to account for the missing trade for labor but not for capital. Second, there is strong negative correlation between measured capital contents of trade with factor-specific productivity adjustments (S6-2) and those with unrestricted technology model (S5-2). Table 6 provides the reason why there is strong negative correlation. With the factor-specific efficiency adjustments, measured factor contents of trade correlate strongly with countries' trade balances: 0.943 for labor and 0.971 for capital. In addition, the signs of measured factor contents of trade correspond to those of countries' total trade balances: 86.2 percent for labor and 93.1 percent for labor. Indeed, since there are no significant variations in techniques, in particular for capital, across industries, the measured factor contents of trade reflect each country's trade balance.[15]

Efficiency and the Success of the HOV Models

Even though capital accumulation does not likely predict across-industry specialization, it is not necessarily the rejection for the HOV model since factor contents of trade can be reasonably predicted from factor abundances. However, the predictions from these two restricted specifications differ tremendously, depending on how to implement the efficiency unit: TFP or factor-augmenting efficiencies. Most of the previous literature on growth accounting specifies the production function by assuming that all differences in efficiency across countries are TFP differences, as summarized by the single multiplicative factor A^c in the production function $Y_i^c = A^c f_i(L_i^c, K_i^c) = (A^c L_i^c)^{\beta_i^c} (A^c K_i^c)^{1-\beta_i^c} = (L_i^c / \theta^c)^{\beta_i^c} (K_i^c / \theta^c)^{1-\beta_i^c}$. As in Casseli (2005), this specification of single efficiency difference is factor-neutral, and a country uses all factors efficiently with a unique proportion. Davis and Weinstein (2001) employed this idea, combined with the country-specific labor share: $\beta^c{}_i \neq \beta^{c'}{}_i$. On the other hand, Caselli (2005) and Caselli and Coleman (2006), based on the Constant Elasticity of Substitution (CES) production function, explored a general setting that allows for the possibility of factor-specific efficiencies (e.g., Trefler 1993; Maskus and Nishioka 2009). Using the Cobb-Douglas form, I can show that TFP, $A^c(=1/\theta^c)$, consists of factor-specific efficiencies:
$Y_i^c = (A_L^c)^{\beta_i} (A_K^c)^{1-\beta_i} f_i(L_i^c, K_i^c) = (A_L^c L_i^c)^{\beta_i} (A_K^c K_i^c)^{1-\beta_i} = (L_i^c / \theta_L^c)^{\beta_i} (K_i^c / \theta_K^c)^{1-\beta_i}$ where industry-specific labor shares ($\beta^c{}_i = \beta^{c'}{}_i$) are constant across countries, and TFP measures of A^c is now composed of the product of contributions from labor and capital ($A^c = (A_L^c)^{\beta_i} (A_K^c)^{1-\beta_i}$).[16]

Caselli and Feyrer (2007) found that capital shares, $1\text{-}\beta^c{}_i$, are similar across countries once they separate the natural capital from reproductive capital to calculate the accurate capital shares.[17] Moreover, they show the macroeconomic data is consistent with the view that international financial markets are efficient at allocating production capital across countries (e.g.,

[15] Leamer (1980) found the similar tendency with Leontief's (1953) data; the United States was an exporter of both capital and labor services.
[16] Which production function is appropriate might depend on the condition on labor share: $\beta^c{}_i \neq \beta^{c'}{}_i$ or $\beta^c{}_i = \beta^{c'}{}_i$.
[17] Developing countries have larger shares of natural capital. Therefore, the GDP minus labor compensation overestimates the compensation for physical capital.

Lucas 1990). In fact, marginal products of capital in Caselli and Feyrer (2007) and the unit capital requirements in the HOV literature are reciprocal,[18] and the evidence of convergence in marginal product of capital implies that unit capital requirements (a^c_{Ki}) should also be equalized across countries.[19] Indeed, while developing countries employ three times more labor, developed countries employ only 37 percent more capital without any efficiency adjustment, suggesting the strong convergence in techniques, a^c_{fi}, only for capital. If we have the condition $\beta^c_i = \beta^{c'}_i$ for any countries, the factor-augmenting productivity model has to be interpreted with caution since the data suggests the possibility of capital mobility across countries.

Mundell (1957), for example, introduced capital mobility into the HO framework. Assume that a labor abundant country imposes a tariff on its importing capital-intensive products. The tariff raises the domestic price of the capital-intensive products and it increases the returns to capital as predicted by the Stolper-Samuelson theorem. Since capital is now mobile, capital flows to the labor abundant country until the rental rates equalize across countries. As a result, the production activities of both labor- and capital-intensive sectors move to the labor abundant country but the consumption point remains the same since the capital-recipient country has to compensate for foreign capital. For the factor contents of trade, the capital abundant country imports both labor and capital services and the labor abundant country exports both services. This prediction is actually consistent with the data as in Table 6: the sign concordances between labor and capital contents of trade are 79.3 percent.

While Mundell's model discussed the factor mobility when the endowment point is in the FPE set, Helpman (1984) introduced vertical FDI in the HO model when the endowment point is outside of the FPE set. With the factor endowment point outside the FPE set, a capital abundant country produces capital-intensive products with domestic labor and capital, and allocates its remaining capital for foreign countries in exchange for compensations. This transferred capital would be combined with foreign labor to produce capital-intensive and/or labor-intensive products. Therefore, there is a gap between factor contents of domestic production and those of

[18] To clarify the association between technique (a^c_{fi}) in the HOV literature and marginal product of capital (MPK^c_i) in Caselli and Feyrer (2007), consider a constant-return production function, $Y^c_i = f(L^c_i, K^c_i) = (L^c_i)^{\beta i}(K^c_i)^{(1-\beta i)}$, and a perfectly competitive capital market. Under this restricted conditions, I can derive the equality between the rental rate of capital for each industry (r^c_i) and the marginal product of capital (MPK^c_i). If the capital share for industry i (β_i) is identical across countries, I have $MPK^c_i = \beta_i(Y^c_i/K^c_i)$ or $MPK^c_i = \beta_i/a^c_{Ki}$ where Y^c_i/K^c_i is roughly equal to a^c_{Ki} by data construction.

[19] Even though Caselli and Feyrer (2007) investigated the macroeconomic data, the tendency of convergence might be applicable for industry-level data.

domestic consumption, which creates a systematic error in factor contents of this country's trade.[20] Again, the capital abundant country could import both labor and capital services and the labor abundant country exports both services. Taking the rapid globalization in production network and FDI into accounts (e.g., Hanson, Mataloni, Slaughter 2005), it is no surprise that capital moves across countries.

III. Conclusion

The long history of the empirical tests on the HOV model had concluded with the evidence against its unrealistic assumptions: identical technique and FPE. This paper extends the previous evidence and shows further that capital abundance plays a limited role to explain global specialization across industries. While recent literature on the factor proportions models of international trade concentrates on the models with the possibility of multiple-cone production with labor-capital framework (e.g., Davis and Weinstein 2001; Choi and Krishna 2004; Lai and Zhu 2007), the industry-level data from 29 countries provides weak evidence for across-industry specialization. Rather, the data supports the view of within-industry specialization (Schott 2004). Accumulation in capital does not shift the production mix towards more capital-intensive one but shift towards more capital-intensive varieties within an industry.

The variation in technique is much greater across countries than industries. This simple observation must be responsible for the previous empirical failures of the HOV model and its variants (e.g., Bowen, Leamer, and Sveikauskas 1987; Trefler 1995; Davis and Weinstein 2001). While this paper considers the limitation of the HOV model when industry-level data is employed with the standard labor-capital framework, it does not necessarily reject all the previous evidence for global specialization. In fact, we can casually observe across-industry specialization such that China specializes in apparel and toys and the United States exports airplanes and semiconductors, but I argue that it is hard to explain such specialization simply from capital accumulation.

The international variation in technique stems exclusively from labor. Developing countries employ more labor but there are no significant differences in capital usage. The persistent difference in labor techniques across countries might involve many issues such as educational attainment, skill composition, learning by doing, and skill complementarity. It must

[20] See Nishioka (2008) for the systematic errors in factor trade in the context of Helpman's (1984) model.

be important to develop the industry-level data with various skill groups for both developed and developing countries so that we can discuss the skill-endowment-driven specialization by applying existing factor-abundance models in the global context. I also find the clear convergence in capital technique and the Heckscher-Ohlin models allowing the possibility of capital mobility (e.g., Mundell 1957; Helpman 1984) are likely to be consistent with the global data. This finding is consistent with the evidence provided by Caselli and Feyrer (2007) who argued that the convergence causes from international financial markets. This view has ignored in the literature of the factor abundance models.

Finally, the evidence for within-industry specialization is derived from the systematic difference in techniques between developed and developing countries, which is developed from the TFP adjustment. Because TFP is roughly the weighted average of performances in labor and capital, the TFP adjustment generates the techniques such that developed countries employ less labor and more capital. Now, firm-level data are available for many countries. To connect the old evidence of trade models to recent firm-heterogeneity literature (e.g., Melitz 2003 and Bernard, Redding, and Schott 2007), it is important to study how industry-level TFPs are composed of firm-level TFP by using firm-level data across countries.

References

Bernard, Andrew B. and J. Bradford Jensen. 1999. "Exceptional Exporter Performance: Cause, Effect, or Both?," *Journal of International Economics* 47:11-25.

Bernard, Andrews B., Stephen Redding, and Peter K. Schott. 2007. "Comparative Advantage and Heterogeneous Firms," *Review of Economic Studies* 74(1): 31-66.

Bowen, Harry P., Edward E. Leamer, and Leo Sveikauskas. 1987. "Multicountry, Multifactor Tests of the Factor Abundance Theory," *American Economic Review* 77(5): 791-809.

Caselli, Francesco. 2005. "Accounting for Cross-Country Income Differences," *in Philippe Aghion & Steven Durlauf (ed.), Handbook of Economic Growth* 1(9): 679-741, Elsevier.

Caselli, Francesco and Wilbur John Coleman II. 2006. "The World Technology Frontier," *American Economic Review* 96(3): 499-522.

Caselli, Francesco and James D. Feyrer. 2007. "The Marginal Product of Capital," *Quarterly Journal of Economics* 122(2): 535-68.

Choi, Yong-Seok, and Pravin Krishna. 2004. "The Factor Content of Bilateral Trade: An Empirical Test," *Journal of Political Economy* 112(4): 887-914.

Davis, Donald R. and David E. Weinstein. 2001. "An Account of Global Factor Trade," *American Economic Review* 91(5): 1423-53.

Debaere, Peter and Ufuk Demiroglu. 2003. "On the Similarity of Country Endowments," *Journal of International Economics* 59: 101-36.

Dornbusch, Rudiger, Stanley Fischer, and Paul A. Samuelson. 1980. "Heckscher-Ohlin Trade Theory with a Continuum of Goods," *Quarterly Journal of Economics* 95(2): 203-24.

Fisher, Eric O'N., and Kathryn G. Marshall. 2008. "Let's Take the Con out of Factor Content," California Polytechnic State University, manuscript.

Fitzgerald, Doireann, and Juan Carlos Hallak. 2004. "Specialization, Factor Accumulation and Development," *Journal of International Economics* 64: 277–302.

Hakura, Dalia S. 2001. "Why Does HOV Fail? The Role of Technological Differences within the EC," *Journal of International Economics* 54: 361-82.

Hanson, Gordon H., Raymond J. Mataloni, Jr., and Matthew J. Slaughter. 2005. "Vertical Production Networks in Multinational Firms," *Review of Economics and Statistics* 87(4): 664-78.

Harrigan, James. 1997. “Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model,” *American Economic Review* 87(4): 475-94.

Helpman, Elhanan 1984. “A Simple Theory of International Trade with Multinational Corporations,” *Journal of Political Economy* 92(3): 451-71.

Helpman, Elhanan. 1999. “The Structure of Foreign Trade,” *Journal of Economic Perspectives* 13(2): 121-44.

Heston, Alan, Robert Summers, and Bettina Aten. 2006. “Penn World Table Version 6.2,” Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Keller, Wolfgang. 2002. “Geographic Localization of International Technology Diffusion,” *American Economic Review* 92 (1): 120-142.

Krugman, Paul R. 1980. “Scale Economy, Product Differentiation, and the Pattern of Trade,” *American Economic Review* 70 (5): 950-959.

Krusell, Per, Lee E. Ohanian, José-Víctor Ríos-Rull, and Giovanni L. Violante. 2000. “Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis,” *Econometrica* 68 (5): 1029-1053.

Lai, Huiwen and Susan Chun Zhu. 2007. “Technology, Endowments, and the Factor Content of Bilateral Trade,” *Journal of International Economics* 71: 389-409.

Leamer, Edward E. 1980. “The Leontief Paradox, Reconsidered,” *Journal of Political Economy* 88(3): 495-503.

Leamer, Edward E. 1984. *Sources of International Comparative Advantage: Theory and Evidence,* Cambridge, MA: MIT Press.

Leontief, Wassily. 1953. “Domestic Production and Foreign Trade: The American Capital Position Re-examined,” *Proceedings of the American Philosophical Society* 97: 332-49.

Lucas, Jr., Robert E. 1992. “Why Doesn't Capital Flow from Rich to Poor Countries?” *American Economic Review Papers and Proceedings* 80 (2): 92-96.

Maskus, Keith E. 1985. “A Test of the Heckscher-Ohlin-Vanek Theorem: The Leontief Commonplace,” *Journal of International Economics* 19: 201-12.

Maskus, Keith E. and Allan Webster. 1999. “Estimating the HOV Model with Technology Differences Using Disaggregated Labor Skill for the United States and the United Kingdom,” *Review of International Economics* 7(1): 8-19.

Maskus, Keith E. and Shuichiro Nishioka. 2009. "Development-Related Biases in Factor Productivities and the HOV Model of Trade," *Canadian Journal of Economics*.

Melitz, Marc J. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica* 71(6): 1695-1725.

Mundell, Robert A. 1957. "International Trade and Factor Mobility," *American Economic Review* 47(3): 321-35.

Nishioka, Shuichiro. 2008. "The Production Fragmentation in Manufacturing: Evidence from the Parent-to-Affiliate Transfers of Business Production Knowledge," mimeo.

Romalis, John. 2004. "Factor Proportions and the Structure of Commodity Trade," *American Economic Review* 94(1): 67-97.

Schott, Peter K. 2003. "One Size Fits All? Heckscher-Ohlin Specialization in Global Production," *American Economic Review* 93(3): 686-708.

Schott, Peter K. 2004. "Across-product Versus Within-product Specialization in International Trade," *Quarterly Journal of Economics* 119(2): 647-678.

Trefler, Daniel. 1993. "International Factor Price Differences: Leontief was Right!" *Journal of Political Economy* 101(6): 961-87.

Trefler, Daniel. 1995. "The Case of the Missing Trade and Other Mysteries," *American Economic Review* 85(5): 1029-46.

Appendix: Data Development

(1) Input-Output Data

Input-output (I-O) tables (total use) for Australia, Austria, Belgium, Brazil, Canada, China, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Indonesia, Ireland, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Turkey, the United Kingdom, and the United States for year 2000 are taken from the OECD Input-Output Database (2007). These I-O tables employ the ISIC Rev.3 with 48 industrial groups. To keep the consistency of sectors across 29 countries, I aggregate the dataset into 30 industries.

Input-output matrices, final consumptions, gross outputs, exports, and imports are drawn from the I-O tables. Final consumption is the sum of final consumption of households, final consumption and investment of government, gross fixed capital formation, and changes in inventory. Therefore, the total use table of country *c* satisfies the equation $\mathbf{T}^{ct}=(\mathbf{I}-\mathbf{A}^{ct})\mathbf{Q}^{ct}-\mathbf{D}^{ct}$ where $\mathbf{A}^{ct}$ is a 30×30 indirect technique for the unit intermediate requirements and $(\mathbf{I}-\mathbf{A}^{ct})\mathbf{Q}^{ct}$ vector equals net output ($\mathbf{Y}^{ct}$) by construction. $\mathbf{A}^{ct}$ is obtained by taking input-output data from the I-O tables and dividing inputs in each sector by the corresponding sector's gross output.

To convert the dataset into 2000 international dollars, I use the country-level PPP rates from the Penn World Table (PWT) 6.2 (Heston, Summers, and Aten, 2006). Unfortunately, I do not have the industry-level PPP rates. This might conceal the cross-industry heterogeneity in technique for each country. For Australia, nominal values in the I-O tables are uniformly multiplied by the growth rates of total nominal GDP to adjust data from earlier years to the year 2000. For Greece, Ireland, New Zealand, Norway, and Portugal, gross outputs in the I-O tables are multiplied by the growth rates of corresponding sectors' nominal GDPs.

(2) Industry-Level Data for Factor Inputs

Physical Capital

Capital stock is developed from the discounted sum of real gross fixed capital formation in 2000 international dollars ($GFCF^{c}_{it}$) from 1980 to 2000.

$$K_i^c = \sum_{t=1980}^{2000} (1-0.1333)^{2000-t} GFCF_{it}^c$$

For OECD countries, values for gross fixed capital formation (GFCF) are derived from the OECD structural analysis (STAN) database (2005) and unreported data are estimated from the ISIC Rev.2 version of the OECD STAN database (1998). As many GFCF data as possible are derived from these databases but there are still some unavailable values. The following procedure is taken to interpolate these data. First, some detailed sectors (e.g., 18 "Motor vehicles, trailers and semi-trailers" and 19 "Other transport equipment") are unavailable for certain years but data for their aggregated value (18+19 "Transport equipment") exist for all years. I use the share of the nearest year to allocate those totals to each detailed sector. Second, if a country reports only aggregated industry sub-totals (18+19 "Transport equipment"), I first develop capital stocks of these sub-totals and allocate these values to each industry according to the compensation for capital (gross operating surplus) obtained from the I-O tables. This procedure is based on the idea that industry capital compensation flows are proportional to industry capital stocks (Lai and Zhu, 2007). In particular, for non-OECD countries (Brazil, Indonesia, and China) and for Greece and Turkey, I first develop country-level capital stocks and allocate each country's total capital stock to 30 industries according to capital compensation data from the I-O tables. Finally, unreported years of Czech Republic (1980-1994), Hungary (1980-1990), Poland (1980-1991), Portugal (1980-1994), and Slovak Republic (1980-1992) are interpolated with industry-level growth rates of available years.

One major problem with using GFCF data from the OECD STAN database (2005) is that most countries include residential investments but three (Canada, the United Kingdom and the United States) do not. In particular, agriculture and real estate are the main sources of errors from residential investments. To avoid serious errors, I obtain the difference between values for gross fixed capital formation from the OECD STAN database and those from *International Financial Statistics* (IMF) for these three countries and add these differences into the real estate sector. Unfortunately, it is impossible to adjust agriculture for residential investment and caution must be exercised when data from that sector are used in the analysis.

To convert GFCF figures into real series, I convert values into nominal U.S. dollars, divide by the price of investment from the Penn World Table 6.2, and deflate by U.S. industry-level prices for gross fixed capital formation, which is obtained from the OECD STAN database (2005). After this conversion into 2000 international dollars, I compute real capital stock data, using a depreciation rate of 0.1333 (e.g., Leamer, 1984; Bowen, Leamer, and Sveikauskas, 1987;

and Davis and Weinstein, 2001). For Japan, industrial GFCF data are unavailable from the STAN database. Therefore, I take the total GFCF series from the World Development Indicators (World Bank) and Japan's sectoral shares are obtained from the nominal investment matrix tables of the ESRI-Histat database (ISIC Rev.3). The OECD Economic Outlook (2008) provides the country-level stocks of physical capital in local nominal values for some OECD countries. I convert these values to 2000 international dollars and allocate them by the sectoral values.

Working-Hour Adjusted Labor

Sectoral labor inputs (total employment) for the year 2000 are derived from the OECD STAN databases (2005) and the ILO LABORSTA Internet Yearly Statistics (http://laborsta.ilo.org/). Most data are available from these sources. If a country reports only aggregated industry sub-totals, I allocate these to each industry according to the compensation of employees obtained from the I-O tables. For most OECD countries, country-level annual-working hours are available from the OECD Employment and Labor Market Statistics (2006) but it is not possible to obtain industry-level annual working hours. The data on weekly working hours are available for all countries except China from ILO LABORSTA Internet Yearly Statistics. I use the following equation, $AH^c=AH^{US}*WH^c/WH^{US}$ where AH^c is annual working hours and WH^c is weekly working hours for country *c*, to estimate the annual working hours for Brazil, Indonesia, and Turkey. I cannot adjust total employment of China by working hours.

(3) Industry-Level Bilateral Trade

Bilateral trade flows for manufacturing from each of 26 OECD countries and each of all 29 countries are available from the OECD STAN Bilateral Trade Database (2005). Here, the imports and exports from the rest of the world are added to those from or to China. Therefore, factor contents of imports from the rest of the world are measured with China's technique. Bilateral trades for three countries, Brazil, Indonesia, and China, are developed from the data on partners' trades and Direction of Trade Statistics (IMF). I scale these bilateral trade flows so that bilateral industry import totals match those from the I-O tables. Because there is no bilateral trade data available for service industries, I allocate the total service imports for each industry derived from the I-O tables into each of 29 countries by the share of total manufacturing imports.

Table. Description of 30 Industries and 29 Countries

Industry #	Description	ISIC Rev.3	Tradables
1	Agriculture, hunting, forestry, and fishing	1-2, 5	1
2	Mining and quarrying	10-14	1
3	Food products and beverages	15-16	1
4	Textiles	17-19	1
5	Wood and of products of wood and cork	20	1
6	Paper and paper products	21-22	1
7	Coke, refined petroleum products and nuclear fuel	23	1
8	Chemicals and chemical products	24	1
9	Rubber and plastics products	25	1
10	Other non-metallic mineral products	26	1
11	Basic metals	27	1
12	Fabricated metal products	28	1
13	Machinery and equipment	29	1
14	Office, accounting and computing machinery	30	1
15	Electrical machinery and apparatus	31	1
16	Radio, television and communication equipment	32	1
17	Medical, precision and optical instruments	33	1
18	Motor vehicles, trailers and semi-trailers	34	1
19	Other transport equipment	35	1
20	Other manufacturing (incuding recycling)	36-37	1
21	Electricity, gas and water supply	40-41	0
22	Construction	45	0
23	Wholesale and retail trade	50-52	1
24	Hotels and restaurants	55	1
25	Transport, storage and communications	60-64	1
26	Financial intermediation	65-67	1
27	Real estate, renting and business activities	70-74	1
28	Public administration and defence	75	0
29	Education	80	0
30	Health and social work	85, 90-93, 95, 99	0

Country #	Country	North
1	Australia	1
2	Austria	1
3	Belgium	1
4	Brazil	0
5	Canada	1
6	China	0
7	Czech	0
8	Denmark	1
9	Finland	1
10	France	1
11	Germany	1
12	Greece	0
13	Hungary	0
14	Indonesia	0
15	Ireland	1
16	Italy	1
17	Japan	1
18	Korea	1
19	Netherlands	1
20	New Zealand	1
21	Norway	1
22	Poland	0
23	Portugal	0
24	Slovak	0
25	Spain	1
26	Sweden	1
27	Turkey	0
28	United Kingdom	1
29	United States	1

Tables and Figures

Table 1. Summary Statistics in Techniques across Industries and Countries

I. Within-country means and standard deviations

Variable	Labor mean	Labor st.dev	Labor st.dev/mean	Capital mean	Capital st.dev	Capital st.dev/mean
All Countries	0.031	0.014	0.435	0.013	0.004	0.323
North (19 countries)	0.018	0.007	0.383	0.014	0.005	0.344
South (10 countries)	0.056	0.026	0.467	0.010	0.003	0.271

II. Within-industry means and standard deviations

Variable	Labor mean	Labor st.dev	Labor st.dev/mean	Capital mean	Capital st.dev	Capital st.dev/mean
All Industries	0.031	0.028	0.900	0.013	0.004	0.348
Manufactuimg	0.030	0.025	0.831	0.012	0.004	0.322
Services	0.035	0.035	0.996	0.012	0.004	0.320

Notes: (1) In panel I, means and standard deviations are first derived across industries for each country. The numbers in the panel I are simple means of these across subsets of countries.

(2) In panel II, means and standard deviations are first derived across countries for each industry. The numbers in the panel II are simple means of these across subsets of industries.

Table 2. Results of Technology Estimations

Model	Hicks-neutral (TFP) (S2-3)	I. Davis and Weinstein (2001) DFS with FPE (S3-3)	Helpman multiple-cone (S4-3)	Unrestricted technology (S5-3)	II. Restricted Models Constant across-country (S6-3)	Constant across-sector (S7-3)
γ_K^T		0.474 (0.012)	0.456 (0.014)			0.492 (0.011)
γ_K^N			0.581			0.492 (0.011)
γ_L^T		-0.474 (0.012)	-0.492 (0.014)			-0.492 (0.011)
γ_L^N			-0.546 (0.019)			-0.492 (0.011)
Parameters (k)	88	89	91	147	116	31
Adjusted R^2	0.554	0.776	0.861	0.872	0.862	0.726
-Log L (LL)	-1239	-640	-227	-125	-205	-846
SIC	1.802	1.117	0.651	0.774	0.733	1.105
AIC	1.526	0.837	0.365	0.313	0.369	1.007

Notes: (1) Standard errors are reported in parentheses.

(2) There are 30 industries and 2 factors.

(3) The number of obervations is 1,740 (=30*29*2).

Table 3. Trade Tests for Labor and Capital

I. Production Tests

	Labor							Capital						
	Davis and Weinstein (2001)					Restricted		Davis and Weinstein (2001)					Restricted	
Model	(S1-1)	(S2-1)	(S3-1)	(S4-1)	(S5-1)	(S6-1)	(S7-1)	(S1-1)	(S2-1)	(S3-1)	(S4-1)	(S5-1)	(S6-1)	(S7-1)
Slope Test	0.149	0.666	0.919	1.033	1.049	0.979	1.032	0.920	0.826	0.927	1.008	1.002	1.039	1.105
Standard error	0.035	0.074	0.027	0.006	0.006	0.006	0.007	0.036	0.046	0.016	0.007	0.006	0.007	0.007
R-squared	0.201	0.667	0.971	0.999	0.999	0.999	0.998	0.947	0.895	0.990	0.999	0.999	0.999	0.999
Variance Test	0.048	0.566	0.846	1.077	1.112	0.955	1.080	0.910	0.710	0.852	1.021	1.006	1.079	1.227

II. Trade Tests

	Labor							Capital						
	Davis and Weinstein (2001)					Restricted		Davis and Weinstein (2001)					Restricted	
Model	(S1-2)	(S2-2)	(S3-2)	(S4-2)	(S5-2)	(S6-1)	(S7-1)	(S1-2)	(S2-2)	(S3-2)	(S4-2)	(S5-2)	(S6-1)	(S7-1)
Sign Test	0.379	0.448	0.931	0.897	0.897	0.759	0.862	0.621	0.655	0.897	0.897	0.897	0.690	0.862
Slope Test	0.005	0.026	0.276	0.308	0.287	0.303	0.417	0.023	-0.110	0.220	0.325	0.315	0.470	0.388
Standard error	0.001	0.005	0.007	0.007	0.006	0.058	0.013	0.049	0.014	0.018	0.025	0.025	0.100	0.030
R-squared	0.407	0.451	0.983	0.987	0.988	0.490	0.975	0.008	0.680	0.839	0.855	0.850	0.439	0.859
Variance Test	0.000	0.001	0.077	0.096	0.083	0.187	0.178	0.066	0.018	0.058	0.124	0.116	0.503	0.175

III. Factor Endowment Shares

	Labor Share (%)							Capital Share (%)						
	Davis and Weinstein (2001)					Restricted		Davis and Weinstein (2001)					Restricted	
Model	V^c	V^{cH}	V^{cD}	V^{cM}	$V^{cM'}$	V^{cF}	V^{cR}	V^c	V^{cH}	V^{cD}	V^{cM}	$V^{cM'}$	V^{cF}	V^{cR}
North (19 countries)	27.9	46.2	46.6	39.3	39.8	70.1	40.1	75.9	86.0	86.2	84.7	84.9	70.3	85.1
South (10 countries)	72.1	53.8	53.4	60.7	60.2	29.9	59.9	24.1	14.0	13.8	15.3	15.1	29.7	14.9

Table 4. Summary Statistics in Unrestricted Helpman's Technologies (S5-2) across Industries and Countries with TFP Adjustments

I. Within-country means and standard deviations

	Labor			Capital		
Variable	mean	st.dev	st.dev/mean	mean	st.dev	st.dev/mean
All Countries	0.019	0.006	0.334	0.009	0.002	0.250
North (19 countries)	0.014	0.004	0.281	0.011	0.003	0.267
South (10 countries)	0.027	0.011	0.385	0.006	0.001	0.193

II. Within-industry means and standard deviations

	Labor			Capital		
Variable	mean	st.dev	st.dev/mean	mean	st.dev	st.dev/mean
All Industries	0.019	0.008	0.434	0.009	0.003	0.294
Manufactuirng	0.018	0.007	0.415	0.009	0.002	0.274
Services	0.021	0.009	0.447	0.009	0.003	0.316

Table 5. The Association between Measured Factor Contents of Trades for 3 Specifications

I. Labor

	Sign Concordance (%)			Correlation			Variance Ratio		
	(S5-2)	(S6-2)	(S7-2)	(S5-2)	(S6-2)	(S7-2)	(S5-2)	(S6-2)	(S7-2)
Unrestricted Helpman (S5-2)	100	-	-	1.000	-	-	1.000	-	-
Across-industry (S6-2)	44.8	100	-	0.635	1.000	-	0.012	1.000	-
Across-country (S7-2)	89.7	55.2	100	0.997	0.589	1.000	2.078	0.006	1.000

II. Capital

	Sign Concordance (%)			Correlation			Variance Ratio		
	(S5-2)	(S6-2)	(S7-2)	(S5-2)	(S6-2)	(S7-2)	(S5-2)	(S6-2)	(S7-2)
Unrestricted Helpman (S5-2)	100	-	-	1.000	-	-	1.000	-	-
Across-industry (S6-2)	72.4	100	-	-0.602	1.000	-	0.590	1.000	-
Across-country (S7-2)	96.6	75.9	100	0.997	-0.628	1.000	1.526	0.387	1.000

Table 6. The Association between Factor Contents of Trade and Trade Balance for (S6-2)

	Sign Concordance (%)			Correlation		
	MLCT	MKCT	TB	MLCT	MKCT	TB
Measured Labor Contents of Trade (MLCT)	100	-	-	1.000	-	-
Measured Capital Contents of Trade (MKCT)	79.3	100	-	0.849	1.000	-
Trade Balance (TB)	86.2	93.1	100	0.943	0.971	1.000

Figure 1. Coefficients on Country Capital to Labor Ratios across Industries

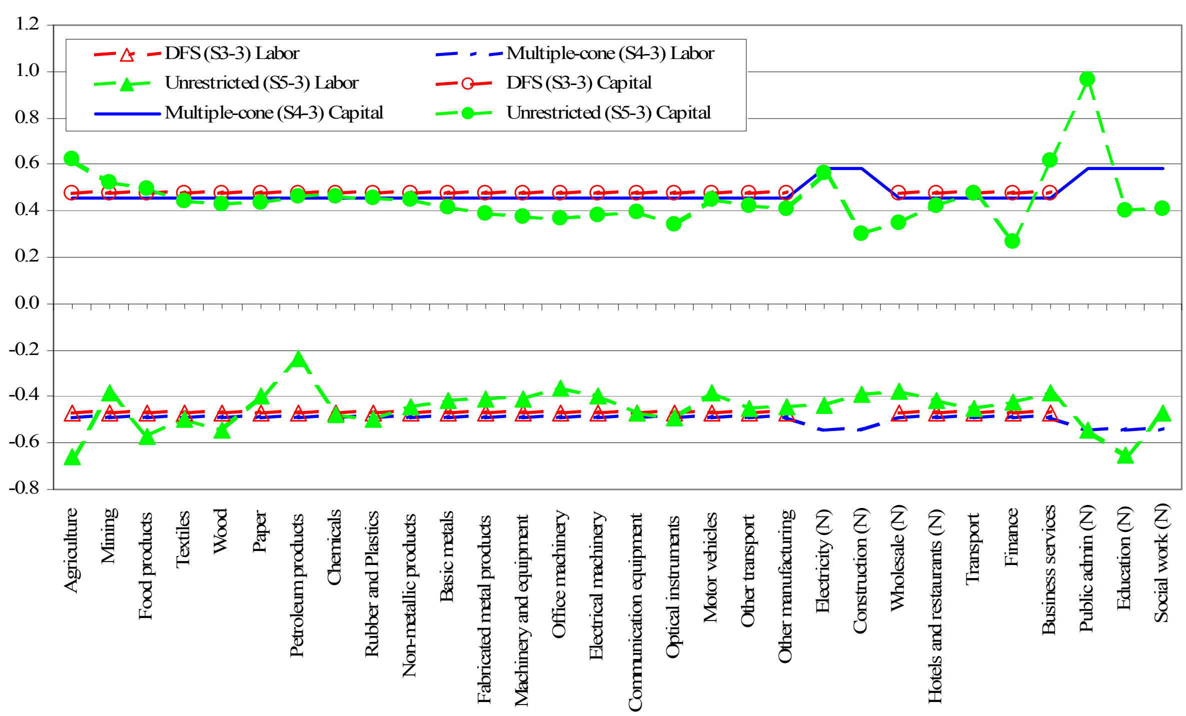

Figure 2-1. Trade with Unrestricted Technology (S5-2) - Labor

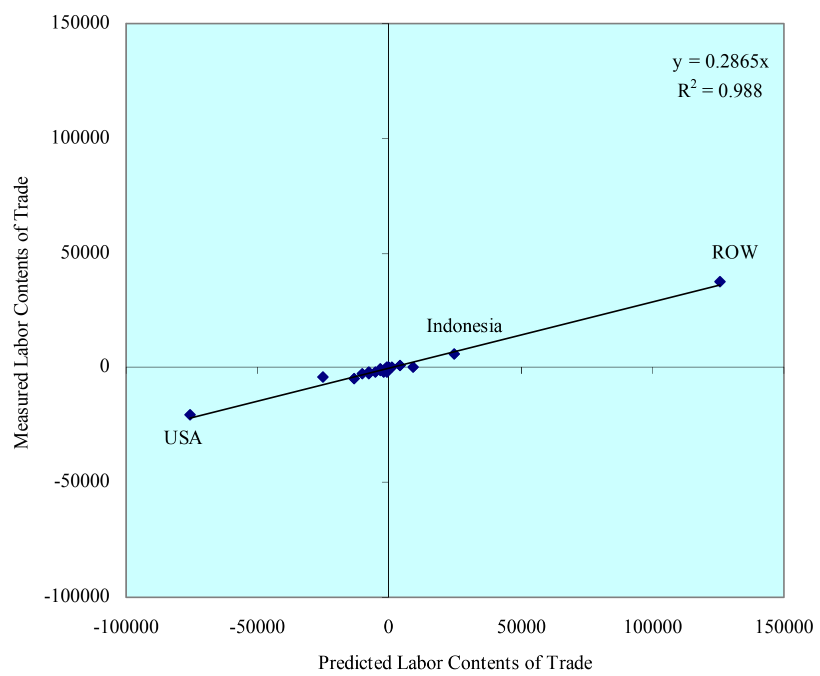

Figure 2-2. Trade with Unrestricted Technology (S5-2) - Capital

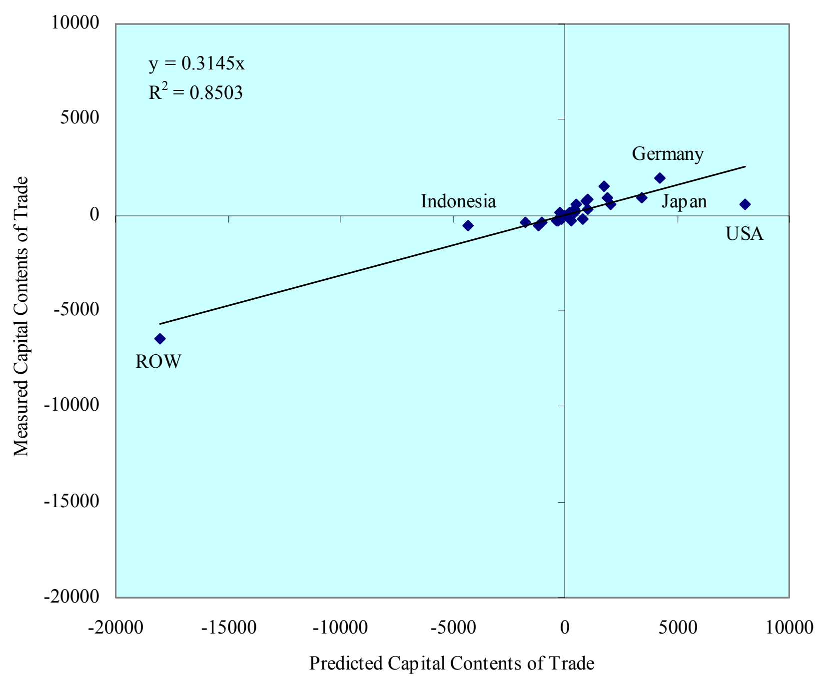

Figure 3-1. Unrestricted Technology (S5-3) with TFP Adjustments - Labor

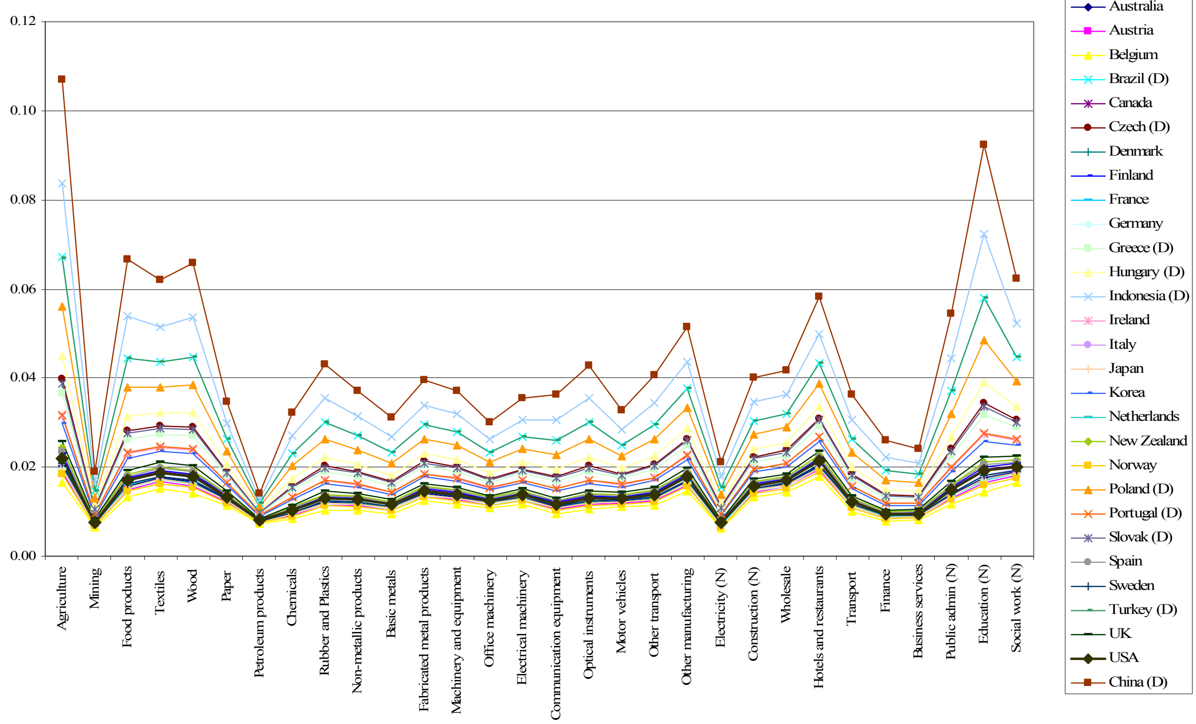

Figure 3-2. Unrestricted Technology (S5-3) with TFP Adjustments - Capital

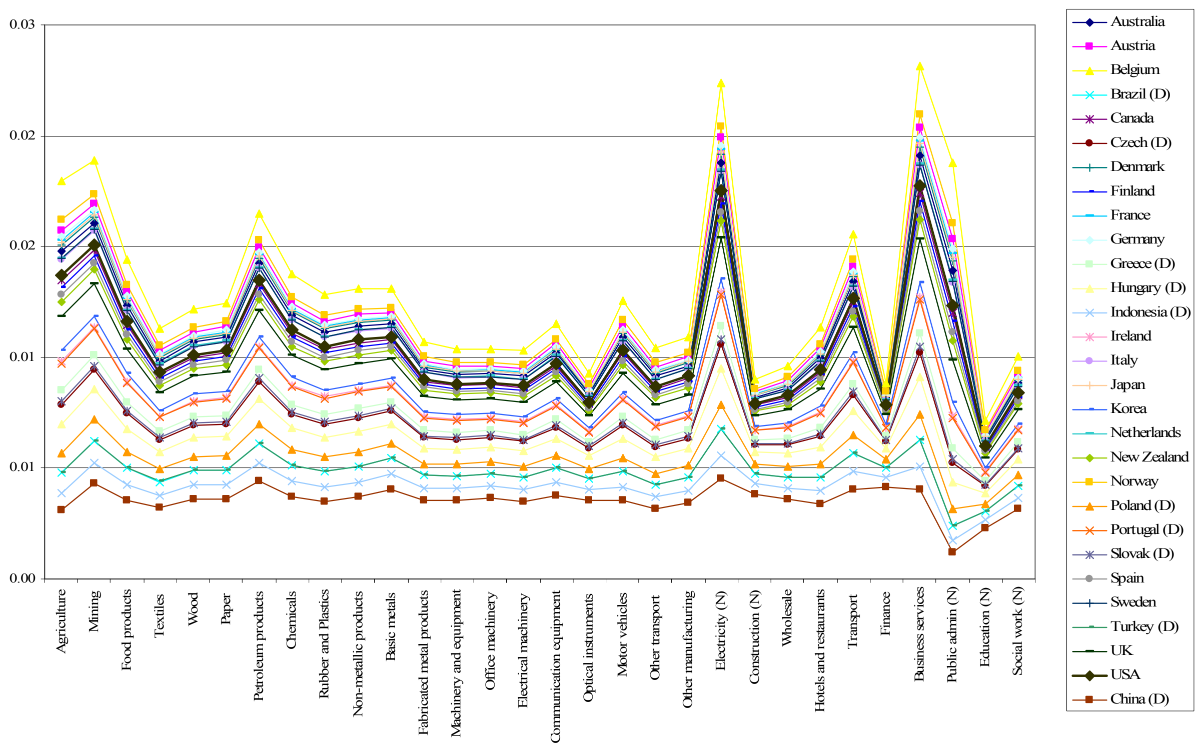

Figure 4. Techniques and Capital Intensity across Industries

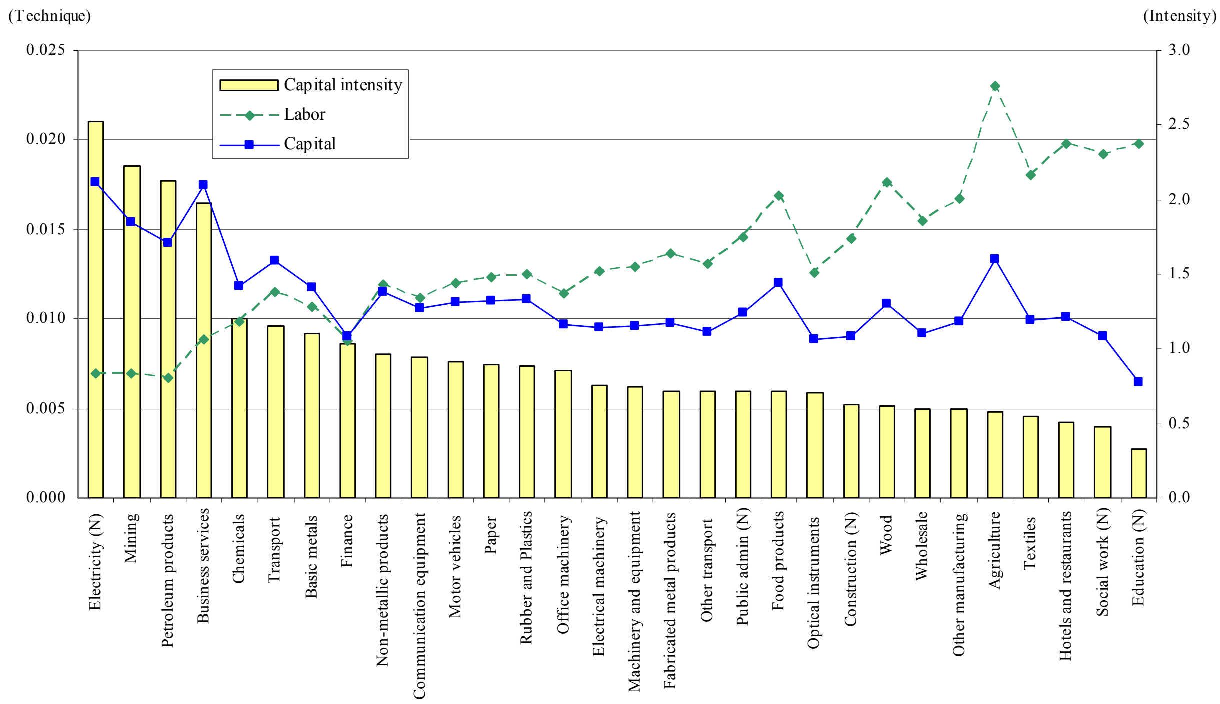

Figure 5. Techniques and Capital Intensity across Countries